TELEPHONY

A COMPREHENSIVE AND DETAILED EXPOSITION OF THE THEORY AND PRACTICE OF THE TELEPHONE ART

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Preface

AT the very opening of this work we have endeavored to give a general view, a mere sketch, of the telephone art as a whole, so that the reader, if a beginner, may be disabused of the idea that telephony is fairly represented by the instrument on his wall or desk. Also, before plunging into the maze of details, we have endeavored to set forth the general principles involved in the transmission of speech and of signals, and to discuss the electrical properties with which the art has to deal. It has been our hope that this would give the student a greater interest and a broad enough view to enable him to correlate individual facts with other phases of the art.

¶ A similar course has been followed in the preparation of the circuit diagrams. The telephone man has a sign language of his own, of which there are many dialects. We have, in the preliminary discussion of each piece of apparatus, shown one or more appropriate conventional symbols representing it, and these symbols have been adhered to in the preparation of all the drawings. Where, as in automatic systems, intricate mechanical functions are involved, we have made the circuit drawings as suggestive as possible of the mechanical as well as the electrical working. Thus, the drawings in large measure tell their own stories, always in the same language, avoiding the necessity of employing the bewildering mass of reference letters and figures so often found. Every drawing used has been prepared especially for this work. The photographs have been collected with care, and, like the drawings, they have been used to illustrate the text rather than as a medium around which to build the text.

¶ No attempt has been made to make the work historically complete, and except in rare occasions, where a distinct lesson could be drawn from obsolete types or methods, we have confined the discussion to modern practice—to the surviving works of the first generation of telephone men.

¶ It is fitting that we should express our appreciation of the intelligent, painstaking, and faithful work of those who have aided us. Our first acknowledgment is to Mr. Leigh S. Keith, whose fund of information, thoughtful criticism, and unlimited patience have contributed in no small degree to whatever merit and accuracy this work may possess. It also gives us pleasure to commend the work, and the spirit in which it has been done, of Miss Leona Ekstrom, of Chicago, and Miss Gertrude Cohen, of San Francisco. These young ladies have carefully refrained from mutilating our thoughts, always returning them to us in form as good or better than when received.

¶ Acknowledgment is due to the various manufacturing companies, who have freely placed at our disposal illustrations and information concerning their products. When compared with the attitude existing some years ago, the willingness on the part of some to make such matters public is, we think, one of the hopeful signs of the times.

¶ Nor must the American School of Correspondence, the publisher of this work, be forgotten in our acknowledgment. It has co-operated in every way in which a publisher may cooperate with authors. The physical form in which the work is to appear will bear evidence of this.

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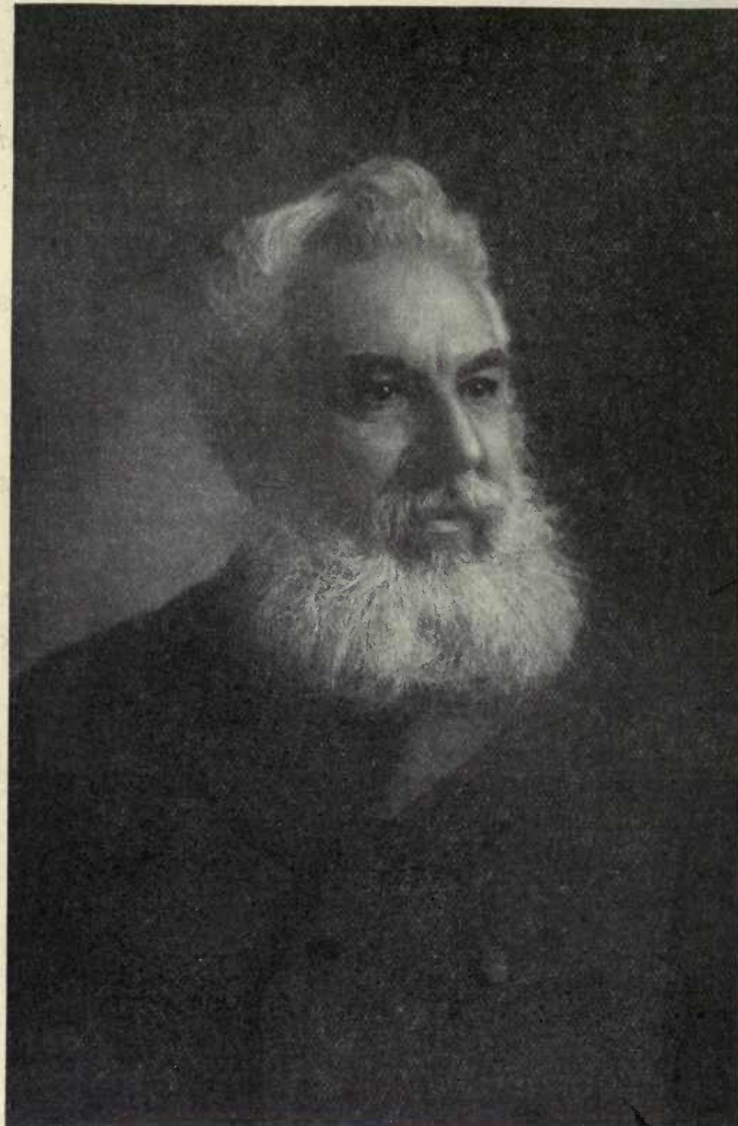


ALEXANDER GRAHAM BELL
The Inventor of the Telephone.

TELEPHONY

INTRODUCTION

The telephone was invented in 1875 by Alexander Graham Bell, a resident of the United States, a native of Scotland, and by profession a teacher of deaf mutes in the art of vocal speech. In that year, Professor Bell was engaged in the experimental development of a system of multiplex telegraphy, based on the use of rapidly varying currents. During those experiments, he observed an iron reed to vibrate before an electromagnet as a result of another iron reed vibrating before a distant electromagnet connected to the nearer one by wires.

The telephone resulted from this observation with great promptness. In the instrument first made, sound vibrated a membrane diaphragm supporting a bit of iron near an electromagnet; a line joined this simple device of three elements to another like it; a battery in the line magnetized both electromagnet cores; the vibration of the iron in the sending device caused the current in the line to undulate and to vary the magnetism of the receiving device. The diaphragm of the latter was vibrated in consequence of the varying pull upon its bit of iron, and these vibrations reproduced the sound that vibrated the sending diaphragm.

The first public use of the electric telephone was at the Centennial Exposition in Philadelphia in 1876. It was there tested by many interested observers, among them Sir William Thomson, later Lord Kelvin, the eminent Scotch authority on matters of electrical communication. It was he who contributed so largely to the success of the early telegraph cable system between England and

America. Two of his comments which are characteristic are as follows:

> To-day I have seen that which yesterday I should have deemed impossible. Soon lovers will whisper their secrets over an electric wire.
>
> ✦ ✦ ✦ ✦
>
> Who can but admire the hardihood of invention which devised such slight means to realize the mathematical conception that if electricity is to convey all the delicacies of sound which distinguish articulate speech, the strength of its current must vary continuously as nearly as may be in simple proportion to the velocity of a particle of the air engaged in constituting the sound.

Contrary to usual methods of improving a new art, the earliest improvement of the telephone simplified it. The diaphragms became thin iron disks, instead of membranes carrying iron; the electromagnet cores were made of permanently magnetized steel instead of temporarily magnetized soft iron, and the battery was omitted from the line. The undulatory current in a system of two such telephones joined by a line is *produced* in the sending telephone by the vibration of the iron diaphragm. The vibration of the diaphragm in the receiving telephone is *produced* by the undulatory current. Sound is *produced* by the vibration of the diaphragm of the receiving telephone.

Such a telephone is at once the simplest known form of electric generator or motor for alternating currents. It is capable of translating motion into current or current into motion through a wide range of frequencies. It is not known that there is any frequency of alternating current which it is not capable of producing and translating. It can produce and translate currents of greater complexity than any other existing electrical machine.

Though possessing these admirable qualities as an electrical machine, the simple electromagnetic telephone had not the ability to transmit speech loudly enough for all practical uses. Transmitters producing stronger telephonic currents were developed soon after the fundamental invention. Some forms of these were invented by Professor Bell himself. Other inventors contributed devices embodying the use of carbon as a resistance to be varied by the motions of the diaphragm. This general form of transmitting telephone has prevailed and at present is the standard type.

It is interesting to note that the earliest incandescent lamps, as invented by Mr. Edison, had a resistance material composed of carbon, and that such a lamp retained its position as the most efficient small electric illuminant until the recent introduction of metal filament lamps. It is possible that some form of metal may be introduced as the resistance medium for telephone transmitters, and that such a change as has taken place in incandescent lamps may increase the efficiency of telephone transmitting devices.

At the time of the invention of the telephone, there were in existence two distinct types of telegraph, working in regular commercial service. In the more general type, many telegraph stations were connected to a line and whatever was telegraphed between two stations could be read by all the stations of that line. In the other and less general type, many lines, each having a single telegraph station, were centered in an office or "exchange," and at the desire of a user his line could be connected to another and later disconnected from it.

Both of these types of telegraph service were imitated at once in telephone practice. Lines carrying many telephones each, were established with great rapidity. Telephones actually displaced telegraphic apparatus in the exchange method of working in America. The fundamental principle on which telegraph or telephone exchanges operate, being that of placing any line in communication with any other in the system, gave to each line an ultimate scope so great as to make this form of communication more popular than any arrangement of telephones on a single line. Beginning in 1877, telephone exchanges were developed with great rapidity in all of the larger communities of the United States. Telegraph switching devices were utilized at the outset or were modified in such minor particulars as were necessary to fit them to the new task.

In its simplest form, a telephone system is, of course, a single line permanently joining two telephones. In its next simplest form, it is a line permanently joining more than two telephones. In its most useful form, it is a line joining a telephone to some means of connecting it at will to another.

A telephone exchange central office contains means for connecting lines at will in that useful way. The least complicated machine for that purpose is a switchboard to be operated by hand, having some way of letting the operator know that a connection is wished and a way of making it. The customary way of connecting the lines always has been by means of flexible conductors fitted with plugs to be inserted in sockets. If the switchboard be small enough so that all the lines are within arm's reach of the operator, the whole process is individual, and may be said to be at its best and simplest. There are but few communities, however, in which the number of lines to be served and calls to be answered is small enough so that the entire traffic of the exchange can be handled by a single person. An obvious way, therefore, is to provide as many operators in a central office as may be required by the number of calls to be answered, and to terminate before each of the operators enough of the lines to bring enough work to keep that operator economically occupied. This presents the additional problem, how to connect a line terminating before one operator to a line normally terminating before another operator. The obvious answer is to provide lines from each operator's place of work to each other operator's place, connecting a calling line to some one of these lines which are local within the central office, and, in turn, connecting that chosen local line to the line which is called.

Such lines between operators have come to be known as *trunk lines*, because of the obvious analogy to trunk lines of railways between common centers, and such a system of telephone lines may be called a *trunking system*. Very good service has been given and can be given by such an arrangement of local trunks, but the growth in lines and in traffic has developed in most instances certain weaknesses which make it advisable to find speedier, more accurate, and more reliable means.

For the serving of a large traffic from a large number of lines, as is required in practically every city of the world, a very great contribution to the practical art was made by the development of the multiple switchboard. Such a switchboard is merely such a device as has been described for the simpler cases, with the further refinement that within reach of each operator in the central office appears *every line which enters that office*, and this without regard to what point in the switchboard the lines may terminate for the *answering* of calls. In other words, while each operator answers a certain subordinate group of the total number of lines, each operator may reach, for calling purposes, every line which enters that office. It is probable that the invention and development of the multiple switchboard was the first great impetus toward the wide-spread use of telephone service.

Coincident with the development of the multiple switchboard for manually operated, central-office mechanisms was the beginning of the development of automatic apparatus under the control of the calling subscriber for finding and connecting with a called line. It is interesting to note the general trend of the early development of automatic apparatus in comparison with the development, to that time, of manual telephone apparatus.

While the manual apparatus on the one hand attempted to meet its problem by providing local trunks between the various operators of a central office, and failing of success in that, finally developed a means which placed all the lines of a central office within connecting reach of each operator, automatic telephony, beginning at that point, failed of success in attempting to bring each line in the central office within connecting reach of each connecting mechanism.

In other terms, the first automatic switching equipment consisted of a machine for each line, which machine was so organized as to be able to find and connect its calling line with any called line of the entire central-office group. It may be said that an attempt to develop this plan was the fundamental reason for the repeated failure of automatic apparatus to solve the problem it attacked. All that the earlier automatic system did was to prove more or less successfully that automatic apparatus had a right to exist, and that to demand of the subscriber that he manipulate from his station a distant machine to make the connection without human aid was not fallacious. When it had been recognized that the entire multiple switchboard idea could not be carried into automatic telephony with success, the first dawn of hope in that art may be said to have come.

Success in automatic telephony did come by the re-adoption of the trunking method. As adopted for automatic telephony, the method contemplates that the calling line shall be extended, link by link, until it finds itself lengthened and directed so as to be able to seize the called line in a very much smaller multiple than the total group of one office of the exchange.

A similar curious reversion has taken place in the development of telephone lines. The earliest telephone lines were merely telegraph lines equipped with telephone instruments, and the earliest telegraph lines were planned by Professor Morse to be insulated wires laid in the earth. A lack of skill in preparing the wires for putting in the earth caused these early underground lines to be failures. At the urging of one of his associates, Professor Morse consented to place his earliest telegraph lines on poles in the air. Each such line originally consisted of two wires, one for the going and one for the returning current, as was then considered the action. Upon its being discovered that a single wire, using the earth as a return, would serve as a satisfactory telegraph line, such practice became universal. Upon the arrival of the telephone, all lines obviously were built in the same way, and until force of newer circumstances compelled it, the present metallic circuit without an earth connection did not come into general use.

The extraordinary growth of the number of telephone lines in a community and the development of other methods of electrical utilization, as well as the growth in the knowledge of telephony itself, ultimately forced the wires underground again. At the same time and for the same causes, a telephone line became one of two wires, so that it becomes again the counterpart of the earliest telegraph line of Professor Morse.

Another curious and interesting example of this reversion to type exists in the simple telephone receiver. An early improvement in telephone receivers after Professor Bell's original invention was to provide the necessary magnetism of the receiver core by making it of steel and permanently magnetizing it, whereas Professor Bell's instrument provided its magnetism by means of direct current flowing in the line. In later days the telephone receiver has returned almost to the original form in which Professor Bell produced it and this change has simplified other elements of telephone-exchange apparatus in a very interesting and gratifying way.

By reason of improvements in methods of line construction and apparatus arrangement, the radius of communication steadily has increased. Commercial speech now is possible between points several thousand miles apart, and there is no theoretical reason why communication might not be established between any two points on the earth's surface. The practical reasons of demand and cost may prevent so great an accomplishment as talking half around the earth.

So far as science is concerned there would seem to be no reason why this might not be done today, by the careful application of what already is known.

In the United States, telephone service from its beginning has been supplied to users by private enterprise. In other countries, it is supplied by means of governmentally-owned equipment. In general, it may be said that the adequacy and the amount, as well as the quality of telephone service, is best in countries where the service is provided by private enterprise.

Telephone systems in the United States were under the control of the Bell Telephone Company from the invention of the device in 1876 until 1893. The fundamental telephone patent expired in 1893. This opened the telephone art to the general public, because it no longer was necessary to secure telephones solely from the patent-holding company nor to pay royalty for the right to use them, if secured at all. Manufacturers of electrical apparatus generally then began to make and sell telephones and telephone apparatus, and operating companies, also independent of the Bell organization, began to install and use telephones. At the end of seventeen years of patent monopoly in the United States, there were in operation a little over 250,000 telephones. In the seventeen years since the expiration of the fundamental patent, independent telephone companies throughout the United States have installed and now have in daily successful use over 3,911,400 telephones. In other words, since its first beginnings, independent telephony has brought into continuous daily use nearly sixteen times as many telephones as were brought into use in the equal time of the complete monopoly of the Bell organization.

At the beginning of 1910, there were in service by the Bell organization about 3,633,900 telephones. These with the 3,911,400 independent telephones, make a total of 7,545,300, or about one-twelfth as many telephones as there are inhabitants of the United States. The influence of this development upon the lives of the people has been profound. Whether the influence has been wholly for good may not be so conclusively apparent. Lord Bacon has declared that, excepting only the alphabet and the art of printing, those inventions abridging distance are of the greatest service to mankind. If this be true, it may be said that the invention of telephony deserves high place among the civilizing influences.

There is no industrial art in which the advancement of the times has been followed more closely by practical application than in telephony. Commercial speech by telephone is possible by means of currents which so far are practically unmeasurable. In other words, it is possible to speak clearly and satisfactorily over a line by means of currents which cannot be read, with certainty as to their amount, by any electrical measuring device so far known. In this regard, telephony is less well fortified than are any of the arts utilizing electrical power in larger quantities. The real wonder is that with so little knowledge of what takes place, particularly as to amount, those working in the art have been able to do as well as they have. When an exact knowledge of quantity is easily obtainable, very striking advances may be looked for.

The student of these phases of physical science and industrial art will do well to combine three processes: study of the words of others; personal experimentation; and digestive thought. The last mentioned is the process of profoundest value. On it finally depends mastery. It is not of so much importance how soon the concept shall finally be gained as *that it is gained.* A statement by another may seem lifeless and inert and the meaning of an observation may be obscure. Digestive thought is the only assimilative process. The whole art of telephony hangs on taking thought of things. Judge R. F. Taylor of Indiana said of Professor Bell, "It has been said that no man by taking thought may add a cubit to his stature, yet here is a man who, by taking thought, has added not cubits but miles to the lengths of men's tongues and ears."

In observations of many students, it is found that the notion of each must pass through a certain period of incubation before his private and personal knowledge of Ohm's law is hatched. Once hatched, however, it is his. By just such a process must come each principal addition to his stock of concepts. The periods may vary and practice in the uses of the mind may train it in alertness in its work. If time is required, time should be given, the object always being to keep thinking or re-reading or re-trying until the thought is wholly encompassed and possessed.

CHAPTER I

ACOUSTICS

Telephony is the art of reproducing at a distant point, usually by the agency of electricity, sounds produced at a sending point. In this art the elements of two general divisions of physical science are concerned, sound and electricity.

Sound is the effect of vibrations of matter upon the ear. The vibrations may be those of air or other matter. Various forms of matter transmit sound vibrations in varying degrees, at different specific speeds, and with different effects upon the vibrations. Any form of matter may serve as a transmitting medium for sound vibrations. Sound itself is an effect of sound vibrations upon the ear.

Propagation of Sound. Since human beings communicate with each other by means of speech and hearing through the air, it is with air that the acoustics of telephony principally is concerned. In air, sound vibrations consist of successive condensations and rarefactions tending to proceed outwardly from the source in all directions. The source is the center of a sphere of sound vibrations. Whatever may be the nature of the sounds or of the medium transmitting them, they consist of waves emitted by the source and observed by the ear. A sound wave is one complete condensation and rarefaction of the transmitting medium. It is produced by one complete vibration of the sound-producing thing.

Sound waves in air travel at a rate of about 1,090 feet per second. The rate of propagation of sound waves in other materials varies with the density of the material. For example, the speed of transmission is much greater in water than in air, and is much less in highly rarefied air than in air at ordinary density. The propagation of sound waves in a vacuum may be said not to take place at all.

Characteristics of Sound. Three qualities distinguish sounds: loudness, pitch, and timbre.

Loudness. Loudness depends upon the violence of the effect upon the ear; sounds may be alike in their other qualities and differ in loudness, the louder sounds being produced by the stronger vibrations of the air or other medium at the ear. Other things being equal, the louder sound is produced by the source radiating the greater energy and so producing the greater *degree* of condensation and rarefaction of the medium.

Pitch. Pitch depends upon the frequency at which the sound waves strike the ear. Pitches are referred to as *high* or *low* as the frequency of waves reaching the ear are greater or fewer. Familiar low pitches are the left-hand strings of a piano; the larger ones of stringed instruments generally; bass voices; and large bells. Familiar high pitches are right-hand piano strings; smaller ones of other stringed instruments; soprano voices; small bells; and the voices of most birds and insects.

Doppler's Principle:—As pitch depends upon the frequency at which sound waves strike the ear, an object may emit sound waves at a constant frequency, yet may produce different pitches in ears differently situated. Such a case is not usual, but an example of it will serve a useful purpose in fixing certain facts as to pitch. Conceive two railroad trains to pass each other, running in opposite directions, the engine bells of both trains ringing. Passengers on each train will hear the bell of the other, first as a *rising* pitch, then as a *falling* one. Passengers on each train will hear the bell of their own train at a *constant* pitch.

The difference in the observations in such a case is due to relative positions between the ear and the source of the sound. As to the bell of their own train, the passengers are a fixed distance from it, whether the train moves or stands; as to the bell of the other train, the passengers first rapidly approach it, then pass it, then recede from it. The distances at which it is heard vary as the secants of a circle, the radius in this case being a length which is the closest approach of the ear to the bell.

If the bell have a constant intrinsic fundamental pitch of 200 waves per second (a wave-length of about 5.5 feet), it first will be heard at a pitch of about 200 waves per second. But this pitch rises rapidly, as if the bell were changing its own pitch, which bells do not do. The rising pitch is heard because the ear is rushing down the wave-train, every instant nearer to the source. At a speed of 45 miles an hour, the pitch rises rapidly, about 12 vibrations per second. If the *rate of approach* between the ear and the bell were constant, the pitch of the bell would be heard at 212 waves per second. But suddenly the ear passes the bell, hears the pitch stop rising and begin to fall; and the tone drops 12 waves per second as it had risen. Such a circumflex is an excellent example of the bearing of wave-lengths and frequencies upon pitch.

Vibration of Diaphragms:—Sound waves in air have the power to move other diaphragms than that of the ear. Sound waves constantly vibrate such diaphragms as panes of windows and the walls of houses. The recording diaphragm of a phonograph is a window pane bearing a stylus adapted to engrave a groove in a record blank. In the cylinder form of record, the groove varies in depth with the vibrations of the diaphragm. In the disk type of phonograph, the groove varies sidewise from its normal true spiral.

If the disk record be dusted with talcum powder, wiped, and examined with a magnifying glass, the waving spiral line may be seen. Its variations are the result of the blows struck upon the diaphragm by a train of sound waves.

In reproducing a phonograph record, increasing the speed of the record rotation causes the pitch to rise, because the blows upon the air are increased in frequency and the wave-lengths shortened. A transitory decrease in speed in recording will cause a transitory rise in pitch when that record is reproduced at uniform speed.

Timbre. Character of sound denotes that difference of effect produced upon the ear by sounds otherwise alike in pitch and loudness. This characteristic is called timbre. It is extraordinarily useful in human affairs, human voices being distinguished from each other by it, and a great part of the joy of music lying in it.

A bell, a stretched string, a reed, or other sound-producing body, emits a certain lowest possible tone when vibrated. This is called its *fundamental tone.* The pitch, loudness, and timbre of this tone depend upon various controlling causes. Usually this fundamental tone is accompanied by a number of others of higher pitch, blending with it to form the general tone of that object. These higher tones are called *harmonics.* The Germans call them *overtones.* They are always of a frequency which is some multiple of the fundamental frequency. That is, the rate of vibration of a harmonic is 2, 3, 4, 5, or some other integral number, times as great as the fundamental itself. A tone having no harmonics is rare in nature and is not an attractive one. The tones of the human voice are rich in harmonics.

In any tone having a fundamental and harmonics (multiples), the wave-train consists of a complex series of condensations and rarefactions of the air or other transmitting medium. In the case of mere noises the train of vibrations is irregular and follows no definite order. This is the difference between vowel sounds and other musical tones on the one hand and all unmusical sounds (or noises) on the other.

Human Voice. Human beings communicate with each other in various ways. The chief method is by speech. Voice is sound vibration produced by the vocal cords, these being two ligaments in the larynx. The vocal cords in man are actuated by the air from the lungs. The size and tension of the vocal cords and the volume and the velocity of the air from the lungs control the tones of the voice. The more tightly the vocal cords be drawn, other things being equal, the higher will be the pitch of the sound; that is, the higher the frequency of vibration produced by the voice. The pitches of the human voice lie, in general, between the frequencies of 87 and 768 per second. These are the extremes of pitch, and it is not to be understood that any such range of pitch is utilized in ordinary speech. An average man speaks mostly between the fundamental frequencies of 85 and 160 per second. Many female speaking voices use fundamental frequencies between 150 and 320 vibrations per second. It is obvious from what has been said that in all cases these speaking fundamentals are accompanied by their multiples, giving complexity to the resulting wave-trains and character to the speaking voice.

Speech-sounds result from shocks given to the air by the organs of speech; these organs are principally the mouth cavity, the tongue, and the teeth. The vocal cords are *voice-organs;* that is, man only truly speaks, yet the lower animals have voice. Speech may be whispered, using no voice. Note the distinction between speech and voice, and the organs of both.

The speech of adults has a mean pitch lower than that of children; of adult males, lower than that of females.

There is no close analogue for the voice-organ in artificial mechanism, but the use of the lips in playing a bugle, trumpet, cornet, or trombone is a fairly close one. Here the lips, in contact with each other, are stretched across one end of a tube (the mouthpiece) while the air is blown between the lips by the lungs. A musical tone results; if the instrument be a bugle or a trumpet of fixed tube length, the pitch will be some one of several certain tones, depending on the tension on the lips. The loudness depends on the force of the blast of air; the character depends largely on the bugle.

Human Ear. The human ear, the organ of hearing in man, is a complex mechanism of three general parts, relative to sound waves: a wave-collecting part; a wave-observing part, and a wave-interpreting part.

The outer ear collects and reflects the waves inwardly to beat upon the tympanum, or ear drum, a membrane diaphragm. The uses of the rolls or convolutions of the outer ear are not conclusively known, but it is observed that when they are filled up evenly with a wax or its equivalent, the sense of direction of sound is impaired, and usually of loudness also.

The diaphragm of the ear vibrates when struck by sound waves, as does any other diaphragm. By means of bone and nerve mechanism, the vibration of the diaphragm finally is made known to the brain and is interpretable therein.

The human ear can appreciate and interpret sound waves at frequencies from 32 to about 32,000 vibrations per second. Below the lesser number, the tendency is to appreciate the separate vibrations as separate sounds. Above the higher number, the vibrations are inaudible to the human ear. The most acute perception of sound differences lies at about 3,000 vibrations per second. It may be that the range of hearing of organisms other than man lies far above the range with which human beings are familiar. Some trained musicians are able to discriminate between two sounds as differing one from the other when the difference in frequency is less than one-thousandth of either number. Other ears are unable to detect a difference in two sounds when they differ by as much as one full step of the chromatic scale. Whatever faculty an individual may possess as to tone discrimination, it can be improved by training and practice.

CHAPTER II

ELECTRICAL REPRODUCTION OF SPEECH

The art of telephony in its present form has for its problem so to relate two diaphragms and an electrical system that one diaphragm will respond to all the fundamental and harmonic vibrations beating upon it and cause the other to vibrate in exact consonance, producing just such vibrations, which beat upon an ear.

The art does not do all this today; it falls short of it in every phase. Many of the harmonics are lost in one or another stage of the process; new harmonics are inserted by the operations of the system itself and much of the volume originally available fails to reappear. The art, however, has been able to change commercial and social affairs in a profound degree.

Conversion from Sound Waves to Vibration of Diaphragm. However produced, by the voice or otherwise, sounds to be transmitted by telephone consist of vibrations of the air. These vibrations, upon reaching a diaphragm, cause it to move. The greatest amplitude of motion of a diaphragm is, or is wished to be, at its center, and its edge ordinarily is fixed. The diaphragm thus serves as a translating device, changing the energy carried by the molecules of the air into localized oscillations of the matter of the diaphragm. The waves of sound in the air advance; the vibrations of the molecules are localized. The agency of the air as a medium for sound transmission should be understood to be one in which its general volume has no need to move from place to place. What occurs is that the vibrations of the sound-producer cause alternate condensations and rarefactions of the air. Each molecule of the air concerned merely oscillates through a small amplitude, producing, by joint action, shells of waves, each traveling outward from the sound-producing center like rapidly growing coverings of a ball.

Conversion from Vibration to Voice Currents. Fig. 1 illustrates a simple machine adapted to translate motion of a diaphragm into an alternating electrical current. The device is merely one form of magneto telephone chosen to illustrate the point of immediate conversion. *1* is a diaphragm adapted to vibrate in response to the sounds reaching it. *2* is a permanent magnet and *3* is its armature. The armature is in contact with one pole of the permanent magnet and nearly in contact with the other. The effort of the armature to touch the pole it nearly touches places the diaphragm under tension. The free arm of the magnet is surrounded by a coil *4*, whose ends extend to form the line.

When sound vibrates the diaphragm, it vibrates the armature also, increasing and decreasing the distance from the free pole of the magnet. The lines of force threading the coil *4* are varied as the gap between the magnet and the armature is varied.

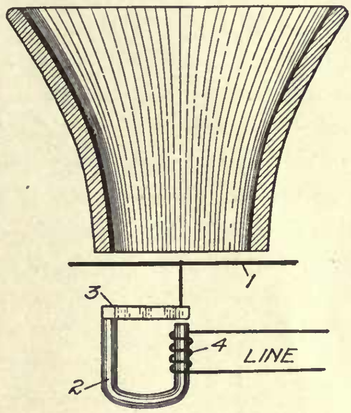


Fig. 1. Type of Magneto Telephone

The result of varying the lines of force through the turns of the coil is to produce an electromotive force in them, and if a closed path is provided by the line, a current will flow. This current is an alternating one having a frequency the same as the sound causing it. As in speech the frequencies vary constantly, many pitches constituting even a single spoken word, so the alternating voice currents are of great varying complexity, and every fundamental frequency has its harmonics superposed.

Conversion from Voice Currents to Vibration. The best knowledge of the action of such a telephone as is shown in Fig. 1 leads to the conclusion that a half-cycle of alternating current is produced by an inward stroke of the diaphragm and a second half-cycle of alternating current by the succeeding outward stroke, these half-cycles flowing in opposite directions. Assume one complete cycle of current to pass through the line and also through another such device as in Fig. 1 and that the first half-cycle is of such direction as to increase the permanent magnetism of the core. The effort of this increase is to narrow the gap between the armature and pole piece. The diaphragm will throb inward during the half-cycle of current. The succeeding half-cycle being of opposite direction will tend to oppose the magnetism of the core. In practice, the flow of opposing current never would be great enough wholly to nullify and reverse the magnetism of the core, so that the opposition results in a mere decrease, causing the armature's gap to increase and the diaphragm to respond by an outward blow.

Complete Cycle of Conversion. The cycle of actions thus is complete; one complete sound-wave in air has produced a cycle of motion in a diaphragm, a cycle of current in a line, a cycle of magnetic change in a core, a cycle of motion in another diaphragm, and a resulting wave of sound. It is to be observed that the chain of operation involves the expenditure of energy only by the speaker, the only function of any of the parts being that of *translating* this energy from one form to another. In every stage of these translations, there are losses; the devising of means of limiting these losses as greatly as possible is a problem of telephone engineering.

Magneto Telephones. The device in Fig. 1 is a practical magneto receiver and transmitter. It is chosen as best picturing the idea to be proposed. Fig. 2 illustrates a pair of magneto telephones of the early Bell type; *1-1* are diaphragms; *2-2* are permanent magnets with

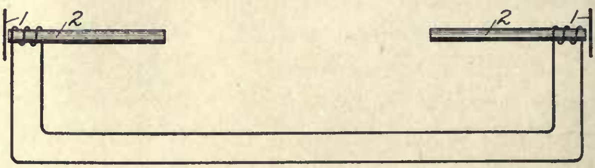


Fig. 2. Magneto Telephones and Line

a free end of each brought as near as possible, without touching, to the diaphragm. Each magnet bears on its end nearest the diaphragm a winding of fine wire, the two ends of each of these windings being joined by means of a two-wire line. All that has been said concerning Fig. 1 is true also of the electrical and magnetic actions of the devices of Fig. 2. In the latter, the flux which threads the fine wire winding is disturbed by motions of the transmitting diaphragm. This disturbance of the flux creates electromotive forces in those windings. Similarly, a variation of the electromotive forces in the windings varies the pull of the permanent magnet of the receiving instrument upon its diaphragm.

Fig. 3 illustrates a similar arrangement, but it is to be understood that the cores about which the windings are carried in this case are of soft iron and not of hard magnetized steel. The necessary magnetism which constantly enables the cores to exert a pull upon the diaphragm is provided by the battery which is inserted serially in the

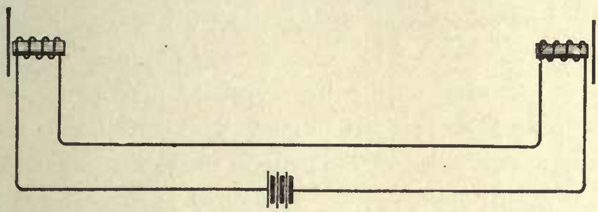


Fig. 3. Magneto Telephones without Permanent Magnets

line. Such an arrangement in action differs in no particular from that of Fig. 2, for the reason that it matters not at all whether the magnetism of the core be produced by electromagnetic or by permanently magnetic conditions. The arrangement of Fig. 3 is a fundamental counterpart of the original telephone of Professor Bell, and it is of particular interest in the present stage of the art for the reason that a tendency lately is shown to revert to the early type, abandoning the use of the permanent magnet.

The modifications which have been made in the original magneto telephone, practically as shown in Fig. 2, have been many. Thirty-five years' experimentation upon and daily use of the instrument has resulted in its refinement to a point where it is a most successful receiver and a most unsuccessful transmitter. Its use for the latter purpose may be said to be nothing. As a receiver, it is not only wholly satisfactory for commercial use in its regular function, but it is, in addition, one of the most sensitive electrical detecting devices known to the art.

Loose Contact Principle. Early experimenters upon Bell's device, all using in their first work the arrangement utilizing current from a battery in series with the line, noticed that sound was given out by disturbing loose contacts in the line circuit. This observation led to the arrangement of circuits in such a way that some imperfect contacts could be shaken by means of the diaphragm, and the resistance of the line circuit varied in this manner. An early and interesting form of such imperfect contact transmitter device consisted merely of metal conductors laid loosely in contact. A simple example is that of three wire nails, the third lying across the other two, the two loose contacts thus formed being arranged in series with a battery, the line, and the receiving instrument. Such a device when slightly jarred, by the voice or other means, causes abrupt variation in the resistance of the line, and will transmit speech.

Early Conceptions. The conception of the possibility and desirability of transmitting speech by electricity may have occurred to many, long prior to its accomplishment. It is certain that one person, at least, had a clear idea of the general problem. In 1854, Charles Bourseul, a Frenchman, wrote: "I have asked myself, for example, if the spoken word itself could not be transmitted by electricity; in a word, if what was spoken in Vienna might not be heard in Paris? The thing is practicable in this way:

"Suppose that a man speaks near a movable disk sufficiently flexible to lose none of the vibrations of the voice; that this disk *al-*

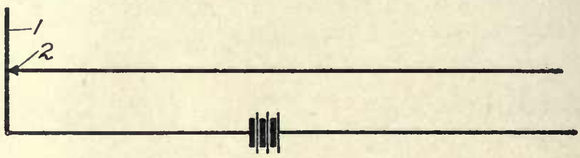


Fig. 4. Reis Transmitter

ternately makes and breaks the connection from a battery; you may have at a distance another disk which will simultaneously execute the same vibrations." The idea so expressed is weak in only one particular. This particular is shown by the words italicized by ourselves. It is impossible to transmit a complex series of waves by any simple series of makes and breaks. Philipp Reis, a German, devised the arrangement shown in Fig. 4 for the transmission of sound, letting the make and break of the contact between the diaphragm *1* and the point *2* interrupt the line circuit. His receiver took several forms, all electromagnetic. His success was limited to the transmission of musical sounds, and it is not believed that articulate speech ever was transmitted by such an arrangement.

It must be remembered that the art of telegraphy, particularly in America, was well established long before the invention of the telephone, and that an arrangement of keys, relays, and a battery, as shown in Fig. 5, was well known to a great many persons. Attaching the armatures of the relays of such a line to diaphragms,

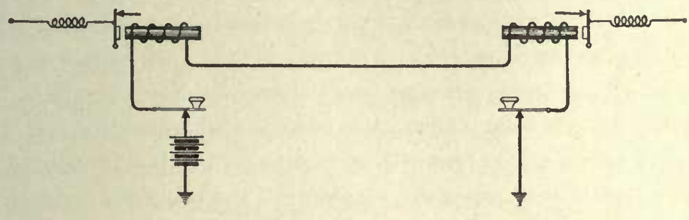


Fig. 5. Typical Telegraph Line

as in Fig. 6, at any time after 1838, would have produced the telephone. "The hardihood of invention" to conceive such a change was the quality required.

Limitations of Magneto Transmitter. For reasons not finally established, the ability of the magneto telephone to produce large currents from large sounds is not equal to its ability to produce large sounds from large currents. As a receiving device, it is unexcelled, and but slight improvement has been made since its first invention. It is inadequate as a transmitter, and as early as 1876, Professor Bell exhibited other means than electromagnetic action for producing the varying currents as a consequence of diaphragm

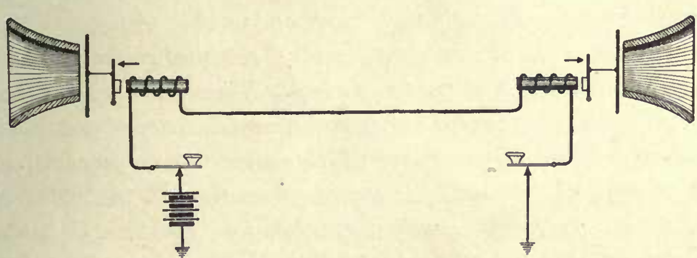


Fig. 6. Telegraph Equipment Converted into Telephone Equipment

motion. Much other inventive effort was addressed to this problem, the aim of all being to send out more robust voice currents.

Other Methods of Producing Voice Currents. Some of these means are the variation of resistance in the path of direct current, variation in the pressure of the source of that current, and variation in the electrostatic capacity of some part of the circuit.

Electrostatic Telephone. The latter method is principally that of Dolbear and Edison. Dolbear's thought is illustrated in Fig. 7. Two conducting plates are brought close together. One is free to vibrate as a diaphragm, while the other is fixed. The element *1* in Fig. 7 is merely a stud to hold rigid the plate it bears against. Each of two instruments connected by a line contains such a pair of plates, and a battery in the line keeps them charged to its potential. The two diaphragms of each instrument are kept drawn towards each other because their unlike charges attract each other. The vibration of one of the diaphragms changes the potential of the other pair; the degree of attraction thus is varied, so that vibration of the diaphragm and sound waves result.

Examples of this method of telephone transmission are more familiar to later practice in the form of condenser receivers. A condenser, in usual present practice, being a pair of closely adjacent conductors of considerable surface insulated from each other, a rap-

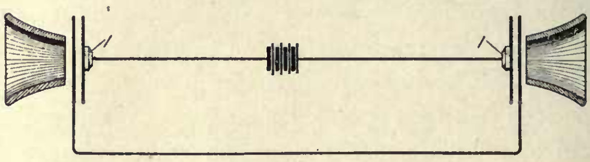


Fig. 7. Electrostatic Telephone

idly varying current actually may move one or both of the conductors. Ordinarily these are of thin sheet metal (foil) interleaved with an insulating material, such as paper or mica. Voice currents can vibrate the metal sheets in a degree to cause the condenser to speak. These condenser methods of telephony have not become commercial.

Variation of Electrical Pressure. Variation of the pressure of the source is a conceivable way of transmitting speech. To utilize it, would require that the vibrations of the diaphragm cause the electromotive force of a battery or machine to vary in harmony with the sound waves. So far as we are informed this method never has come into practical use.

Variation of Resistance. Variation of resistance proportional to the vibrations of the diaphragm is the method which has produced the present prevailing form of transmission. Professor Bell's Centennial exhibit contained a water-resistance transmitter. Dr. Elisha Gray also devised one. In both, the diaphragm acted to increase and diminish the distance between two conductors immersed in water, lowering and raising the resistance of the line. It later was discovered by Edison that carbon possesses a peculiarly great property of varying its resistance under pressure. Professor David E. Hughes discovered that two conducting bodies, preferably of rather poor conductivity, when laid together so as to form a *loose contact* between them, possessed, in remarkable degree, the ability to vary the resistance of the path through them when subject to such vibrations as would alter the *intimacy of contact.* He thus discovered and formulated the principles of *loose contact* upon which the operation of all modern transmitters rests. Hughes' device was named by him a "microphone," indicating a magnification of sound or an ability to respond to and make audible minute sounds. It is shown in Fig. 8. Firmly attached to a board are two carbon blocks, shown in section in the figure. A rod of carbon with cone-shaped ends is supported loosely between the two blocks, conical depressions in the blocks receiving the ends of the rod. A battery and magneto receiver are connected in series with the device. Under certain conditions of contact, the arrangement is extraordinarily sensitive to small sounds and approaches an ability indicated by its name. Its practical usefulness has been not as a serviceable speech transmitter, but as a stimulus to the devising of transmitters using carbon in other ways. Variation of the resistance of metal conductors and of contact between metals has served to transmit voice currents, but no material approaches carbon in this property.

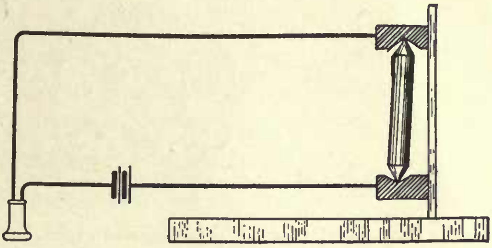


Fig. 8. Hughes' Microphone

Carbon. *Adaptability.* The application of carbon to use in transmitters has taken many forms. They may be classified as those having a single contact and those having a plurality of contacts; in all cases, the *intimacy of contact* is varied by the diaphragm excursions. An example of the single-contact type is the Blake transmitter, long familiar in America. An example of the multiple-contact type is the loose-carbon type universal now. Other types popular at other times and in particular places use solid rods or blocks of carbon having many points of contact, though not in a powdered or granular form. Fig. 9 shows an example of each of the general forms of transmitters.

The use of granular carbon as a transmitter material has extended greatly the radius of speech, and has been a principal contributing cause for the great spread of the telephone industry.

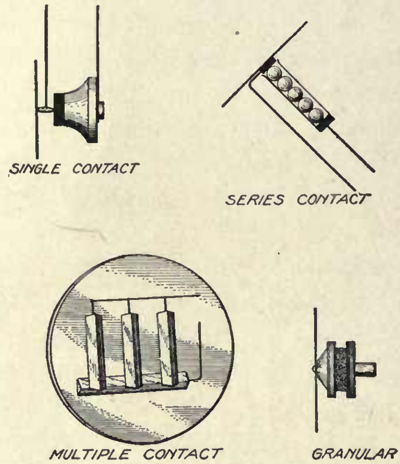


Fig. 9. General Types of Transmitters

Superiority. The superiority of carbon over other resistance-varying materials for transmitters is well recognized, but the reason for it is not well known. Various theories have been proposed to explain why, for example, the resistance of a mass of carbon granules varies with the vibrations or compressions to which they are subjected.

Four principal theories respectively allege:

First, that change in pressure actually changes the specific resistance of carbon.

Second, that upon the surface of carbon bodies exists some gas in some form of attachment or combination, variations of pressure causing variations of resistance merely by reducing the thickness of this intervening gas

Third, that the change of resistance is caused by variations in the length of electrical arcs between the particles.

Fourth, that change of pressure changes the area of contact, as is true of solids generally.

One may take his choice. A solid carbon block or rod is not found to decrease its resistance by being subjected to pressure. The gas theory lacks experimental proof also. The existence of arcs between the granules never has been seen or otherwise observed under normal working conditions of a transmitter; when arcs surely are experimentally established between the granules the usefulness of the transmitter ceases. The final theory, that change of pressure changes area of surface contact, does not explain why other conductors than carbon are not good materials for transmitters. This, it may be noticed, is just what the theories set out to make clear.

There are many who feel that more experimental data is required before a conclusive and satisfactory theory can be set up. There is need of one, for a proper theory often points the way for effective advance in practice.

Carbon and magneto transmitters differ wholly in their methods of action. The magneto transmitter *produces* current; the carbon transmitter *controls* current. The former is an alternating-current generator; the latter is a rheostat. The magneto transmitter produces alternating current without input of any electricity at all; the carbon transmitter merely controls a direct current, supplied by an external source, and varies its amount without changing its direction.

The carbon transmitter, however, may be associated with other devices in a circuit in such a way as to *transform* direct currents into

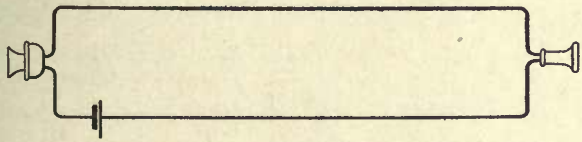


Fig. 10. Battery in Line Circuit

alternating ones, or it may be used merely to change constant direct currents into *undulating* ones, which *never* reverse direction, as alternating currents *always* do. These distinctions are important.

Limitations. A carbon transmitter being merely a resistance-varying device, its usefulness depends on how much its resistance can vary in response to motions of air molecules. A granular-carbon transmitter may vary between resistances of 5 to 50 ohms while transmitting a particular tone, having the lower resistance when its diaphragm is driven inward. Conceive this transmitter to be in a line as shown in Fig. 10, the line, distant receiver, and battery together having a resistance of 1,000 ohms. The minimum resistance then is 1,005 ohms and the maximum 1,050 ohms. The variation is limited to about 4.5 per cent. The greater the resistance of the line and other elements than the transmitter, the less relative change the transmitter can produce, and the less loudly the distant receiver can speak.

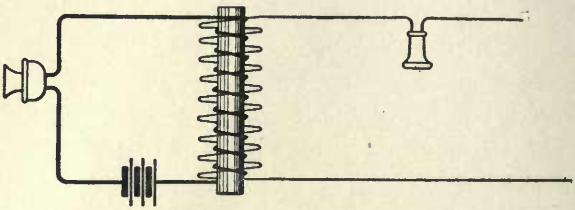


Fig. 11. Battery in Local Circuit

Induction Coil. Mr. Edison realized this limitation to the use of the carbon transmitter direct in the line, and contributed the means of removing it. His method is to introduce an induction coil between the line and the transmitter, its function being to translate the variation of the direct current controlled by the transmitter into true alternating currents.

An induction coil is merely a transformer, and for the use under discussion consists of two insulated wires wound around an iron core. Change in the current carried by one of the windings *produces* a current in the other. If direct current be flowing in one of the windings, and remains constant, no current whatever is produced in the other. It is important to note that it is change, and change only, which produces that alternating current.

Fig. 11 shows an induction coil related to a carbon transmitter, a battery, and a receiver. Fig. 12 shows exactly the same arrangement, using conventional signs. The winding of the induction coil which is in series with the transmitter and the battery is called the primary winding; the other is called the secondary winding. In the arrangement of Figs. 11 and 12 the battery has no metallic connection with the line, so that it is called a *local battery*. The circuit containing the battery, transmitter, and primary winding of the induction coil is called the *local circuit*.

Let us observe what is the advantage of this arrangement over the case of Fig. 10. Using the same values of resistance in the transmitter and line, assume the local circuit apart from the transmitter to have a fixed resistance of 5 ohms. The limits of variations in the local circuit, therefore, are 10 and 55 ohms, thus making the maximum 5.5 times the minimum, or an increase of 450 per cent as against 4.5 per cent in the case of Fig. 10. The changes, therefore, are 100 times as great.

The relation between the windings of the induction coil in this practice are such that the secondary winding contains many more turns than the primary winding. Changes in the circuit of the primary winding produce potentials in the secondary winding correspondingly higher than the potentials producing them. These secondary potentials depend upon the *ratio* of turns in the two windings and therefore, within close limits, may be chosen as wished. High potentials in the secondary winding are admirably adapted to transmit currents in a high-resistance line, for exactly the same reason that long-distance power transmission meets with but one-quarter of one kind of loss when the sending potential is doubled, one-hundredth of that loss when it is raised tenfold, and similarly. The induction

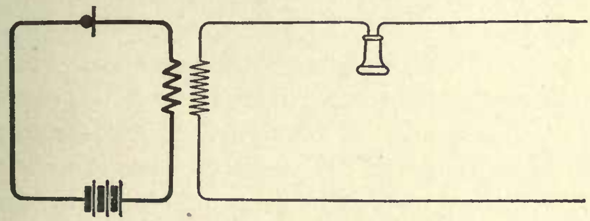


Fig. 12. Conventional Diagram of Talking Circuit

coil, therefore, serves the double purpose of a step-up transformer to limit line losses and a device for vastly increasing the range of change in the transmitter circuit.

Fig. 13 is offered to remind the student of the action of an induction coil or transformer in whose primary circuit a direct current is increased and decreased. An increase of current in the local winding produces an impulse of *opposite* direction in the turns of the secondary winding; a decrease of current in the local winding produces an impulse of *the same* direction in the turns of the secondary winding. The key of Fig. 13 being closed, current flows upward in the primary winding as drawn in the figure, inducing a downward impulse of current in the secondary winding and its circuit as noted at the right of the figure. On the key being opened, current ceases in the primary circuit, inducing an upward impulse of current in the secondary winding and circuit as shown. During other than instants of opening and closing (changing) the local circuit, no current whatever flows in the secondary circuit.

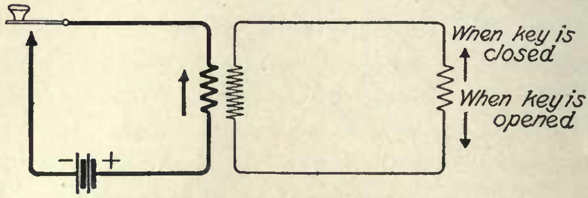


Fig. 13. Induction-Coil Action

It is by these means that telephone transmitters draw direct current from primary batteries and send high-potential alternating currents over lines; the same process produces what in Therapeutics are called "Faradic currents," and enables also a simple vibrating contact-maker to produce alternating currents for operating polarized ringers of telephone sets.

Detrimental Effects of Capacity. Electrostatic capacity plays an important part in the transmission of speech. Its presence between the wires of a line and between them and the earth causes one of the losses from which long-distance telephony suffers. Its presence in condensers assists in the solution of many circuit and apparatus problems.

A condenser is a device composed of two or more conductors insulated from each other by a medium called the *dielectric*. A pair of metal plates separated by glass, a pair of wires separated by air, or a pair of sheets of foil separated by paper or mica may constitute a condenser. The use of condensers as pieces of apparatus and the problems presented by electrostatic capacity in lines are discussed in other chapters.

Measurements of Telephone Currents. It has been recognized in all branches of engineering that a definite advance is possible only when quantitative data exists. The lack of reliable means of measuring telephone currents has been a principal cause of the difficulty in solving many of its problems. It is only in very recent times that accurate and reliable means have been worked out for measuring the small currents which flow in telephone lines. These ways are of two general kinds: by thermal and by electromagnetic means.

Thermal Method. The thermal methods simply measure, in some way, the amount of heat which is produced by a received telephone current. When this current is allowed to pass through a conductor the effect of the heat generated in that conductor is observed in one of three ways: by the expansion of the conductor, by its change in resistance, or by the production of an electromotive force in a thermo-electric couple heated by the conductor. Any one of these three ways can be used to get some idea of the amount of current which is received. None of them gives an accurate knowledge of the forms of the waves which cause the reproduction of speech in the telephone receiver.

Electromagnetic Method. An electromagnetic device adapted to tell something of the magnitude of the telephone current and also something of its form, *i. e.*, something of its various increases and decreases and also of its changes in direction is the oscillograph. An oscillograph is composed of a magnetic field formed by direct currents or by a permanent magnet, a turn of wire under mechanical tension in that field, and a mirror borne by the turn of wire, adapted to reflect a beam of light to a photographic film or to a rotating mirror.

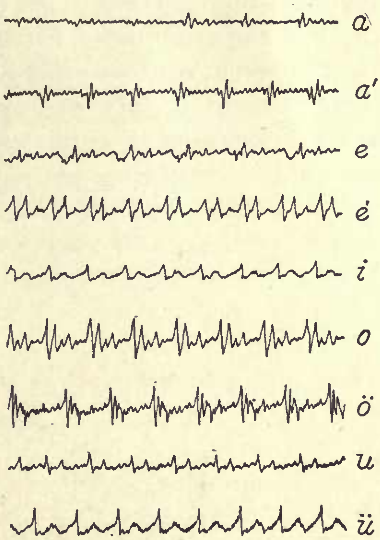


Fig. 14. Oscillogram of Telephone Currents

When a current is to be measured by the oscillograph, it is passed through the turn of wire in the magnetic field. While no current is passing, the wire does not move in the magnetic field and its mirror reflects a stationary beam of light. A photographic film moved in a direction normal to the axis of the turn of wire will have drawn upon it a straight line by the beam of light. If the beam of light, however, is moved by a current, from side to side at right angles to this axis, it will draw a wavy line on the photographic film and this wavy line will picture the alternations of that current and the oscillations of the molecules of air which carried the originating sound. Fig. 14 is a photograph of nine different vowel sounds which have caused the oscillograph to take their pictures. They are copies of records made by Mr. Bela Gati, assisted by Mr. Tolnai. The measuring instrument consisted of an oscillograph of the type described, the transmitter being of the carbon type actuated by a 2-volt battery. The primary current was transformed by an induction coil of the ordinary type and the transformed current was sent through a non-inductive resistance of 3,000 ohms. No condensers were placed in the circuit. It will be seen that the integral values of the curves, starting from zero, are variable. The positive and the negative portions of the curves are not equal, so that the solution of the individual harmonic motion is difficult and laborious.

These photographs point out several facts very clearly. One is that the alternations of currents in the telephone line, like the motions of the molecules of air of the original sound, are highly complex and are not, as musical tones are, regular recurrences of equal vibrations. They show also that any vowel sound may be considered to be a regular recurrence of certain groups of vibrations of different amplitudes and of different frequencies.

CHAPTER III

ELECTRICAL SIGNALS

Electric calls or signals are of two kinds: audible and visible.

Audible Signals. *Telegraph Sounder.* The earliest electric signal was an audible one, being the telegraph sounder, or the Morse register considered apart from its registering function. Each tele-

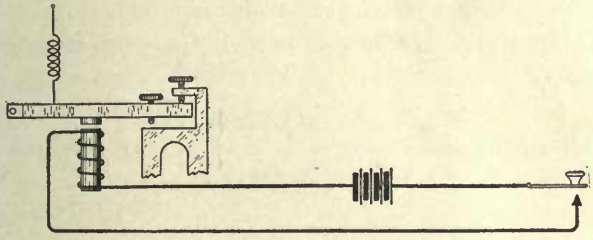


Fig. 15. Telegraph Sounder and Key

graph sounder serves as an audible electric signal and is capable of signifying more than that the call is being made. Such a signal is operated by the making and breaking of current from a battery. An

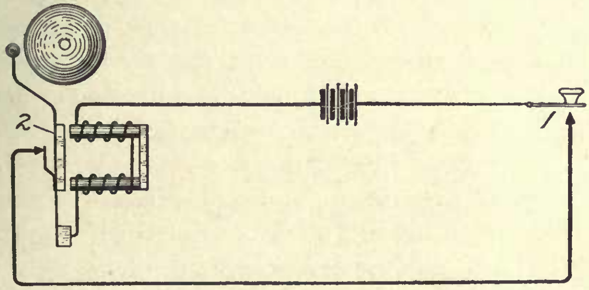


Fig. 16. Vibrating Bell

arrangement of this kind is shown in Fig. 15, in which pressure upon the key causes the current from the battery to energize the sounder and give one sharp audible rap of the lever upon the striking post.

Vibrating Bell. The vibrating bell, so widely used as a door bell, is a device consequent to the telegraph. Its action is to give a series of blows on its gong when its key or push button closes the battery circuit. At the risk of describing a trite though not trivial thing, it may be said that when the contact *1* of Fig. 16 is closed, current from the battery energizes the armature *2*, causing the latter to strike a blow on the gong and to break the line circuit as well, by opening the contact back of the armature. So de-energized, the armature falls back and the cycle is repeated until the button contact is released. A comparison of this action with that of the polarized ringer (to be described later) will be found of interest.

Magneto-Bell. The magneto-bell came into wide use with the spread of telephone service. Its two fundamental parts are an alternating-current generator and a polarized bell-ringing device.

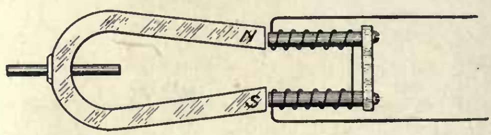


Fig. 17. Elemental Magneto-Generator

Each had its counterpart long before the invention of the telephone, though made familiar by the latter. The alternating-current generator of the magneto-bell consists of a rotatable armature composed of a coil of insulated wire and usually a core of soft iron, its rotation taking place in a magnetic field. This field is usually provided by a permanent magnet, hence the name "magneto-generator." The purist in terms may well say, however, that every form whatever of the dynamo-electric generator is a magneto-generator, as magnetism is one link in every such conversion of mechanical power into electricity. The terms magneto-electric, magneto-generator, etc., involving the term "magneto," have come to imply the presence of *permanently* magnetized steel as an element of the construction.

In its early form, the magneto-generator consisted of the arrangement shown in Fig. 17, wherein a permanent magnet can rotate on an axis before an electromagnet having soft iron cores and a winding. Reversals of magnetism produce current in alternately reversing half-cycles, one complete rotation of the magnet producing one such cycle. Obviously the result would be the same if the magnet were stationary and the coils should rotate, which is the construction of more modern devices. The turning of the crank of a magneto-bell rotates the armature in the magnetic field by some form of gearing at a rate usually of the order of twenty turns per second, producing an alternating current of that frequency. This current is caused by an effective electromotive force which may be as great as 100 volts, produced immediately by the energy of the user. In an equipment using a magneto-telephone as both receiver and transmitter and a magneto-bell as its signal-sending machine, as was usual in 1877, it is interesting to note that the entire motive power for signals and speech transmission was supplied by the muscular tissues of the user—a case of working one's passage.

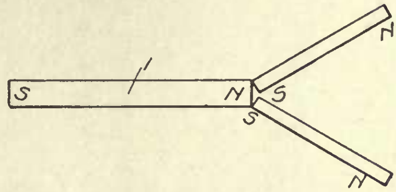


Fig. 18. Extension of a Permanent Magnet

The alternating current from the generator is received and converted into sound by means of the *polarized ringer,* a device which is interesting as depending upon several of the electrical, mechanical, and magnetic actions which are the foundations of telephone engineering.

"Why the ringer rings" may be gathered from a study of Figs. 18 to 21. A permanent magnet will impart temporary magnetism to pieces of iron near it. In Fig. 18 two pieces of iron are so energized. The ends of these pieces which are nearest to the permanent magnet *1* are of the opposite polarity to the end they approach, the free ends being of opposite polarity. In the figure, these free ends are marked *N,* meaning they are of a polarity to point north if free to point at all. English-speaking persons call this *north polarity.* Similarly, as in Fig. 19, any arrangement of iron near a permanent magnet always will have free poles of the same polarity as the end of the permanent magnet nearest them.

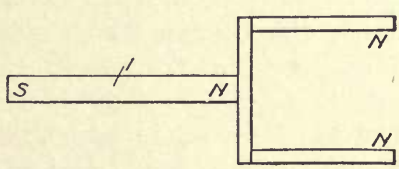


Fig. 19. Extension of a Permanent Magnet

A permanent magnet so related to iron forms part of a polarized ringer. So does an electromagnet composed of windings and iron cores. Fig. 20 reminds us of the law of electromagnets. If current flows from the plus towards the minus side, with the windings as drawn, polarities will be induced as marked.

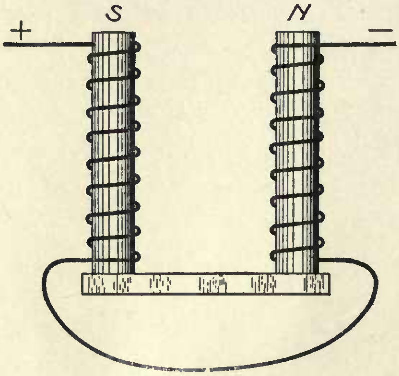


Fig. 20. Electromagnet

If, now, such an electromagnet, a permanent magnet, and a pivoted armature be related to a pair of gongs as shown in Fig. 21, a polarized ringer results. It should be noted that a permanent magnet has both its poles presented (though one of the poles is not actually attached) to two parts of the iron of the *electro*-magnet. The result is that the ends of the armature are of south polarity and those of the core are of north polarity. All the markings of Fig. 21 relate to the polarity produced by the permanent magnet. If, now, a current flow in the ringer winding from plus to minus, obviously the right-hand pole will be additively magnetized, the current tending to produce north magnetism there; also the left-hand pole will be subtractively magnetized, the current tending to produce south magnetism there. If the current be of a certain strength, relative to the certain ringer under study, magnetism in the left pole will be neutralized and that in the right pole doubled. Hence the armature will be attracted more by the right pole than by the left and will strike the right-hand gong. A reversal of current produces an opposite action, the left-hand gong being struck. The current ceasing, the armature remains where last thrown.

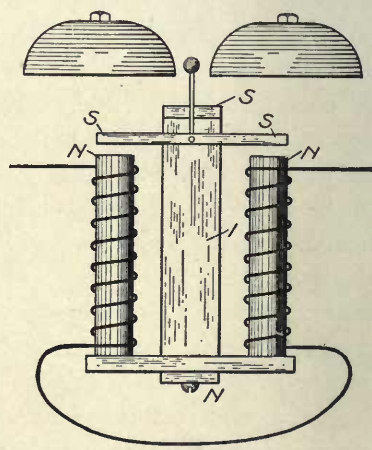


Fig. 21. Polarized Ringer

It is important to note that the strength of action depends upon the strength of the current up to a certain point only. That depends upon the strength of the permanent magnet. Whenever the current is great enough just to neutralize the normal magnetism of one pole and to double that of the other, no increase in current will cause the device to ring any louder. This makes obvious the importance of a proper permanent magnetism and displays the fallacy of some effort to increase the output of various devices depending upon these principles. This discussion of magneto-electric signaling is introduced here because of a belief in its being fundamental. Chapter VIII treats of such a signaling in further detail.

Telephone Receiver. The telephone receiver itself serves a useful purpose as an audible signal. An interrupted or alternating current of proper frequency and amount will produce in it a musical tone which can be heard throughout a large room. This fact enables a telephone central office to signal a subscriber who has left his receiver off the switch hook, so that normal conditions may be restored.

Visible Signals. *Electromagnetic Signal.* Practical visual signals are of two general kinds: electromagnetic devices for moving a target or pointer, and incandescent lamps. The earliest and most widely used visible signal in telephone practice was the annunciator, having a shutter adapted to fall when the magnet is energized. Fig. 22 is such a signal. Shutter *1* is held by the catch *2* from dropping to the right by its own gravity. The name "gravity-drop" is thus obvious. Current energizing the core attracts the armature *3*, lifts the catch *2*, and the shutter falls. A simple modification of the gravity-drop produces the visible signal shown in Fig. 23. Energizing the core lifts a target so as to render it visible through an opening in the plate *1*. A contrast of color between the plate and the target heightens the effect.

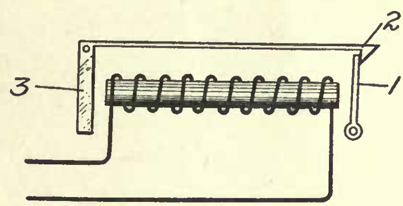


Fig. 22. Gravity-Drop

The gravity-drop is principally adapted to the magneto-bell system of signaling, where an alternating current is sent over the line to a central office by the operation of a bell crank at the subscriber's station, this current, lasting only as long as the crank is turned, energizes the drop, which may be restored by hand or otherwise and will remain latched. The visible signal is better adapted to lines in which the signaling is done by means of direct current, as, for example, in systems where the removal of the receiver from the hook at the subscriber's station closes the line circuit, causing current to flow through the winding of the visible signal and so displaying it until the receiver has been hung upon the hook or the circuit opened by some operation at the central office. Visible signals of the magnetic type of Fig. 23 have been widely used in connection with common-battery systems, both for line signals and for supervisory purposes, indicating the state and the progress of the connection and conversation.

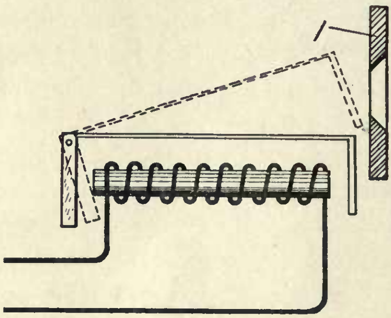


Fig. 23. Electromagnetic Visible Signal

Electric-Lamp Signal. Incandescent electric lamps appeared in telephony as a considerable element about 1890. They are better than either form of mechanical visible signals because of three principal qualities: simplicity and ease of restoring them to normal as compared with drops; their compactness; and their greater prominence when displayed. Of the latter quality, one may say that they are more *insistent,* as they give out light instead of reflecting it, as do all other visible signals. In its best form, the lamp signal is mounted behind a hemispherical lens, either slightly clouded or cut in facets. This lens serves to distribute the rays of light from the lamp, with the result that the signal may be seen from a wide angle with the axis of the lens, as shown in Fig. 24. This is of particular advantage in connection with manual-switchboard connecting cords, as it enables the signals to be mounted close to and even among the cords, their great visible prominence when shining saving them from being hidden.

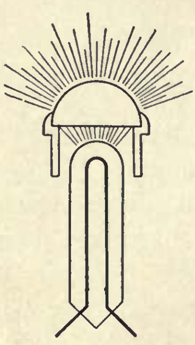


Fig. 24. Lamp Signal and Lens

The influence of the lamp signal was one of the potent ones in the development of the type of multiple switchboard which is now universal as the mechanism of large manual exchanges. The first large trial of such an equipment was in 1896 in Worcester, Mass. No large and successful multiple switchboard with any other type of signal has been built since that time.

Any electric signal has upper and lower limits of current between which it is to be actuated. It must receive current enough to operate but not enough to become damaged by overheating. The magnetic types of visible signals have a wider range between these limits than have lamp signals. If current in a lamp is too little, its filament either will not glow at all or merely at a dull red, insufficient for a proper signal. If the current is too great, the filament is heated beyond its strength and parts at the weakest place.

This range between current limits in magnetic visible signals is great enough to enable them to be used direct in telephone lines, the operating current through the line and signal in series with a fixed voltage at the central office being not harmfully great when the entire line resistance is shunted out at or near the central office. The increase of current may be as great as ten times without damage to the winding of such a signal. In lamps, the safe margin is much less. The current which just gives a sufficient lighting of the signal may be about doubled with safety to the filament of the lamp. Consequently it is not feasible to place the lamp directly in series with long exposed lines. A short circuit of such a line near the central office will burn it out.

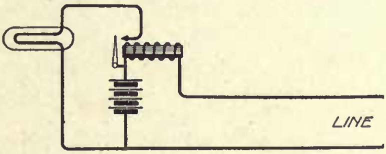


Fig. 25. Lamp Signal Controlled by Relay

The qualities of electromagnets and lamps in these respects are used to advantage by the lamp signal arrangement shown in Fig. 25. A relay is in series with the line and provides a large range of sensibility. It is able to carry any current the central-office current source can pass through it. The local circuit of the relay includes the lamp. Energizing the relay lights the lamp, and the reverse; the lamp is thus isolated from danger and receives the current best adapted to its needs.

All lines are not long and when enclosed in cable or in well-insulated interior wire, may be only remotely in danger of being short-circuited. Such conditions exist in private-branch exchanges, which are groups of telephones, usually local to limited premises, connected to a switchboard on those premises. Such a situation permits the omission of the line relay, the lamp being directly in the line. Fig. 26 shows the extreme simplicity of the arrangement, containing no moving parts or costly elements. Lamps for such service have improved greatly since the demand began to grow. The small bulk permitted by the need of compactness, the high filament resistance required for simplicity of the general power scheme of the system, and the need of considerable sturdiness in the completed thing have made the task a hard one. The practical result, however, is a signal lamp which is highly satisfactory.

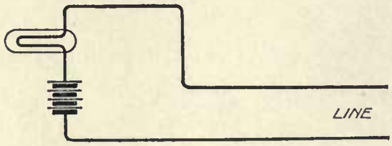


Fig. 26. Lamp Signal Directly in Line

The nature of carbon and certain earths being that their conductivity *rises* with the temperature and that of metals being that their conductivity *falls* with the temperature, has enabled the Nernst lamp to be successful. The same relation of properties has enabled incandescent-lamp signals to be connected direct to lines without relays, but compensated against too great a current by causing the resistance in series with the lamp to be increased inversely as the resistance of the filament. Employment of a "ballast" resistance in this way is referred to in Chapter XI. In Fig. 27 is shown its relation to a signal lamp directly in the line. *1* is the carbon-filament lamp; *2* is the ballast. The latter's conductor is fine iron wire in a vacuum. The resistance of the lamp falls as that of the ballast rises. Within certain limits, these changes balance each other, widening the range of allowable change in the total resistance of the line.

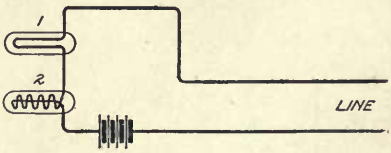


Fig. 27. Lamp Signal and Ballast

CHAPTER IV

TELEPHONE LINES

The line is a path over which the telephone current passes from telephone to telephone. The term "telephone line circuit" is equivalent. "Line" and "line circuit" mean slightly different things to some persons, "line" meaning the out-of-doors portion of the line and "line circuit" meaning the indoor portion, composed of apparatus and associated wiring. Such shades of meaning are inevitable and serve useful purposes. The opening definition hereof is accurate.

A telephone line consists of two conductors. One of these conductors may be the earth; the other always is some conducting material other than the earth—almost universally it is of metal and in the form of a wire. A line using one wire and the earth as its pair of conductors has several defects, to be discussed later herein. Both conductors of a line may be wires, the earth serving as no part of the circuit, and this is the best practice. A line composed of one wire and the earth is called a *grounded line;* a line composed of two wires not needing the earth as a conductor is called a *metallic circuit.*

In the earliest telephone practice, all lines were grounded ones. The wires were of iron, supported by poles and insulated from them by glass, earthenware, or rubber insulators. For certain uses, such lines still represent good practice. For telegraph service, they represent the present standard practice.

Copper is a better conductor than iron, does not rust, and when drawn into wire in such a way as to have a sufficient tensile strength to support itself is the best available conductor for telephone lines. Only one metal surpasses it in any quality for the purpose: silver is a better conductor by 1 or 2 per cent. Copper is better than silver in strength and price.

In the open country, telephone lines consist of bare wires of copper, of iron, of steel, or of copper-covered steel supported on insulators borne by poles. If the wires on the poles be many, cross-arms carry four to ten wires each and the insulators are mounted on pins in the cross-arms. If the wires on the poles be few, the insulators are mounted on brackets nailed to the poles. Wires so carried are called *open wires.*

In towns and cities where many wires are to be carried along the same route, the wires are reduced in size, insulated by a covering over each, and assembled into a group. Such a bundle of insulated wires is called a *cable.* It may be drawn into a duct in the earth and be called an *underground cable;* it may be laid on the bottom of the sea or other water and be called a *submarine cable;* or it may be suspended on poles and be called an *aërial cable.* In the most general practice each wire is insulated from all others by a wrapping of paper ribbon, which covering is only adequate when very dry. Cables formed of paper-insulated wires, therefore, are covered by a seamless, continuous lead sheath, no part of the paper insulation of the wires being exposed to the atmosphere during the cable's entire life in service. Telephone cables for certain uses are formed of wires insulated with such materials as soft rubber, gutta-percha, and cotton or jute saturated with mineral compounds. When insulated with rubber or gutta-percha, no continuous lead sheath is essential for insulation, as those materials, if continuous upon the wire, insulate even when the cable is immersed in water. Sheaths and other armors can assist in protecting these insulating materials from mechanical injury, and often are used for that purpose. The uses to which such cables are suitable in telephony are not many, as will be shown.

A wire supported on poles requires that it be large enough to support its own weight. The smaller the wire, the weaker it is, and with poles a given distance apart, the strength of the wire must be above a certain minimum. In regions where freezing occurs, wires in the open air can collect ice in winter and everywhere open wires are subject to wind pressure; for these reasons additional strength is required. Speaking generally, the practical and economical spacing of poles requires that wires, to be strong enough to meet the above conditions, shall have a diameter not less than .08 inch, if of hard-drawn copper, and .064 inch, if of iron or steel. The honor of developing ways of drawing copper wire with sufficient tensile strength for open-air uses belongs to Mr. Thomas B. Doolittle of Massachusetts.

Lines whose lengths are limited to a few miles do not require a conductivity as great as that of copper wire of .08-inch diameter. A wire of that size weighs approximately 100 pounds per mile. Less than 100 pounds of copper per mile of wire will not give strength enough for use on poles; but as little as 10 pounds per mile of wire gives the necessary conductivity for the lines of the thousands of telephone stations in towns and cities.

Open wires, being exposed to the elements, suffer damage from storms; their insulation is injured by contact with trees; they may make contact with electric power circuits, perhaps injuring apparatus, themselves, and persons; they endanger life and property by the possibility of falling; they and their cross-arm supports are less sightly than a more compact arrangement.

Grouping small wires of telephone lines into cables has, therefore, the advantage of allowing less copper to be used, of reducing the space required, of improving appearance, and of increasing safety. On the other hand, this same grouping introduces negative advantages as well as the foregoing positive ones. It is not possible to talk as far or as well over a line in an ordinary cable as over a line of two open wires. Long-distance telephone circuits, therefore, have not yet been placed in cables for lengths greater than 200 or 300 miles, and special treatment of cable circuits is required to talk through them for even 100 miles. One may talk 2,000 miles over open wires. The reasons for the superiority of the open wires have to do with position rather than material. Obviously it is possible to insulate and bury any wire which can be carried in the air. The differences in the properties of lines whose wires are differently situated with reference to each other and surrounding things are interesting and important.

A telephone line composed of two conductors always possesses four principal properties in some amount: (1) conductivity of the conductors; (2) electrostatic capacity between the conductors; (3) inductance of the circuit; (4) insulation of each conductor from other things.

Conductivity of Conductors. The conductivity of a wire depends upon its material, its cross-section, its length, and its temperature. Conductivity of a copper wire, for example, increases in direct ratio to its weight, in inverse ratio to its length, and its conductivity falls as the temperature rises. Resistance is the reciprocal of conductivity and the properties, conductivity and resistance, are more often expressed in terms of resistance. The unit of the latter is the *ohm;* of the former the *mho.* A conductor having a resistance of 100 ohms has a conductivity of .01 mho. The exact correlative terms are *resistance* and *conductance, resistivity* and *conductivity.* The use of the terms as in the foregoing is in accordance with colloquial practice.

Current in a circuit having resistance only, varies inversely as the resistance. Electromotive force being a cause, and resistance a state, current is the result. The formula of this relation, Ohm's law, is

$$C = \frac{E}{R}$$

C being the current which results from E, the electromotive force, acting upon R, the resistance. The units are: of current, the ampere; of electromotive force, the volt; of resistance, the ohm.

As the conductivity or resistance of a line is the property of controlling importance in telegraphy, a similar relation was expected in early telephony. As the current in the telephone line varies rapidly, certain other properties of the line assume an importance they do not have in telegraphy in any such degree.

The importance that these properties assume is, that if they did not act and the resistance of the conductors alone limited speech, transmission would be possible direct from Europe to America over a pair of wires weighing 200 pounds per mile of wire, which is less than half the weight of the wire of the best long-distance land lines now in service. The distance from Europe to America is about twice as great as the present commercial radius by land lines of 435-pound wire. In other words, good speech is possible through a mere resistance twenty times greater than the resistance of the longest actual open-wire line it is possible to talk through. The talking ratio between a mere resistance and the resistance of a regular telephone cable is still greater.

Electrostatic Capacity. It is the possession of electrostatic capacity which enables the condenser, of which the Leyden jar is a good example, to be useful in a telephone line. The simplest form of a condenser is illustrated in Fig. 28, in which two conducting surfaces are separated by an insulating material. The larger the surfaces, the closer they are together; and the higher the specific inductive capacity of the insulator, the greater the capacity of the device. An insulator used in this relation to two conducting surfaces is called the *dielectric*.

Two conventional signs are used to illustrate condensers, the upper one of Fig. 29 growing out of the original condenser of two

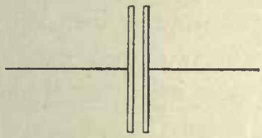


Fig. 28. Simple Condenser

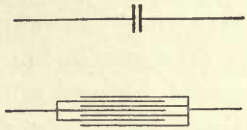


Fig. 29. Condenser Symbols

metal plates, the lower one suggesting the thought of interleaved conductors of tin foil, as for many years was the practice in condenser construction.

With relation to this property, a telephone line is just as truly a condenser as is any other arrangement of conductors and insulators. Assume such a line to be open at the distant end and its wires to be well insulated from each other and the earth. Telegraphy through such a line by ordinary means would be impossible. All that the battery or other source could do would be to cause current to flow into the line for an infinitesimal time, raising the wires to its potential, after which no current would flow. But, by virtue of electrostatic capacity, the condition is much as shown in Fig. 30. The

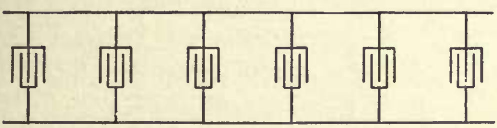


Fig. 30. Line with Shunt Capacity

condensers which that figure shows bridged across the line from wire to wire are intended merely to fix in the mind that there is a path for the transfer of electrical energy from wire to wire.

A simple test will enable two of the results of a short-circuiting capacity to be appreciated. Conceive a very short line of two wires to connect two local battery telephones. Such a line possesses negligible resistance, inductance, and shunt capacity. Its insulation is practically infinite. Let condensers be bridged across the line, one by one, while conversation goes on. The listening observer will notice that the sounds reaching his ear steadily grow less loud as the capacity across the line increases. The speaking observer will notice that the sounds he hears through the receiver in series with the line steadily grow louder as the capacity across the line increases. Fig. 31 illustrates the test.

The speaker's observation in this test shows that increasing the capacity across the line increased the amount of current entering it. The hearer's observation in this test shows that increasing the capacity across the line decreased the amount of energy turned into sound at his receiver.

The unit of electrostatic capacity is the *farad.* As this unit is inconveniently large, for practical applications the unit *microfarad*—a millionth of a farad—is employed. If quantities are known in

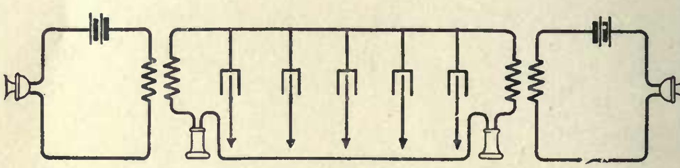


Fig. 31. Test of Line with Varying Shunt Capacity

microfarads and are to be used in calculations in which the values of the capacity require to be farads, care should be taken to introduce the proper corrective factor.

The electrostatic capacity between the conductors of a telephone line depends upon their surface area, their length, their position, and the nature of the materials separating them from each other and from other things. For instance, in an open wire line of two wires, the electrostatic capacity depends upon the diameter of the wires, upon the length of the line, upon their distance apart, upon their distance above the earth, and upon the specific inductive capacity of the air. Air being so common an insulating medium, it is taken as a convenient material whose specific inductive capacity may be used as a basis of reference. Therefore, the specific inductive capacity of air is taken as unity. All solid matter has higher specific inductive capacity than air.

The electrostatic capacity of two open wires .165 inch diameter, 1 ft. apart, and 30 ft. above the earth, is of the order of .009 microfarads per mile. This quantity would be higher if the wires were closer together; or nearer the earth; or if they were surrounded by a gas other than the air or hydrogen; or if the wires were insulated not by a gas but by any solid covering. As another example, a line composed of two wires of a diameter of .036 inch, if wrapped with paper and twisted into a pair as a part of a telephone-cable, has a mutual electrostatic capacity of approximately .08 microfarads per mile, this quantity being greater if the cable be more tightly compressed.

The use of paper as an insulator for wires in telephone cables is due to its low specific inductive capacity. This is because the insulation of the wires is so largely dry air. Rubber and similar insulating materials give capacities as great as twice that of dry paper.

The condenser or other capacity acts as an effective barrier to the steady flow of direct currents. Applying a fixed potential causes a mere rush of current to charge its surface to a definite degree, dependent upon the particular conditions. The condenser does not act as such a barrier to alternating currents, for it is possible to talk through a condenser by means of the alternating voice currents of telephony, or to pass through it alternating currents of much lower frequency. A condenser is used in series with a polarized ringer for the purpose of letting through alternating current for ringing the bell, and of preventing the flow of direct current.

The degree to which the condenser allows alternating currents to pass while stopping direct currents, depends on the capacity of the condenser and on the frequencies of alternating current. The larger the condenser capacity or the higher the frequency of the alternations, the greater will be the current passing through the circuit. The degree to which the current is opposed by the capacity is the reactance of that capacity for that frequency. The formula is

$$\text{Capacity reactance} = \frac{1}{C\omega}$$

wherein C is the capacity in farads and ω is $2\pi n$, or twice 3.1416 times the frequency.

All the foregoing leads to the generalization that the higher the frequency, the less the opposition of a capacity to an alternating current. If the frequency be zero, the reactance is infinite, *i. e.*, the circuit is open to direct current. If the frequency be infinite, the reactance is zero, *i. e.*, the circuit is as if the condenser were replaced by a solid conductor of no resistance. Compare this statement with the correlative generalization which follows the next thought upon inductance.

Inductance of the Circuit. Inductance is the property of a circuit by which change of current in it tends to produce in itself and other conductors an electromotive force other than that which causes

Fig. 32. Spiral of Wire

Fig. 33. Spiral of Wire Around Iron Core

the current. Its unit is the *henry*. The inductance of a circuit is one henry when a change of one ampere per second produces an electromotive force of one volt. Induction *between* circuits occurs because the circuits possess inductance; it is called *mutual induction*. Induction *within* a circuit occurs because the circuit possesses inductance; it is called *self-induction*. Lenz' law says: *In all cases of electromagnetic induction, the induced currents have such a direction that their reaction tends to stop the motion which produced them.*

All conductors possess inductance, but straight wires used in lines have negligible inductance in most actual cases. All wires which are wound into coils, such as electromagnets, possess inductance in a greatly increased degree. A wire wound into a spiral, as indicated in Fig. 32, possesses much greater inductance than when drawn out straight. If iron be inserted into the spiral, as shown in Fig. 33, the inductance is still further increased. It is for the purpose of eliminating inductance that resistance coils are wound with double wires, so that current passing through such coils turns in one direction half the way and in the other direction the other half.

A simple test will enable the results of a series inductance in a line to be appreciated. Conceive a very short line of two wires to connect two local battery telephones. Such a line possesses negligible resistance, inductance, and shunt capacity. Its insulation is practically infinite. Let inductive coils such as electromagnets be inserted serially in the wires of the line one by one, while conversation goes on.

The listening observer will notice that the sounds reaching his ear steadily grow faint as the inductance in the line increases and the speaking observer will notice the same thing through the receiver in series with the line.

Both observations in this test show that the amount of current entering and emerging from the line decreased as the inductance increased. Compare this with the test with bridged capacity and the loading of lines described later herein, observing the curious beneficial result when both hurtful properties are present in a line. The test is illustrated in Fig. 34.

The degree in which any current is opposed by inductance is termed the reactance of that inductance. Its formula is

$$\text{Inductive reactance} = L\omega$$

wherein L is the inductance in henrys and ω is $2\pi n$, or twice 3.1416 times the frequency. To distinguish the two kinds of reactance, that due to the capacity is called *capacity reactance* and that due to inductance is called *inductive reactance.*

All the foregoing leads to the generalization that the higher the frequency, the greater the opposition of an inductance to an alternating current. If the frequency be zero, the reactance is zero, *i. e.*, the circuit conducts direct current as mere resistance. If the fre-

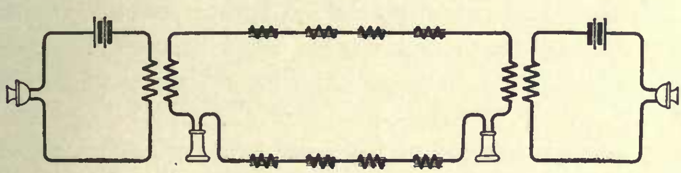


Fig. 34. Test of Line with Varying Serial Inductance

quency be infinite, the reactance is infinite, *i. e.*, the circuit is "open" to the alternating current and that current cannot pass through it. Compare this with the correlative generalization following the preceding thought upon capacity.

Capacity and inductance depend only on states of matter. Their reactances depend on states of matter and actions of energy.

In circuits having both resistance and capacity or resistance and inductance, both properties affect the passage of current. The joint reaction is expressed in ohms and is called *impedance*. Its value is the square root of the sum of the squares of the resistance and reactance, or, Z being impedance,

$$Z = \sqrt{R^2 + \frac{1}{C^2\omega^2}}$$

and

$$Z = \sqrt{R^2 + L^2\omega^2}$$

the symbols meaning as before.

In words, these formulas mean that, knowing the frequency of the current and the capacity of a condenser, or the frequency of the current and the inductance of a circuit (a line or piece of apparatus), and in either case the resistance of the circuit, one may learn the impedance by calculation.

Insulation of Conductors. The fourth property of telephone lines, insulation of the conductors, usually is expressed in ohms as an insulation resistance. In practice, this property needs to be intrinsically high, and usually is measured by millions of ohms resistance from the wire of a line to its mate or to the earth. It is a convenience to employ a large unit. A million ohms, therefore, is called a *megohm*. In telephone cables, an insulation resistance of 500 megohms per mile at 60° Fahrenheit is the usual specification. So high an insulation resistance in a paper-insulated conductor is only attained by applying the lead sheath to the cable when its core is made practically anhydrous and kept so during the splicing and terminating of the cable.

Insulation resistance varies inversely as the length of the conductor. If a piece of cable 528 feet long has an insulation resistance of 6,750 megohms, a mile (ten times as much) of such cable, will have an insulation resistance of 675 megohms, or one-tenth as great.

Inductance vs. Capacity. The mutual capacity of a telephone line is greater as its wires are closer together. The self-induction of a telephone line is smaller as its wires are closer together. The electromotive force induced by the capacity of a line leads the impressed electromotive force by 90 degrees. The inductive electromotive force lags 90 degrees behind the impressed electromotive force. And so, in general, the natures of these two properties are opposite. In a cable, the wires are so close together that their induction is negligible, while their capacity is so great as to limit commercial transmission through a cable having .06 microfarads per mile capacity and 94 ohms loop resistance per mile, to a distance of about 30 miles. In the case of open wires spaced 12 inches apart, the limit of commercial transmission is greater, not only because the wires are larger, but because the capacity is lower and the inductance higher.

Table I shows the practical limiting conversation distance over uniform lines with present standard telephone apparatus.

TABLE I

Limiting Transmission Distances

Size and Gauge of Wire	Limiting Distance
No. 8 B. W. G. copper	900 miles
10 B. W. G. copper	700 miles
10 B. & S. copper	400 miles
12 N. B. S. copper	400 miles
12 B. & S. copper	240 miles
14 N. B. S. copper	240 miles
8 B. W. G. iron	135 miles
10 B. W. G. iron	120 miles
12 B. W. G. iron	90 miles
16 B. & S. cable, copper	40 miles
19 B. & S. cable, copper	30 miles
22 B. & S. cable, copper	20 miles

In 1893, Oliver Heaviside proposed that the inductance of telephone lines be increased above the amount natural for the interaxial spacing, with a view to counteracting the hurtful effects of the capacity. His meaning was that the increased inductance—a harmful quality in a circuit not having also a harmfully great capacity—would act oppositely to the capacity, and if properly chosen and applied, should decrease or eliminate distortion by making the line's effect on fundamentals and harmonics more nearly uniform, and as well should reduce the attenuation by neutralizing the action of the capacity in dissipating energy.

There are two ways in which inductance might be introduced into a telephone line. As the capacity whose effects are to be neutralized is distributed uniformly throughout the line, the counteracting inductance must also be distributed throughout the line. Mere increase of distance between two wires of the line very happily acts both to increase the inductance and to lower the capacity; unhappily for practical results, the increase of separation to bring the qualities into useful neutralizing relation is beyond practical limits. The wires would need to be so far above the earth and so far apart as to make the arrangement commercially impossible.

Practical results have been secured in increasing the distributed inductance by wrapping fine iron wire over each conductor of the line. Such a treatment increases the inductance and improves transmission.

The most marked success has come as a result of the studies of Professor Michael Idvorsky Pupin. He inserts inductances in series with the wires of the line, so adapting them to the constants of the circuit that attenuation and distortion are diminished in a gratifying degree. This method of counteracting the effects of a distributed capacity by the insertion of localized inductance requires not only that the requisite total amount of inductance be known, but that the proper subdivision and spacing of the local portions of that inductance be known. Professor Pupin's method is described in a paper entitled "Wave Transmission Over Non-uniform Cables and Long-Distance Air Lines," read by him at a meeting of the American Institute of Electrical Engineers in Philadelphia, May 19, 1900.

NOTE. United States Letters Patent were issued to Professor Pupin on June 19, 1900, upon his practical method of reducing attenuation of electrical waves. A paper upon "Propagation of Long Electric Waves" was read by Professor Pupin before the American Institute of Electrical Engineers on March 22, 1899, and appears in Vol. 15 of the Transactions of that society. The student will find these documents useful in his studies on the subject. He is referred also to "Electrical Papers" and "Electromagnetic Theory" of Oliver Heaviside.

Professor Pupin likens the transmission of electric waves over long-distance circuits to the transmission of mechanical waves over a string. Conceive an ordinary light string to be fixed at one end and shaken by the hand at the other; waves will pass over the string from the shaken to the fixed end. Certain reflections will occur from the fixed end. The amount of energy which can be sent in this case from the shaken to the fixed point is small, but if the string be loaded by attaching bullets to it, uniformly throughout its length, it now may transmit much more energy to the fixed end.

The addition of inductance to a telephone line is analogous to the addition of bullets to the string, so that a telephone line is said to be *loaded* when inductances are inserted in it, and the inductances themselves are known as *loading coils.*

Fig. 35 shows the general relation of Pupin loading coils to the capacity of the line. The condensers of the figure are merely conventionals to represent the condenser which the line itself forms. The inductances of the figure are the actual loading coils.

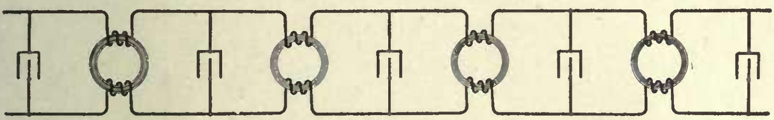


Fig. 35. Loaded Line

The loading of open wires is not as successful in practice as is that of cables. The fundamental reason lies in the fact that two of the properties of open wires—insulation and capacity—vary with atmospheric change. The inserted inductance remaining constant, its benefits may become detriments when the other two "constants" change.

The loading of cable circuits is not subject to these defects. Such loading improves transmission; saves copper; permits the use of longer underground cables than are usable when not loaded; lowers maintenance costs by placing interurban cables underground; and permits submarine telephone cables to join places not otherwise able to speak with each other.

Underground long-distance lines now join or are joining Boston and New York, Philadelphia and New York, Milwaukee and Chicago. England and France are connected by a loaded submarine cable. There is no theoretical reason why Europe and America should not speak to each other.

The student wishing to determine for himself what are the effects of the properties of lines upon open or cable circuits will find most of the subject in the following equation. It tells the value of a in terms of the four properties, a being the attenuation constant of the line.

That is, the larger a is, the more the voice current is reduced in passing over the line. The equation is

$$a=\sqrt{\tfrac{1}{2}\sqrt{(R^2+L^2\omega^2)(S^2+C^2\omega^2)}+\tfrac{1}{2}(RS-LC\omega^2)}$$

The quantities are

R = Resistance in ohms
L = Inductance in henrys
C = Mutual (shunt) capacity in farads
$\omega = 2\pi n$ = 6.2832 times the frequency
S = Shunt leakage in mhos

The quantity S is a measure of the combined direct-current conductance (reciprocal of insulation resistance) and the apparent conductance due to dielectric hysteresis.

NOTE. An excellent paper, assisting such study, and of immediate practical value as helping the understanding of cables and their reasons, is that of Mr. Frank B. Jewett, presented at the Thousand Islands Convention of the American Institute of Electrical Engineers, July 1, 1909.

Chapter 43 treats cables in further detail. They form a most important part of telephone wire-plant practice, and their uses are becoming wider and more valuable.

Possible Ways of Improving Transmission. Practical ways of improving telephone transmission are of two kinds: to improve the lines and to improve the apparatus. The foregoing shows what are the qualities of lines and the ways they require to be treated. Apparatus treatment, in the present state of the art, is addressed largely to the reduction of losses. Theoretical considerations seem to show, however, that great advance in apparatus effectiveness still is possible. More powerful transmitters—and more *faithful* ones—more sensitive and accurate receivers, and more efficient translating devices surely are possible. Discovery may need to intervene, to enable invention to restimulate.

In both telegraphy and telephony, the longer the line the weaker the current which is received at the distant end. In both telegraphy and telephony, there is a length of line with a given kind and size of wire and method of construction over which it is just possible to send intelligible speech or intelligible signals. A repeater, in telegraphy, is a device in the form of a relay which is adapted to receive these highly attenuated signal impulses and to re-transmit them with fresh power over a new length of line. An arrangement of two such relays makes it possible to telegraph both ways over a pair of lines united by such a repeater. It is practically possible to join up several such links of lines to repeating devices and, if need be, even submarine cables can be joined to land lines within practical limits. If it were necessary, it probably would be possible to telegraph around the world in this way.

If it were possible to imitate the telegraph repeater in telephony, attenuated voice currents might be caused to actuate it so as to send on those voice currents with renewed power over a length of line, section by section. Such a device has been sought for many years, and it once was quoted in the public press that a reward of one million dollars had been offered by Charles J. Glidden for a successful device of that kind. The records of the patent offices of the world show what effort has been made in that direction and many more devices have been invented than have been patented in all the countries together.

Like some other problems in telephony, this one seems simpler at first sight than it proves to be after more exhaustive study. It is possible for any amateur to produce at once a repeating device which will relay telephone circuits in one direction. It is required, however, that in practice the voice currents be relayed in both directions, and further, that the relay actually augment the energy which passes through it; that is, that it will send on a more powerful current than it receives. Most of the devices so far invented fail in one or the other of these particulars. Several ways have been shown of assembling repeating devices which will talk both ways, but not many assembling repeating devices have been shown that will talk both ways and augment in both directions.

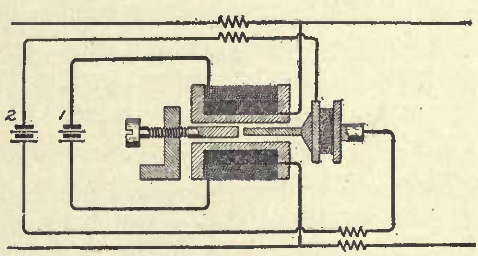


Fig. 36. Shreeve Repeater and Circuit

Practical repeaters have been produced, however, and at least one type is in daily successful use. It is not conclusively shown even of it that it augments in the same degree all of the voice waves which reach it, or even that it augments some of them at all. Its action, however, is distinctly an improvement in commercial practice. It is the invention of Mr. Herbert E. Shreeve and is shown in Fig. 39.

Primarily it consists of a telephone receiver, of a particular type devised by Gundlach, associated with a granular carbon transmitter button. It is further associated with an arrangement of induction coils or repeating coils, the object of these being to accomplish the two-way action, that is, of speaking in both directions and of preventing reactive interference between the receiving and transmitting elements. The battery *1* energizes the field of the receiving element; the received line current varies that field; the resulting motion varies the resistance of the carbon button and transforms current from battery *2* into a new alternating line current.

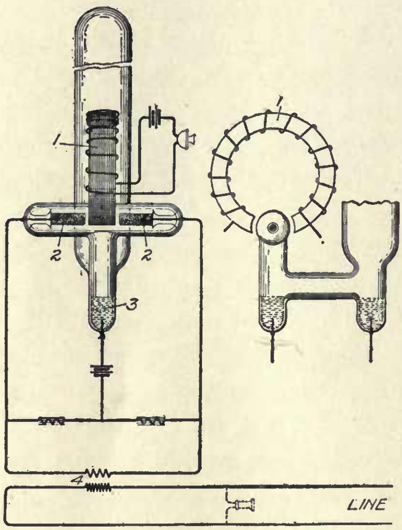


Fig. 37. Mercury-Arc Telephone Relay

By reactive interference is meant action whereby the transmitter element, in emitting a wave, affects its own controlling receiver element, thus setting up an action similar to that which occurs when the receiver of a telephone is held close to its transmitter and humming or singing ensues. No repeater is successful unless it is free from this reactive interference.

Enough has been accomplished by practical tests of the Shreeve device and others like it to show that the search for a method of relaying telephone voice currents is not looking for a pot of gold at the end of the rainbow. The most remarkable truth established by the success of repeaters of the Shreeve type is that a device embodying so large inertia of moving parts can succeed at all. It this mean anything, it is that a device in which inertia is absolutely eliminated might do very much better. Many of the methods already proposed by inventors attack the problem in this way and one of the most recent and most promising ways is that of Mr. J. B. Taylor, the circuit of whose telephone-relay patent is shown in Fig. 37. In it, *1* is an electromagnet energized by voice currents; its varying field varies an arc between the electrodes *2-2* and *3* in a vacuum tube. These fluctuations are transformed into line currents by the coil *4*.

CHAPTER V

TRANSMITTERS

Variable Resistance. As already pointed out in Chapter II, the variable-resistance method of producing current waves, corresponding to sound waves for telephonic transmission, is the one that lends itself most readily to practical purposes. Practically all telephone transmitters of today employ this variable-resistance principle. The reason for the adoption of this method instead of the other possible ones is that the devices acting on this principle are capable, with great simplicity of construction, of producing much more powerful results than the others. Their simplicity is such as to make them capable of being manufactured at low cost and of being used successfully by unskilled persons.

Materials. Of all the materials available for the variable-resistance element in telephone transmitters, carbon is by far the most suitable, and its use is well nigh universal. Sometimes one of the rarer metals, such as platinum or gold, is to be found in commercial transmitters as part of the resistance-varying device, but, even when this is so, it is always used in combination with carbon in some form or other. Most of the transmitters in use, however, depend solely upon carbon as the conductive material of the variable-resistance element.

Arrangement of Electrodes. Following the principles pointed out by Hughes, the transmitters of today always employ as their variable-resistance elements one or more loose contacts between one or more pairs of electrodes, which electrodes, as just stated, are usually of carbon. Always the arrangement is such that the sound waves will vary the intimacy of contact between the electrodes and, therefore, the resistance of the path through the electrodes.

A multitude of arrangements have been proposed and tried. Sometimes a single pair of electrodes has been employed having a single point of loose contact between them. These may be termed single-contact transmitters. Sometimes the variable-resistance element has included a greater number of electrodes arranged in multiple, or in series, or in series-multiple, and these have been termed multiple-electrode transmitters, signifying a plurality of electrodes. A later development, an outgrowth of the multiple-electrode transmitter, makes use of a pair of principal electrodes, between which is included a mass of finely divided carbon in the form of granules or small spheres or pellets. These, regardless of the exact form of the carbon particles, are called granular-carbon transmitters.

Single Electrode. *Blake.* The most notable example of the single-contact transmitter is the once familiar Blake instrument. At

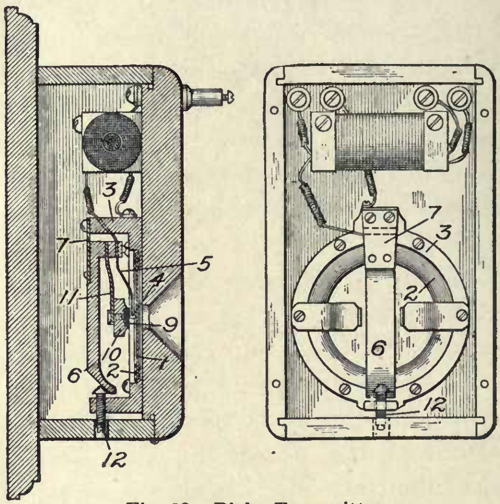


Fig. 38. Blake Transmitter

one time this formed a part of the standard equipment of almost every telephone in the United States, and it was also largely used abroad. Probably no transmitter has ever exceeded it in clearness of articulation, but it was decidedly deficient in power in comparison with the modern transmitters. In this instrument, which is shown in Fig. 38, the variable-resistance contact was that between a carbon and a platinum electrode. The diaphragm *1* was of sheet iron mounted, as usual in later transmitters, in a soft rubber gasket *2*. The whole diaphragm was mounted in a cast-iron ring *3*, supported on the inside of the box containing the entire instrument. The front electrode *4* was mounted on a light spring *5*, the upper end of which was supported by a movable bar or lever *6*, flexibly supported on a spring *7* secured to the casting which supported the diaphragm. The tension of this spring *5* was such as to cause the platinum point to press lightly away from the center of the diaphragm. The rear electrode was of carbon in the form of a small block *9*, secured in a heavy brass button *10*. The entire rear electrode structure was supported on a heavier spring *11* carried on the same lever as the spring *5*. The tension of this latter spring was such as to press against the front electrode and, by its greater strength, press this against the center of the diaphragm. The adjustment of the instrument was secured by means of the screw *12*, carried in a lug extending rearwardly from the diaphragm supporting casting, this screw, by its position, determining the strength with which the rear electrode pressed against the front electrode and that against the diaphragm. This instrument was ordinarily mounted in a wooden box together with the induction coil, which is shown in the upper portion of the figure.

The Blake transmitter has passed almost entirely out of use in this country, being superseded by the various forms of granular instruments, which, while much more powerful, are not perhaps capable of producing quite such clear and distinct articulation.

The great trouble with the single-contact transmitters, such as the Blake, was that it was impossible to pass enough current through the single point of contact to secure the desired power of transmission without overheating the contact. If too much current is sent through such transmitters, an undue amount of heat is generated at the point of contact and a vibration is set up which causes a peculiar humming or squealing sound which interferes with the transmission of other sounds.

Multiple Electrode. To remedy this difficulty the so-called multiple-electrode transmitter was brought out. This took a very great number of forms, of which the one shown in Fig. 39 is typical. The diaphragm shown at *1*, in this particular form, was made of thin pine wood. On the rear side of this, suspended from a rod *3* carried in a bracket *4*, were a number of carbon rods or pendants *5*, loosely resting against a rod *2*, carried on a bracket *6* also mounted on the rear of the diaphragm. The pivotal rod *3* and the rod *2*, against which the pendants rested, were sometimes, like the pendant rods, made of carbon and sometimes of metal, such as brass. When the diaphragm vibrated, the intimacy of contact between the pendant rod *5* and the rod *2* was altered, and thus the resistance of the path through all of the pendant rods in multiple was changed.

A multitude of forms of such transmitters came into use in the early eighties, and while they in some measure remedied the difficulty encountered with the Blake transmitter, *i. e.*, of not being able to carry a sufficiently large current, they were all subject to the effects of extreme sensitiveness, and would rattle or break when called upon to transmit sounds of more than ordinary loudness. Furthermore, the presence of such large masses of material, which it was necessary to throw into vibration by the sound waves, was distinctly against this form of transmitter. The inertia of the moving parts was so great that clearness of articulation was interfered with.

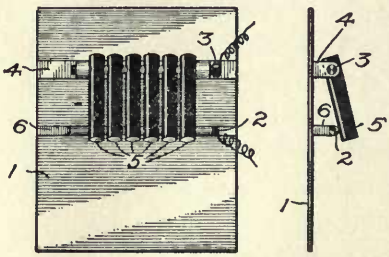


Fig. 39. Multiple-Electrode Transmitter

Granular Carbon. The idea of employing a mass of granular carbon, supported between two electrodes, one of which vibrated with the sound waves and the other was stationary, was proposed by Henry Hunnings in the early eighties. While this idea forms the basis of all modern telephone transmitters, yet it did not prevent the almost universal adoption of the single-contact form of instrument during the next decade.

Western Electric Solid=Back Transmitter. In the early nineties, however, the granular-carbon transmitter came into its own with the advent and wide adoption of the transmitter designed by Anthony C. White, known as the *White,* or *solid-back,* transmitter. This has for many years been the standard instrument of the Bell companies operating throughout the United States, and has found large use abroad. A horizontal cross-section of this instrument is shown in Fig. 40, and a rear view of the working parts in Fig. 41. The working parts are all mounted on the front casting *1*. This is supported in a cup *2*, in turn supported on the lug *3*, which is pivoted on the transmitter arm or other support. The front and rear electrodes of this instrument are formed of thin carbon disks shown in solid black.

The rear electrode, the larger one of these disks, is securely attached by solder to the face of a brass disk having a rearwardly projecting screw-threaded shank, which serves to hold it and the rear electrode in place in the bottom of a heavy brass cup *4*. The front electrode is mounted on the rear face of a stud. Clamped against the head of this stud, by a screw-threaded clamping ring *7*, is a mica washer, or disk *6*. The center portion of this mica washer is therefore rigid with respect to the front electrode and partakes of its movements. The outer edge of this mica washer is similarly clamped against the

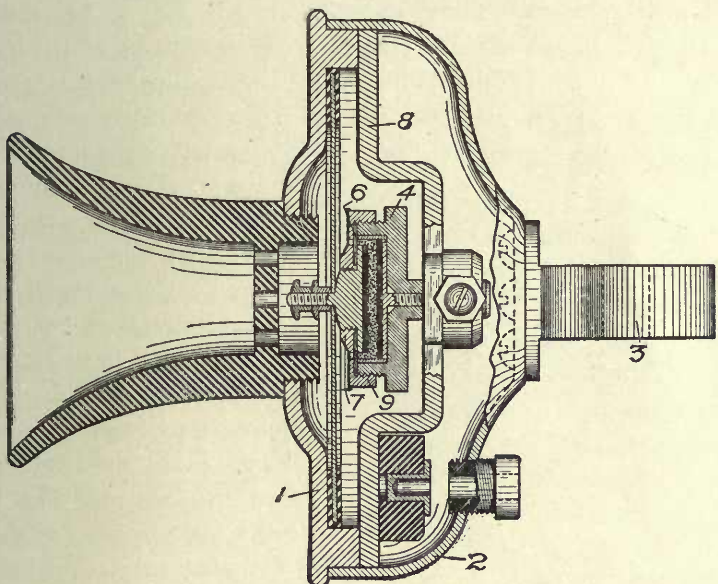


Fig. 40. White Solid-Back Transmitter

front edge of the cup *4*, a screw-threaded ring *9* serving to hold the edge of the mica rigidly against the front of the cup. The outer edge of this washer is, therefore, rigid with respect to the rear electrode, which is fixed. Whatever relative movement there is between the two electrodes must, therefore, be permitted by the flexing of the mica washer. This mica washer not only serves to maintain the electrodes in their normal relative positions, but also serves to close the chamber which contains the electrodes, and, therefore, to prevent the granular carbon, with which the space between the electrodes is filled, from falling out.

The cup *4*, containing the electrode chamber, is rigidly fastened with respect to the body of the transmitter by a rearwardly projecting shank held in a bridge piece *8* which is secured at its ends to the front block. The needed rigidity of the rear electrode is thus obtained and this is probably the reason for calling the instrument the *solid-back*. The front electrode, on the other hand, is fastened to the center of the diaphragm by means of a shank on the stud, which passes through a hole in the diaphragm and is clamped thereto by two small nuts. Against the rear face of the diaphragm of this transmitter there rest two damping springs. These are not shown in Fig. 40 but are in Fig. 41. They are secured at one end to the rear flange of the front casting *1*, and bear with their other or free ends against the rear face of the diaphragm. The damping springs are prevented from coming into actual contact with the diaphragm by small insulating pads. The purpose of the damping springs is to reduce the sensitiveness of the diaphragm to extraneous sounds. As a result, the White transmitter does not pick up all of the sounds in its vicinity as readily as do the more sensitive transmitters, and thus the transmission is not interfered with by extraneous noises. On the other hand, the provision of these heavy damping springs makes it necessary that this transmitter shall be spoken into directly by the user.

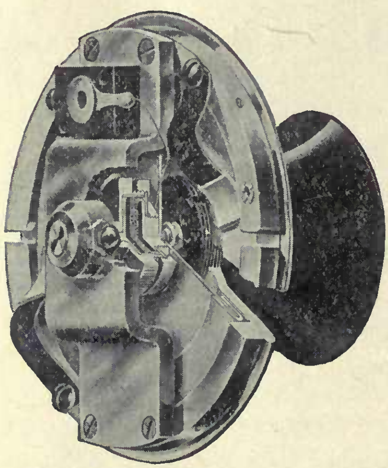


Fig. 41. White Solid-Back Transmitter

The action of this transmitter is as follows: Sound waves are concentrated against the center of the diaphragm by the mouth-piece, which is of the familiar form. These waves impinge against the diaphragm, causing it to vibrate, and this, in turn, produces similar vibrations in the front electrode. The vibrations of the front electrode are permitted by the elasticity of the mica washer *6*. The rear electrode is, however, held stationary within the heavy chambered block *4* and which in turn is held immovable by its rigid mounting. As a result, the front electrode approaches and recedes from the rear electrode, thus compressing and decompressing the mass of granular carbon between them. As a result, the intimacy of contact between the electrode plates and the granules and also between the granules themselves is altered, and the resistance of the path from one electrode to the other through the mass of granules is varied.

New Western Electric Transmitter. The White transmitter was the prototype of a large number of others embodying the same features of having the rear electrode mounted in a stationary cup or chamber and the front electrode movable with the diaphragm, a washer of mica or other flexible insulating material serving to close the front of the electrode chamber and at the same time to permit the necessary vibration of the front electrode with the diaphragm.

One of these transmitters, embodying these same features but with modified details, is shown in Fig. 42, this being the new transmitter manufactured by the Western Electric Company. In this the bridge of the original White transmitter is dispensed with, the electrode chamber being supported by a pressed metal cup *1*, which supports the chamber as a whole. The electrode cup, instead of being made of a solid block as in the White instrument, is composed of two portions, a cylindrical or tubular portion *2* and a back *3*. The cylindrical portion is externally screw-threaded so as to engage an internal screw thread in a flanged opening in the center of the cup *1*. By this means the electrode chamber is held in place in the cup *1*, and by the same means

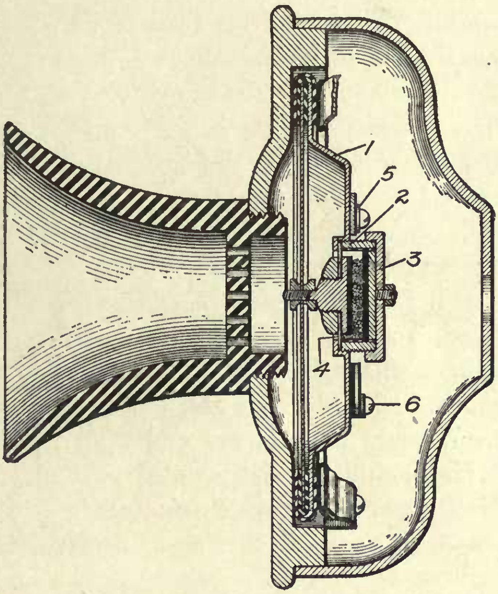


Fig. 42. New Western Electric Transmitter

the mica washer *4* is clamped between the flange in this opening and the tubular portion *2* of the electrode chamber. The front electrode is carried, as in the White transmitter, on the mica washer and is rigidly attached to the center of the diaphragm so as to partake of the movement thereof. It will be seen, therefore, that this is essentially a White transmitter, but with a modified mounting for the electrode chamber.

A feature in this transmitter that is not found in the White transmitter is that both the front and the rear electrodes, in fact, the entire working portions of the transmitter, are insulated from the exposed metal parts of the instrument. This is accomplished by insulating the diaphragm and the supporting cup *1* from the transmitter front. The terminal *5* on the cup *1* forms the electrical connection for the rear electrode, while the terminal *6*, which is mounted *on* but insulated *from* the cup *1* and is connected with the front electrode by a thin flexible connecting strip, forms the electrical connection for the front electrode.

Kellogg Transmitter. The transmitter of the Kellogg Switchboard and Supply Company, originally developed by Mr. W. W. Dean and modified by his successors in the Kellogg Company, is shown in Fig. 43. In this, the electrode chamber, instead of being mounted in a stationary and rigid position, as in the case of the White instrument, is mounted on, and, in fact, forms a part of the diaphragm. The electrode which is associated with the mica washer instead of moving with the diaphragm, as in the White instrument, is rigidly connected to a bridge so as to be as free as possible from all vibrations.

Referring to Fig. 43, which is a horizontal cross-section of the instrument, *1* indicates the diaphragm. This is of aluminum and it has in its center a forwardly deflected portion forming a chamber for the electrodes. The front electrode *2* of carbon is backed by a disk of brass and rigidly secured in the front of this chamber, as clearly indicated. The rear electrode *3*, also of carbon, is backed by a disk of brass, and is clamped against the central portion of a mica disk by means of the enlarged head of stud *6*. A nut *7*, engaging the end of a screw-threaded shank from the back of the rear electrode, serves to bind these two parts together securely, clamping the mica washer between them. The outer edge of the mica washer is clamped to the main diaphragm *1* by an aluminum ring and rivets, as clearly indicated. It is seen, therefore, that the diaphragm itself contains the electrode chamber as an integral part thereof. The entire structure of the diaphragm, the front and back electrodes, and the granular carbon within are permanently assembled in the factory and cannot be dissociated without destroying some of the parts. The rear electrode is held rigidly in place by the bridge *5* and the stud *6*, this stud passing through a block *9* mounted on the

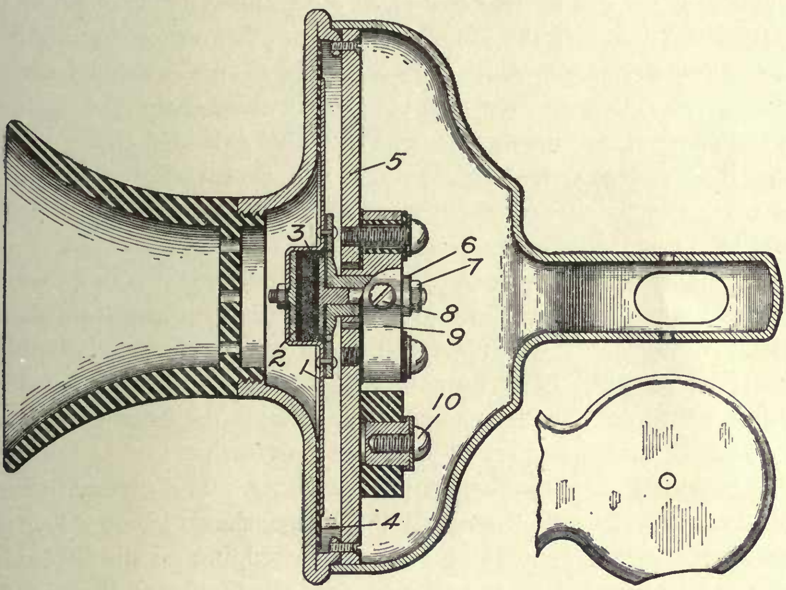


Fig. 43. Kellogg Transmitter

bridge but insulated from it. The stud *6* is clamped in the block *9* by means of the set screw *8*, so as to hold the rear electrode in proper position after this position has been determined.

In this transmitter, as in the transmitter shown in Fig. 42, all of the working parts are insulated from the exposed metal casing. The diaphragm is insulated from the front of the instrument by means of a washer *4* of impregnated cloth, as indicated. The rear electrode is insulated from the other portions of the instrument by means of the mica washer and by means of the insulation between the block *9* and the bridge *5*. The terminal for the rear electrode is mounted on the block *9*, while the terminal for the front electrode, shown at *10*, is mounted on, but insulated from, the bridge. This terminal *10* is connected with the diaphragm and therefore with the front electrode by means of a thin, flexible metallic connection. This transmitter is provided with damping springs similar to those of the White instrument.

It is claimed by advocates of this type of instrument that, in addition to the ordinary action due to the compression and decompression of the granular carbon between the electrodes, there exists another action due to the agitation of the granules as the chamber is caused to vibrate by the sound waves. In other words, in addition to the ordinary action, which may be termed *the piston action between the electrodes*, it is claimed that the general shaking-up effect of the granules when the chamber vibrates produces an added effect. Certain it is, however, that transmitters of this general type are very efficient and have proven their capability of giving satisfactory service through long periods of time.

Another interesting feature of this instrument as it is now manufactured is the use of a transmitter front that is struck up from sheet metal rather than the employment of a casting as has ordinarily been the practice. The formation of the supporting lug for the transmitter from the sheet metal which forms the rear casing or shell of the instrument is also an interesting feature.

Automatic Electric Company Transmitter. The transmitter of the Automatic Electric Company, of Chicago, shown in Fig. 44, is of the same general type as the one just discussed, in that the electrode chamber is mounted on and vibrates with the diaphragm instead of being rigidly supported on the bridge as in the case of the White or solid-back type of instrument. In this instrument the transmitter front *1* is struck up from sheet metal and contains a rearwardly projecting flange, carrying an internal screw thread. A heavy inner cup *2*, together with the diaphragm *3*, form an enclosure containing the electrode chamber. The diaphragm is, in this case, permanently secured at its edge to the periphery of the inner cup *2* by a band of metal *4* so formed as to embrace the edges of both the cup and the diaphragm and permanently lock them together. This inner chamber is held in place in the transmitter front *1* by means of a lock ring *5* externally screw-threaded to engage the internal screw-thread on the flange on the front. The electrode chamber proper is made in the form of a cup, rigidly secured to the diaphragm so as to move therewith, as clearly indicated. The rear electrode is mounted on a screw-threaded stud carried in a block which is fitted to a close central opening in the cup *2*.

This transmitter does not make use of a mica washer or diaphragm, but employs a felt washer which surrounds the shank of the rear electrode and serves to close and seal the carbon containing cup. By this means the granular carbon is retained in the cham-

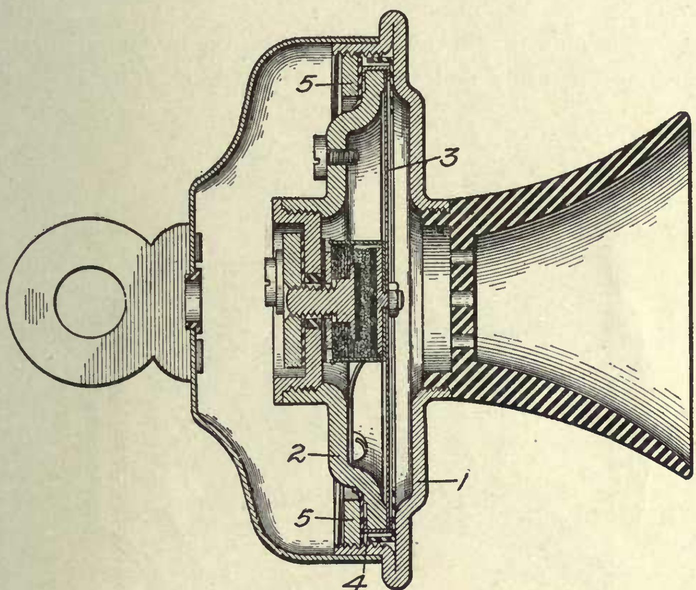


Fig. 44. Automatic Electric Company Transmitter

ber and the necessary flexibility or freedom of motion is permitted between the front and the rear electrodes. As in the Kellogg and the later Bell instruments, the entire working parts of this transmitter are insulated from the metal containing case, the inner chamber, formed by the cup *2* and the diaphragm *3*, being insulated from the transmitter front and its locking ring by means of insulating washers, as shown.

Monarch Transmitter. The transmitter of the Monarch Telephone Manufacturing Company, shown in Fig. 45, differs from both the stationary-cup and the vibrating-cup types, although it has the characteristics of both. It might be said that it differs from each of these two types of transmitters in that it has the characteristics of both.

This transmitter, it will be seen, has two flexible mica washers between the electrodes and the walls of the electrode cup. The front and the back electrodes are attached to the diaphragm and the bridge, respectively, by a method similar to that employed in the solid-back transmitters, while the carbon chamber itself is free to vibrate with the diaphragm as is characteristic of the Kellogg transmitter.

An aluminum diaphragm is employed, the circumferential edge of which is forwardly deflected to form a seat. The edge of the

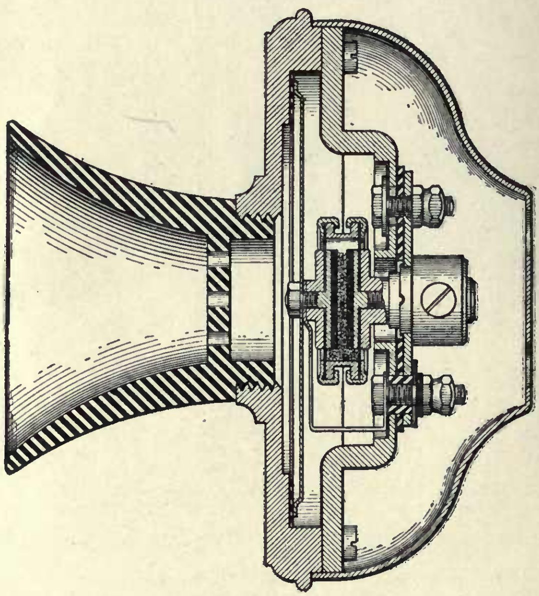


Fig. 45. Monarch Transmitter

diaphragm rests *against* and is separated *from* the brass front by means of a one-piece gasket of specially treated linen. This forms an insulator which is not affected by heat or moisture. As in the transmitters previously described, the electrodes are firmly soldered to brass disks which have solid studs extending from their centers. In the case of both the front and the rear electrodes, a mica disk is placed over the supporting stud and held in place by a brass hub which has a base of the same size as the electrode. The carbon-chamber wall consists of a brass ring to which are fastened the mica disks of the front and the back electrodes by means of brass collars clamped over the edge of the mica and around the rim of the brass ring forming the chamber.

Electrodes. The electrode plates of nearly all modern transmitters are of specially treated carbon. These are first copper-plated and soldered to their brass supporting disks. After this they are turned and ground so as to be truly circular in form and to present absolutely flat faces toward each other. These faces are then highly polished and the utmost effort is made to keep them absolutely clean. Great pains are taken to remove from the pores of the carbon, as well as from the surface, all of the acids or other chemicals that may have entered them during the process of electroplating them or of soldering them to the brass supporting disk. That the two electrodes, when mounted in a transmitter, should be parallel with each other, is an item of great importance as will be pointed out later.

In a few cases, as previously stated, gold or platinum has been substituted for the carbon electrodes in transmitters. These are capable of giving good results when used in connection with the proper form of granular carbon, but, on the whole, the tendency has been to abandon all forms of electrode material except carbon, and its use is now well nigh universal.

Preparation of Carbon. The granular carbon is prepared from carefully selected anthracite coal, which is specially treated by roasting or "re-carbonizing" and is then crushed to approximately the proper fineness. The crushed carbon is then screened with extreme care to eliminate all dust and to retain only granules of uniform size.

Packing. In the earlier forms of granular-carbon transmitters a great deal of trouble was experienced due to the so-called packing of the instrument. This, as the term indicates, was a trouble due to the tendency of the carbon granules to settle into a compact mass and thus not respond to the variable pressure. This was sometimes due to the presence of moisture in the electrode chamber; sometimes to the employment of granules of varying sizes, so that they would finally arrange themselves under the vibration of the diaphragm into a fairly compact mass; or sometimes, and more frequently, to the granules in some way wedging the two electrodes apart and holding them at a greater distance from each other than their normal distance. The trouble due to moisture has been entirely eliminated by so sealing the granule chambers as to prevent the entrance of moisture. The trouble due to the lack of uniformity in size of the granules has been entirely eliminated by making them all of one size and by making them of sufficient hardness so that they would not break up into granules of smaller size. The trouble due to the settling of the granules and wedging the electrodes apart has been practically eliminated in well-designed instruments, by great mechanical nicety in manufacture.

Almost any transmitter may be packed by drawing the diaphragm forward so as to widely separate the electrodes. This allows the granules to settle to a lower level than they normally occupy and when the diaphragm is released and attempts to resume its normal position it is prevented from doing so by the mass of granules between. Transmitters of the early types could be packed by placing the lips against the mouthpiece and drawing in the breath. The slots now provided at the base of standard mouthpieces effectually prevent this.

In general it may be said that the packing difficulty has been almost entirely eliminated, not by the employment of remedial devices, such as those often proposed for stirring up the carbon, but by preventing the trouble by the design and manufacture of the instruments in such forms that they will not be subject to the evil.

Carrying Capacity. Obviously, the power of a transmitter is dependent on the amount of current that it may carry, as well as on the amount of variation that it may make in the resistance of the path through it. Granular carbon transmitters are capable of carrying much heavier current than the old Blake or other single or multiple electrode types. If forced to carry too much current, however, the same frying or sizzling sound is noticeable as in the earlier types. This is due to the heating of the electrodes and to small arcs that occur between the electrodes and the granules.

One way to increase the current-carrying capacity of a transmitter is to increase the area of its electrodes, but a limit is soon reached in this direction owing to the increased inertia of the moving electrode, which necessarily comes with its larger size.

The carrying capacity of transmitters may also be increased by providing special means for carrying away the heat generated in the variable-resistance medium. Several schemes have been proposed for this. One is to employ unusually heavy metal for the electrode chamber, and this practice is best exemplified in the White solid-back instrument. It has also been proposed by others to water-jacket the electrode chamber, and also to keep it cool by placing it in close proximity to the relatively cool joints of a thermopile. Neither of these two latter schemes seems to be warranted in ordinary commercial practice.

Sensitiveness. In all the transmitters so far discussed damping springs of one form or another have been employed to reduce the sensitiveness of the instrument. For ordinary commercial use too great a degree of sensitiveness is a fault, as has already been pointed out. There are, however, certain adaptations of the telephone transmitter which make a maximum degree of sensitiveness desirable. One of these adaptations is found in the telephone equipments for assisting partially deaf people to hear. In these the transmitter is carried on some portion of the body of the deaf person, the receiver is strapped or otherwise held at his ear, and a battery for furnishing the current is carried in his pocket. It is not feasible, for this sort of use, that the sound which this transmitter is to reproduce shall always occur immediately in front of the transmitter. It more often occurs at a distance of several feet. For this reason the transmitter is made as sensitive as possible, and yet is so constructed that it will not be caused to produce too loud or unduly harsh sounds in response to a loud sound taking place immediately in front of it. Another adaptation of such highly sensitive transmitters is found in the special intercommunicating telephone systems for use between the various departments or desks in business offices. In these it is desirable that the transmitter shall be able to respond adequately to sounds occurring anywhere in a small-sized room, for instance.

Acousticon Transmitter. In Fig. 46 is shown a transmitter adapted for such use. This has been termed by its makers the *acousticon transmitter.* Like all the transmitters previously discussed, this is of the variable-resistance type, but it differs from them all in that it has no damping springs; in that carbon balls are substituted for carbon granules; and in that the diaphragm itself serves as the front electrode.

This transmitter consists of a cup *1*, into which is set a cylindrical block *2*, in one face of which are a number of hemispherical recesses. The diaphragm *3* is made of thin carbon and is so placed in the transmitter as to cover the openings of the recesses in the carbon block, and lie close enough to the carbon block, without engaging it, to prevent the carbon particles from falling out. The diaphragm thus serves as the front electrode and the carbon block as the rear electrode. The recesses in the carbon block are about two-thirds filled with small carbon balls, which are about the size of fine sand. The front piece *4* of the transmitter is of sheet metal and serves to hold the diaphragm in place. To admit the sound waves it is provided with a circular opening opposite to and about the size of the rear electrode block. On this front piece are mounted the two terminals of the transmitter, connected respectively to the two electrodes, terminal *5* being insulated from the front piece and connected by a thin metal strip with the diaphragm, while terminal *6* is mounted directly on the front piece and connected through the cup *1* with the carbon block *2*, or back electrode of the transmitter.

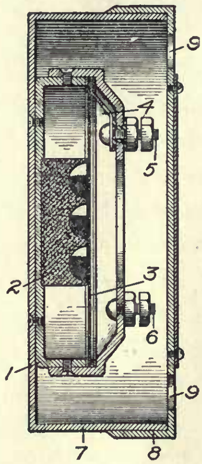


Fig 46. Acousticon Transmitter

When this transmitter is used in connection with outfits for the deaf, it is placed in a hard rubber containing case, consisting of a hollow cylindrical piece *7*, which has fastened to it a cover *8*. This cover has a circular row of openings or holes near its outer edge, as shown at *9*, through which the sound waves may pass to the chamber within, and thence find their way through the round hole in the center of the front plate *4* to the diaphragm *3*. It is probable also that the front face of the cover *8* of the outer case vibrates, and in this way also causes sound waves to impinge against the diaphragm. This arrangement provides a large receiving surface for the sound waves, but, owing to the fact that the openings in the containing case are not opposite the opening in the transmitter proper, the sound waves do not impinge directly against the diaphragm. This peculiar arrangement is probably the result of an endeavor to prevent the transmitter from being too strongly actuated by violent sounds close to it. Instruments of this kind are very sensitive and under proper conditions are readily responsive to words spoken in an ordinary tone ten feet away.

Switchboard Transmitter. Another special adaptation of the telephone transmitter is that for use of telephone operators at central-office switchboards. The requirements in this case are such that the operator must always be able to speak into the transmitter while seated before the switchboard, and yet allow both of her hands to be free for use. This was formerly accomplished by suspending an ordinary granular-carbon transmitter in front of the operator, but a later development has resulted in the adoption of the so-called breast transmitter, shown in Fig. 47. This is merely an ordinary granular-carbon transmitter mounted on a plate which is strapped on the breast of the operator, the transmitter being provided with a long curved mouthpiece which projects in such a manner as to lie just in front of the operator's lips. This device has the advantage of automatically following the operator in her movements. The breast transmitter shown in Fig. 47, is that of the Dean Electric Company.

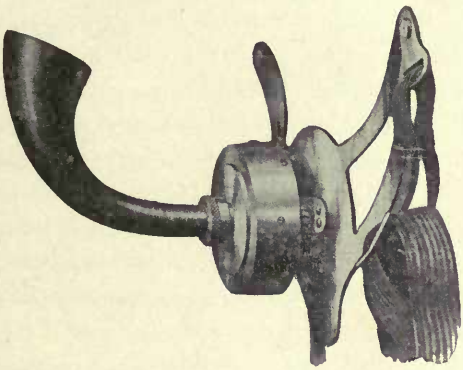


Fig. 47. Switchboard Transmitter

Conventional Diagram. There are several common ways of illustrating transmitters in diagrams of circuits in which they are employed. The three most common ways are shown in Fig. 48. The one at the left is supposed to be a side view of an ordinary instrument, the one in the center a front view, and the one at the right to be merely a suggestive arrangement of the diaphragm and the rear electrode. The one at the right is best and perhaps most common; the center one is the poorest and least used.

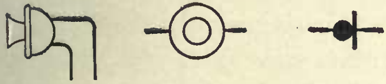


Fig. 48. Transmitter Symbols

CHAPTER VI

RECEIVERS

The telephone receiver is the device which translates the energy of the voice currents into the energy of corresponding sound waves. All telephone receivers today are of the electromagnetic type, the voice currents causing a varying magnetic pull on an armature or diaphragm, which in turn produces the sound waves corresponding to the undulations of the voice currents.

Early Receivers. The early forms of telephone receivers were of the *single-pole* type; that is, the type wherein but one pole of the electromagnet was presented to the diaphragm. The single-pole receiver that formed the companion piece to the old Blake transmitter and that was the standard of the Bell companies for many years, is shown in Fig. 49. While this has almost completely passed out of use, it may be profitably studied in order that a comparison may be made between certain features of its construction and those of the later forms of receivers.

The coil of this receiver was wound on a round iron core *2*, flattened at one end to afford means for attaching the permanent magnet. The permanent magnet was of laminated construction, consisting of four hard steel bars *1*, extending nearly the entire length of the receiver shell. These steel bars were all magnetized separately and placed with like poles together so as to form a single bar magnet. They were laid together in pairs so as to include between the pairs the flattened end of the pole piece *2* at one end and the flattened portion of the tail piece *3* at the other end. This whole magnet structure, including the core, the tail piece, and the permanently magnetized steel bars, was clamped together by screws as shown. The containing shell was of hard rubber consisting of three pieces, the barrel *4*, the ear-piece *5*, and the tail cap *6*. The barrel and the ear piece engaged each other by means of a screw thread and served to clamp the diaphragm between them. The compound bar magnet was held in place within the shell by means of a screw *7* passing through the hard rubber tail cap *6* and into the tail block *3* of the magnet. External binding posts mounted on the tail cap, as shown, were connected by heavy leading-in wires to the terminals of the electromagnet.

A casual consideration of the magnetic circuit of this instrument will show that it was inefficient, since the return path for the lines of force set up by the bar magnet was necessarily through a very long air path. Notwithstanding this, these receivers were capable of giving excellent articulation and were of marvelous delicacy of action. A very grave fault was that the magnet was supported in the shell at the end farthest removed from the diaphragm. As a result it was difficult to maintain a permanent adjustment between the pole piece and the diaphragm. One reason for this was that hard rubber and steel contract and expand under changes of temperature at very different rates, and therefore the distance between the pole piece and the diaphragm changed with changes of temperature. Another grave defect, brought about by this tying together of the permanent magnet and the shell which supported the diaphragm at the end farthest from the diaphragm, was that any mechanical shocks were thus given a good chance to alter the adjustment.

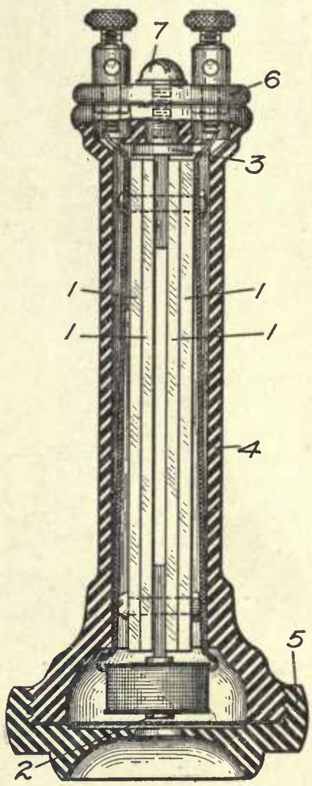


Fig. 49. Single-Pole Receiver

Modern Receivers. Receivers of today differ from this old single-pole receiver in two radical respects. In the first place, the modern receiver is of the bi-polar type, consisting essentially of a horseshoe magnet presenting both of its poles to the diaphragm. In the second place, the modern practice is to either support all of the working parts of the receiver, *i. e.*, the magnet, the coils, and the diaphragm, by an inner metallic frame entirely independent of the shell; or, if the shell is used as a part of the structure, to rigidly fasten the several parts close to the diaphragm rather than at the end farthest removed from the diaphragm.

Western Electric Receiver. The standard bi-polar receiver of the Western Electric Company, in use by practically all of the Bell operating companies throughout this country and in large use abroad, is shown in Fig. 50. In this the shell is of three pieces, consisting of the barrel *1*, the ear cap *2*, and the tail cap *3*. The tail cap and the barrel are permanently fastened together to form substantially a single piece. Two permanently magnetized bar magnets *4-4* are employed, these being clamped together at their upper ends, as shown, so as to include the soft iron block *5* between them. The north pole of one of these magnets is clamped to the south pole of the other, so that in reality a horseshoe magnet is formed. At their lower ends, these two permanent magnets are clamped against the soft iron pole pieces *6-6*, a threaded block *7* also being clamped rigidly between these pole pieces at this point. On the ends of the pole pieces the bobbins are wound. The whole magnet structure is secured within the shell *1* by means of a screw thread on the block *7* which engages a corresponding internal screw thread in the shell *1*. As a result of this construction the whole magnet structure is bound rigidly to the shell structure at a point close to the diaphragm, comparatively speaking, and as a result of this close coupling, the relation between the diaphragm and the pole piece is very much more rigid and substantial than in the case where the magnet structure and the shell were secured together at the end farthest removed from the diaphragm.

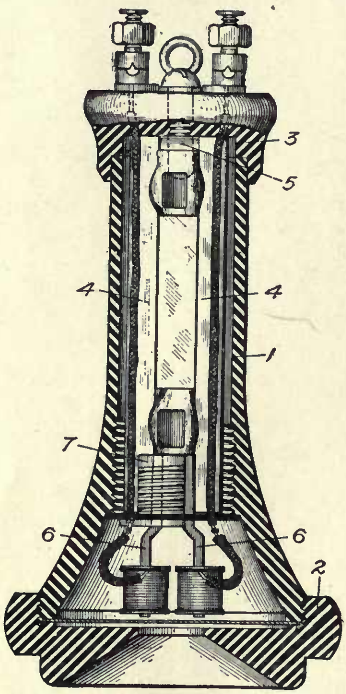


Fig. 50. Western Electric Receiver

Although this receiver shown in Fig. 50 is the standard in use by the Bell companies throughout this country, its numbers running well into the millions, it cannot be said to be a strictly modern receiver, because of at least one rather antiquated feature. The binding posts, by which the circuit conductors are led to the coils of this instrument, are mounted on the outside of the receiver shell, as indicated, and are thus subject to danger of mechanical injury and they are also exposed to the touch of the user, so that he may, in case of the wires being charged to an abnormal potential, receive a shock. Probably a more serious feature than either one of these is that the terminals of the flexible cords which attach to these binding posts are attached outside of the receiver shell, and are therefore exposed to the wear and tear of use, rather than being protected as they should be within the shell. Notwithstanding this undesirable feature, this receiver is a very efficient one and is excellently constructed.

Kellogg Receiver. In Fig. 51 is shown a bi-polar receiver with internal or concealed binding posts. This particular receiver is typical of a large number of similar kinds and is manufactured by the Kellogg Switchboard and Supply Company. Two straight permanently magnetized bar magnets *1-1* are clamped together at their opposite ends so as to form a horseshoe magnet. At the end opposite the diaphragm these bars clamp between them a cylindrical piece of iron *2*, so as to complete the magnetic circuit at the end. At the end nearest the diaphragm they clamp between them the ends of the soft iron pole pieces *3-3*, and also a block of composite metal *4* having a large circular flange *4'* which serves as a means for supporting the magnet structure within the shell. The screws by means of which the disk *4'* is clamped to the shouldered seat in the shell do not enter the shell directly, but rather enter screw-threaded brass blocks which are moulded into the structure of the shell. It is seen from this construction that the diaphragm and the pole pieces and the magnet

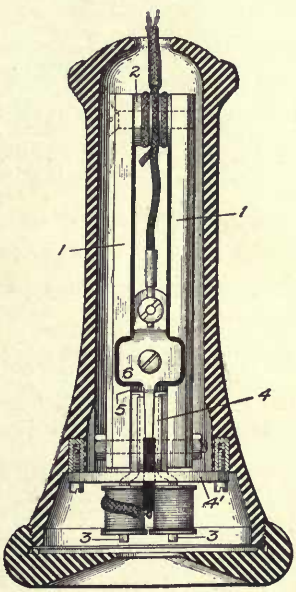


Fig. 51. Kellogg Receiver

structure itself are all rigidly secured together through the medium of the shell at a point as close as possible to the diaphragm.

Between the magnets *1-1* there is clamped an insulating block *5*, to which are fastened the terminal plates *6*, one on each side of the receiver. These terminal plates are thoroughly insulated from the magnets themselves and from all other metallic parts by means of sheets of fiber, as indicated by the heavy black lines. On these plates *6* are carried the binding posts for the receiver cord terminals. A long tongue extends from each of the plates *6* through a hole in the disk *4′*, into the coil chamber of the receiver, at which point the terminal of the magnet winding is secured to it. This tongue is insulated from the disk *4′*, where it passes through it, by means of insulating bushing, as shown. The other terminal of the magnet coils is brought out to the other plate *6* by means of a similar tongue on the other side.

In order that the receiver terminals proper may not be subjected to any strain in case the receiver is dropped and its weight caught on the receiver cord, a strain loop is formed as a continuation of the braided covering of the receiver cord, and this is tied to the permanent magnet structure, as shown. By making this strain loop short, it is obvious that whatever pull the cord receives will not be taken by the cord conductors leading to the binding posts or by the binding posts or the cord terminals themselves.

A number of other manufacturers have gone even a step further than this in securing permanency of adjustment between the receiver diaphragm and pole pieces. They have done this by not depending at all on the hard rubber shell as a part of the structure, but by enclosing the magnet coil in a cup of metal upon which the diaphragm is mounted, so that the permanency of relation between the diaphragm and the pole pieces is dependent only upon the metallic structure and not at all upon the less durable shell.

Direct-Current Receiver. Until about the middle of the year 1909, it was the universal practice to employ permanent magnets for giving the initial polarization to the magnet cores of telephone receivers. This is still done, and necessarily so, in receivers employed in connection with magneto telephones. In common-battery systems, however, where the direct transmitter current is fed from the central office to the local stations, it has been found that this current which must flow at any rate through the line may be made to serve the additional purpose of energizing the receiver magnets so as to give them the necessary initial polarity. A type of receiver has come into wide use as a result, which is commonly called the *direct-current receiver*, deriving its name from the fact that it employs the direct current that is flowing in the common-battery line to magnetize the receiver cores. The Automatic Electric Company, of Chicago, was probably the first company to adopt this form of receiver as its standard type. Their receiver is shown in cross-section in Fig. 52, and a photograph of the same instrument partially disassembled is given in Fig. 53. The most noticeable thing about the construction of this receiver is the absence of permanent magnets. The entire working parts are contained within the brass cup *1*, which serves not only as a container for the magnet, but also as a seat for the diaphragm. This receiver is therefore illustrative of the type mentioned above, wherein the relation between the diaphragm and the pole pieces is not dependent upon any connection through the shell.

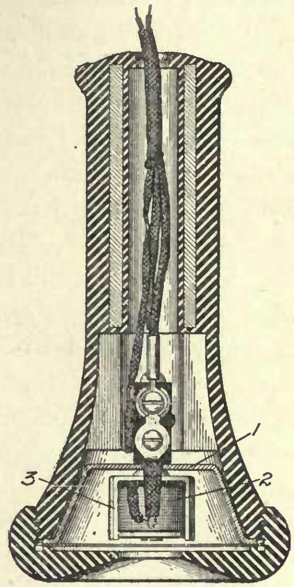


Fig. 52. Automatic Electric Company Direct-Current Receiver

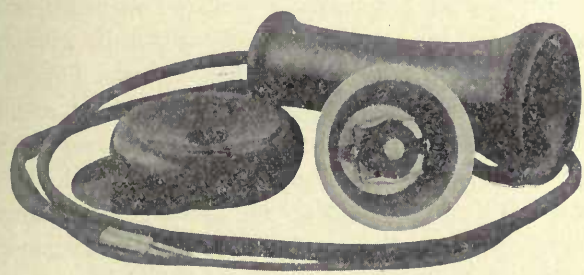


Fig. 53. Automatic Electric Company Direct-Current Receiver

The coil of this instrument consists of a single cylindrical spool *2*, mounted on a cylindrical core. This bobbin lies within a soft iron-punching *3*, the form of which is most clearly shown in Fig. 53, and this punching affords a return path to the diaphragm for the lines of force set up in the magnet core. Obviously a magnetizing current passing through the winding of the coil will cause the end of the core toward the diaphragm to be polarized, say positively, while the end of the enclosing shell will be polarized in the other polarity, negatively. Both poles of the magnet are therefore presented to the diaphragm and the only air gap in the magnetic circuit is that between the diaphragm and these poles. The magnetic circuit is therefore one of great efficiency, since it consists almost entirely of iron, the only air gap being that across which the attraction of the diaphragm is to take place.

The action of this receiver will be understood when it is stated that in common-battery practice, as will be shown in later chapters, a steady current flows over the line for energizing the transmitter. On this current is superposed the incoming voice currents from a distant station. The steady current flowing in the line will, in the case of this receiver, pass through the magnet winding and establish a normal magnetic field in the same way as if a permanent magnet were employed. The superposed incoming voice currents will then be able to vary this magnetic field in exactly the same way as in the ordinary receiver.

An astonishing feature of this recent development of the so-called direct-current receiver is that it did not come into use until after about twenty years of common-battery practice. There is nothing new in the principles involved, as all of them were already understood and some of them were employed by Bell in his original telephone; in fact, the idea had been advanced time and again, and thrown aside as not being worth consideration. This is an illustration of a frequent occurrence in the development of almost any rapidly growing art. Ideas that are discarded as worthless in the early stages of the art are finally picked up and made use of. The reason for this is that in some cases the ideas come in advance of the art, or they are proposed before the art is ready to use them. In other cases the idea as originally proposed lacked some small but essential detail, or, as is more often the case, the experimenter in the early days did not have sufficient skill or knowledge to make it fit the requirements as he saw them.

Monarch Receiver. The receiver of the Automatic Electric

Company just discussed employs but a single electromagnet by which the initial magnetization of the cores and also the variable magnetization necessary for speech reproduction is secured. The problem of the direct-current receiver has been attacked in another way by Ernest E. Yaxley, of the Monarch Telephone Manufacturing Company, with the result shown in Fig. 54. The construction in this case is not unlike that of an ordinary permanent-magnet receiver, except that in the place of the permanent magnets two soft iron cores *1-1* are employed. On these are wound two long bobbins of insulated wire so that the direct current flowing over the telephone line will pass through these and magnetize the cores to the same degree and for the same purpose as in the case of permanent magnets. These soft iron magnet cores *1-1* continue to a point near the coil chamber, where they join the two soft iron pole pieces *2-2*, upon which the ordinary voice-current coils are wound. The two long coils *4-4*, which may be termed the direct-current coils, are of somewhat lower resistance than the two voice-current coils *3-3*. They are, however, by virtue of their greater number of turns and the greater amount of iron that is included in their cores, of much higher impedance than the voice-current coils *3-3*. These two sets of coils *4-4* and *3-3* are connected in multiple. As a result of their lower ohmic resistance the coils *4-4* will take a greater amount of the steady current which comes over the line, and therefore the greater proportion of the steady current will be employed in magnetizing the bar magnets. On account of their higher impedance to alternating currents, however, nearly all of the voice currents which are superposed on the steady currents, flowing in the line will pass through the voice-current coils *3-3*, and, being near the diaphragm, these currents will so vary the steady magnetism in the cores *2-2* as to produce the necessary vibration of the diaphragm.

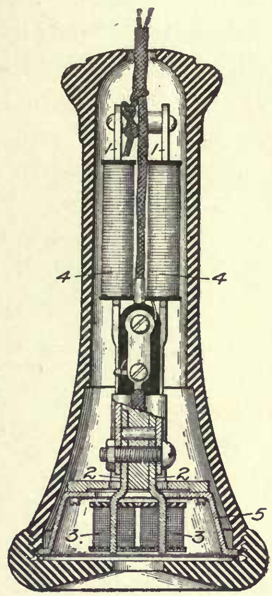


Fig. 54. Monarch Direct-Current Receiver

This receiver, like the one of the Automatic Electric Company, does not rely on the shell in any respect to maintain the permanency of relation between the pole pieces and the diaphragm. The cup *5*, which is of pressed brass, contains the voice-current coils and also acts as a seat for the diaphragm. The entire working parts of this receiver may be removed by merely unscrewing the ear piece from the hard rubber shell, thus permitting the whole works to be withdrawn in an obvious manner.

Dean Receiver. Of such decided novelty as to be almost revolutionary in character is the receiver recently put on the market by the Dean Electric Company and shown in Fig. 55. This receiver is of the direct-current type and employs but a single cylindrical bobbin of wire. The core of this bobbin and the return path for the magnetic lines of force set up in it are composed of soft iron punchings of substantially **E** shape. These punchings are laid together so as to form a laminated soft-iron field, the limbs of which are about square in cross-section. The coil is wound on the center portion of this *E* as a core, the core being, as stated, approximately square in cross-section. The general form of magnetic circuit in this instrument is therefore similar to that of the Automatic Electric Company's receiver, shown in Figs. 52 and 53, but the core is laminated instead of being solid as in that instrument.

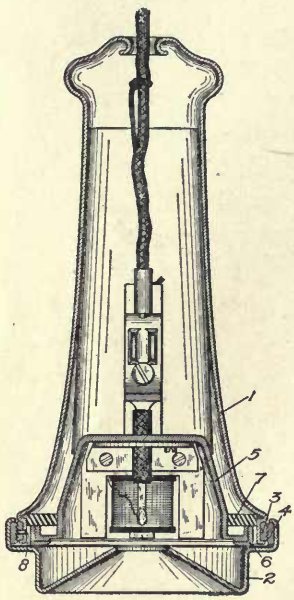


Fig. 55. Dean Steel Shell Receiver

The most unusual feature of this Dean receiver is that the use of hard rubber or composition does not enter into the formation of the shell, but instead a shell composed entirely of steel stampings has been substituted therefor. The main portion of this shell is the barrel *1*. Great skill has evidently been exercised in the forming of this by the cold-drawn process, it presenting neither seams nor welds. The ear piece *2* is also formed of steel of about the same gauge as the barrel *1*. Instead of screw-threading the steel parts, so that they would directly engage each other, the ingenious device has been employed of swaging a brass ring *3* in the barrel portion and a similar brass ring *4* in the ear cap portion, these two being slotted and keyed, as shown at *8*, so as to prevent their turning in their respective seats. The ring *3* is provided with an external screw thread and the ring *4* with an internal screw thread, so that the receiver cap is screwed on to the barrel in the same way as in the ordinary rubber shell. By the employment of these brass screw-threaded rings, the rusting together of the parts so that they could not be separated when required—a difficulty heretofore encountered in steel construction of similar parts—has been remedied.

The entire working parts of this receiver are contained within the cup *5*, the edge of which is flanged outwardly to afford a seat for

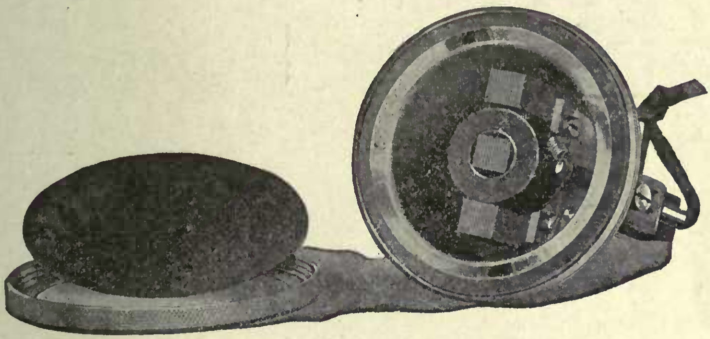


Fig. 56. Working Parts of Dean Receiver

the diaphragm. The diaphragm is locked in place on the shell by a screw-threaded ring *6*, as is clearly indicated. A ring *7* of insulating material is seated within the enlarged portion of the barrel *1*, and against this the flange of the cup *5* rests and is held in place by the cap *2* when it is screwed home. The working parts of this receiver partially disassembled are shown in Fig. 56, which gives a clear idea of some of the features not clearly illustrated in Fig. 55.

It cannot be denied that one of the principal items of maintenance of subscribers' station equipment has been due to the breakage of receiver shells. The users frequently allow their receiver to fall and strike heavily against the wall or floor, thus not only subjecting the cords to great strain, but sometimes cracking or entirely breaking the receiver shell. The innovation thus proposed by the Dean Company of making the entire receiver shell of steel is of great interest. The shell, as will be seen, is entirely insulated from the circuit of the receiver so that no contact exists by which a user could receive a shock. The shell is enameled inside and out with a heavy black insulating enamel baked on, and said to be of great durability. How this enamel will wear remains to be seen. The insulation of the interior portions of the receiver is further guarded by providing a lining of fiber within the shell at all points where it seems possible that a cross could occur between some of the working parts and the metal of the shell. This type of receiver has not been on the market long enough to draw definite conclusions, based on experience in use, as to what its permanent performance will be.

Thus far in this chapter only those receivers which are commonly called *hand receivers* have been discussed. These are the receivers that are ordinarily employed by the general public.

Operator's Receiver. At the central office in telephone exchanges the operators are provided with receivers in order that they

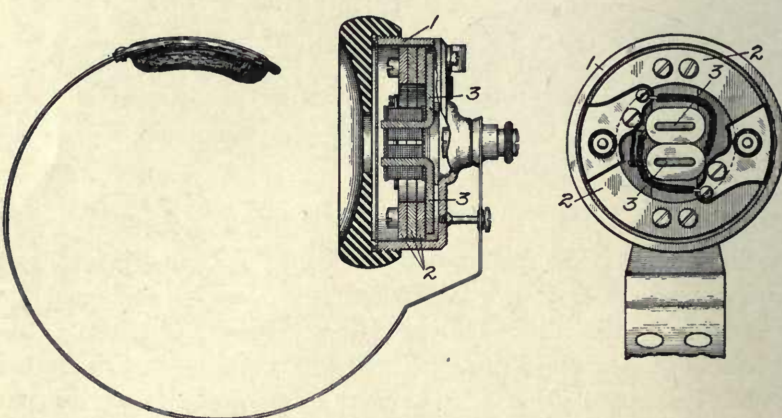


Fig. 57. Operator's Receiver

may communicate with the subscribers or with other operators. In order that they may have both of their hands free to set up and take down the connections and to perform all of the switching operations required, a special form of receiver is employed for this purpose, which is worn as a part of a head-gear and is commonly termed a *head receiver*. These are necessarily of very light construction, in order not to be burdensome to the operators, and obviously they must be efficient. They are ordinarily held in place at the ear by a metallic head band fitting over the head of the operator.

Such a receiver is shown in cross-section in Fig. 57, and completely assembled with its head band in Fig. 58. Referring to Fig. 57 the shell *1* of the receiver is of aluminum and the magnets are formed of steel rings *2*, cross-magnetized so as to present a north pole on one side of the ring and a south pole on the other. The two L-shaped pole pieces *3* are secured by screws to the poles of these ring magnets, and these pole pieces carry the magnet coils, as is clearly indicated. These poles are presented to a soft iron diaphragm in exactly the same way as in the larger hand receivers, the diaphragm being clamped in place by a hard rubber ear piece, as shown. The head bands are frequently of steel covered with leather. They have assumed numerous forms, but the general form shown in Fig. 58 is the one commonly adopted.

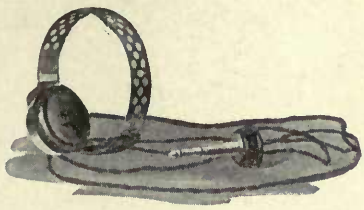


Fig. 58. Operator's Receiver and Cord

Conventional Symbols. The usual diagrammatic symbols for hand and head receivers are shown in Fig. 59. They are self-explanatory. The symbol at the left in this figure, showing the general

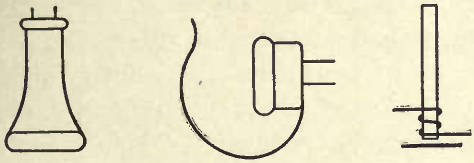


Fig. 59. Receiver Symbols

outline of the receiver, is the one most commonly used where any sort of a receiver is to be indicated in a circuit diagram, but where it becomes desirable to indicate in the diagram the actual connections with the coil or coils of the receiver, the symbol shown at the right is to be preferred, and obviously it may be modified as to number of windings and form of core as desired.

CHAPTER VII

PRIMARY CELLS

Galvani, an Italian physician, discovered, in 1786, that a current of electricity could be produced by chemical action. In 1800, Volta, a physicist, also an Italian, threw further light on Galvani's discovery and produced what we know as the *voltaic*, or *galvanic*, cell. In honor of these two discoverers we have the words volt, galvanic, and the various words and terms derived therefrom.

Simple Voltaic Cell. A very simple voltaic cell may be made by placing two plates, one of copper and one of zinc, in a glass vessel partly filled with dilute sulphuric acid, as shown in Fig. 60. When the two plates are not connected by a wire or other conductor, experiment shows that the copper plate bears a positive charge with respect to the zinc plate, and the zinc plate bears a negative charge with respect to the copper. When the two plates are connected by a wire, a current flows from the copper to the zinc plate through the metallic path of the wire, just as is to be expected when any conductor of relatively high electrical potential is joined to one of relatively low electrical potential. Ordinarily, when one charged body is connected to another of different potential, the resulting current is of but momentary duration, due to the redistribution of the charges and consequent equalization of potential. In the case of the simple cell, however, the current is continuous, showing that some action is maintaining the charges on the two plates and therefore maintaining the difference of potential between them. The energy of this current is derived from the chemical action of the acid on the zinc. The cell is in reality a sort of a zinc-burning furnace.

In the action of the cell, when the two plates are joined by a wire, it may be noticed that the zinc plate is consumed and that bubbles of hydrogen gas are formed on the surface of the copper plate.

Theory. Just why or how chemical action in a voltaic cell results in the production of a negative charge on the consumed plate is not known. Modern theory has it that when an acid is diluted in water the molecules of the acid are split up or *dissociated* into two oppositely charged atoms, or groups of atoms, one bearing a positive charge and the other a negative charge of electricity. Such charged atoms or groups of atoms are called *ions.* This separation of the molecules of a chemical compound into positively and negatively charged ions is called *dissociation.*

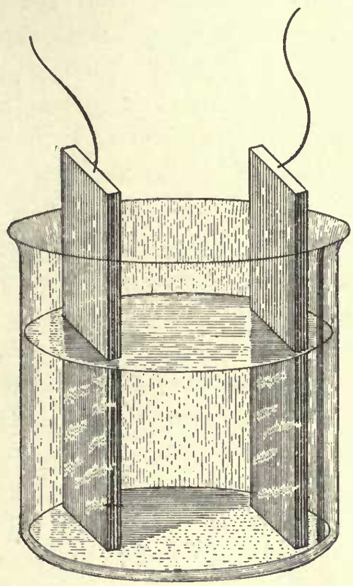


Fig. 60. Simple Voltaic Cell

Thus, in the simple cell under consideration the sulphuric acid, by dissociation, splits up into hydrogen ions bearing positive charges, and SO_4 ions bearing negative charges. The solution as a whole is neutral in potential, having an equal number of equal and opposite charges.

It is known that when a metal is being dissolved by an acid, each atom of the metal which is torn off by the solution leaves the metal as a positively charged ion. The carrying away of positive charges from a hitherto neutral body leaves that body with a negative charge. Hence the zinc, or *consumed* plate, becomes negatively charged.

In the chemical attack of the sulphuric acid on the zinc, the positive hydrogen ions are liberated, due to the affinity of the negative SO_4 ions for the positive zinc ions, this resulting in the formation of zinc sulphate in the solution. Now the solution itself becomes positively charged, due to the positive charges leaving the zinc plate with the zinc ions, and the free positively charged hydrogen ions liberated in the solution as just described are repelled to the copper plate, carrying their positive charges thereto. Hence the copper plate, or the *unconsumed* plate, becomes positively charged and also coated with hydrogen bubbles.

The plates or electrodes of a voltaic cell need not consist of zinc and copper, nor need the fluid, called the *electrolyte*, be of sulphuric acid; any two dissimilar elements immersed in an electrolyte that attacks one of them more readily than the other will form a voltaic cell. In every such cell it will be found that one of the plates is consumed, and that on the other plate some element is deposited, this element being sometimes a gas and sometimes a solid. The plate which is consumed is always the negative plate, and the one on which the element is deposited is always the positive, the current through the connecting wire always being, therefore, from the unconsumed to the consumed plate. Thus, in the simple copper-zinc cell just considered, the zinc is consumed, the element hydrogen is deposited on the copper, and the current flow through the external circuit is from the copper to the zinc.

The positive charges, leaving the zinc, or consumed, plate, and passing through the electrolyte to the copper, or unconsumed, plate, constitute in effect a current of electricity flowing within the electrolyte. The current within the cell passes, therefore, from the zinc plate to the copper plate. The zinc is, therefore, said to be positive with respect to the copper.

Difference of Potential. The amount of electromotive force that is generated between two dissimilar elements immersed in an electrolyte is different for different pairs of elements and for different electrolytes. For a given electrolyte each element bears a certain relation to another; *i. e.*, they are either electro-positive or electro-negative relative to each other. In the following list a group of elements are arranged with respect to the potentials which they assume with respect to each other with dilute sulphuric acid as the electrolyte. The most electro-positive elements are at the top and the most electro-negative at the bottom.

+ Sodium	Lead	Copper
Magnesium	Iron	Silver
Zinc	Nickel	Gold
Cadmium	Bismuth	Platinum
Tin	Antimony	− Graphite (Carbon)

Any two elements selected from this list and immersed in dilute sulphuric acid will form a voltaic cell, the amount of difference of potential, or electromotive force, depending on the distance apart in this series of the two elements chosen. The current within the cell will always flow from the one nearest the top of the list to the one nearest the bottom, *i. e.*, from the most electro-positive to the most electro-negative; and, therefore, the current in the wire joining the two plates will flow from the one lowest down in the list to the one highest up.

From this series it is easy to see why zinc and copper, and also zinc and carbon, are often chosen as elements of voltaic cells. They are widely separated in the series and comparatively cheap.

This series may not be taken as correct for all electrolytes, for different electrolytes alter somewhat the order of the elements in the series. Thus, if two plates, one of iron and the other of copper, are immersed in dilute sulphuric acid, a current is set up which proceeds through the liquid from the iron to the copper; but, if the plates after being carefully washed are placed in a solution of potassium sulphide, a current is produced in the opposite direction. The copper is now the positive element.

Table II shows the electrical deportment of the principal metals in three different liquids. It is arranged like the preceding one, each metal being electro-positive to any one lower in the list.

TABLE II

Behavior of Metals in Different Electrolytes

Caustic Potash	Hydrochloric Acid	Potassium Sulphide
+ Zinc	+ Zinc	+ Zinc
Tin	Cadmium	Copper
Cadmium	Tin	Cadmium
Antimony	Lead	Tin
Lead	Iron	Silver
Bismuth	Copper	Antimony
Iron	Bismuth	Lead
Copper	Nickel	Bismuth
Nickel	Silver	Nickel
− Silver	− Antimony	− Iron

It is important to remember that in all cells, no matter what elements or what electrolyte are used, the electrode *which is consumed* is the one that becomes *negatively charged* and its terminal, therefore, becomes the *negative terminal* or *pole*, while the electrode *which is not consumed* is the one that becomes *positively charged*, and its terminal is, therefore, the *positive terminal* or *pole of the cell*. However, because the current in the electrolyte flows from the *consumed* plate to the *unconsumed* plate, the consumed plate is called the *positive* plate and the unconsumed, the *negative*. This is likely to become confusing, but if one remembers that the *active* plate is the *positive* plate, because it sends forth *positive* ions in the electrolyte, and, therefore, itself becomes *negatively* charged, one will have the proper basis always to determine the direction of the current flow, which is the important thing.

Polarization. If the simple cell already described have its terminals connected by a wire for some time, it will be found that the current rapidly weakens until it ceases to be manifest. This weakening results from two causes: first, the hydrogen gas which is liberated in the action of the cell is deposited in a layer on the copper plate, thereby covering the plate and reducing the area of contact with the liquid. This increases the internal resistance of the cell, since hydrogen is a non-conductor. Second, the plate so covered becomes in effect a hydrogen electrode, and hydrogen stands high as an electro-positive element. There is, therefore, actual reduction in the electromotive force of the cell, as well as an increase in internal resistance. This phenomenon is known as polarization, and in commercial cells means must be taken to prevent such action as far as possible.

The means by which polarization of cells is prevented or reduced in practice may be divided into three general classes:

First—*mechanical means.* If the hydrogen bubbles be simply brushed away from the surface of the electrode the resistance and the counter polarity which they cause will be diminished. The same result may be secured if air be blown into the solution through a tube, or if the liquid be kept agitated. If the surface of the electrode be roughened or covered with points, the bubbles collect more freely at the points and are more quickly carried away to the surface of the liquid. These means are, however, hardly practical except in cells for laboratory use.

Second—*chemical means.* If a highly oxidizing substance be added to the electrolyte, it will destroy the hydrogen bubbles by combining with them while they are in a nascent state, and this will prevent the increase in internal resistance and the opposing electromotive force. Such substances are bichromate of potash, nitric acid, and chlorine, and are largely used.

Third—*electro-chemical means.* Double cells, arranged to separate the elements and liquids by means of porous partitions or by gravity, may be so arranged that solid copper is liberated instead of hydrogen at a point where the current leaves the liquid, thereby entirely obviating polarization. This method also is largely used.

Local Action. When a simple cell stands idle, *i. e.*, with its circuit open, small hydrogen bubbles may be noticed rising from the zinc electrode instead of from copper, as is the case where the circuit is closed. This is due to impurities in the zinc plate, such as particles of iron, tin, arsenic, carbon, etc. Each of these particles acts with the surrounding zinc just as might be expected of any pair of dissimilar elements opposed to each other in an electrolyte; in other words, they constitute small voltaic cells. Local currents, therefore, are generated, circulating between the two adjacent metals, and, as a result, the zinc plate and the electrolyte are needlessly wasted and the general condition of the cell is impaired. This is called *local action.*

Amalgamated Zincs. Local action might be prevented by the use of chemically pure zinc, but this, on account of its expense, cannot be employed commercially. Local action, however, may be overcome to a great extent by amalgamating the zinc, *i. e.*, coating it with mercury. The iron particles or other impurities do not dissolve in the mercury, as does the zinc, but they float to the surface, whence the hydrogen bubbles which may form speedily carry them off, and, in other cases, the impurities fall to the bottom of the cell. As the zinc in the pasty amalgam dissolves in the acid, the film of mercury unites with fresh zinc, and so always presents a clear, bright, homogeneous surface to the action of the electrolyte.

The process of amalgamating the zinc may be performed by dipping it in a solution composed of

Nitric Acid	1 lb.
Muriatic Acid	2 lbs.
Mercury	8 oz.

The acids should be first mixed and then the mercury slowly added until dissolved. Clean the zinc with lye and then dip it in the solution for a second or two. Rinse in clean water and rub with a brush.

Another method of amalgamating zincs is to clean them by dipping them in dilute sulphuric acid and then in mercury, allowing the surplus to drain off.

Commercial zincs, for use in voltaic cells as now manufactured, usually have about 4 per cent of mercury added to the molten zinc before casting into the form of plates or rods.

Series and Multiple Connections. When a number of voltaic cells are joined in series, the positive pole of one being connected to the negative pole of the next one, and so on throughout the series, the *electromotive forces* of all the cells are added, and the electromotive force of the group, therefore, becomes the sum of the electromotive forces of the component cells. The currents through all the cells in this case will be equal to that of one cell.

If the cells be joined in multiple, the positive poles all being connected by one wire and the negative poles by another, then the *currents* of all the cells will be added while the electromotive force of the combination remains the same as that of a single cell, assuming all the cells to be alike in electromotive force.

Obviously combinations of these two arrangements may be made, as by forming strings of cells connected in series, and connecting the strings in multiple or parallel.

The term battery is frequently applied to a single voltaic cell, but this term is more properly used to designate a plurality of cells joined together in series, or in multiple, or in series multiple so as to combine their actions in causing current to flow through an external circuit. We may therefore refer to a battery of so many cells. It has, however, become common, though technically improper, to refer to a single cell as a battery, so that the term battery, as indicating necessarily more than one cell, has largely lost its significance.

Cells may be of two types, primary and secondary.

Primary cells are those consisting of electrodes of dissimilar elements which, when placed in an electrolyte, become immediately ready for action.

Secondary cells, commonly called *storage cells* and *accumulators,* consist always of two inert plates of metal, or metallic oxide, immersed in an electrolyte which is incapable of acting on either of them until a current has first been passed through the electrolyte from one plate to the other. On the passage of a current in this way, the decomposition of the electrolyte is effected and the composition of the plates is so changed that one of them becomes electro-positive and the other electro-negative. The cell is then, when the *charging* current ceases, capable of acting as a voltaic cell.

This chapter is devoted to the primary cell or battery alone.

Types of Primary Cells. Primary cells may be divided into two general classes: first, those adapted to furnish constant current; and second, those adapted to furnish only intermittent currents. The difference between cells in this respect rests largely in the means employed for preventing or lessening polarization. Obviously in a cell in which polarization is entirely prevented the current may be allowed to flow constantly until the cell is completely exhausted; that is, until the zinc is all eaten up or until the hydrogen is exhausted from the electrolyte or both. On the other hand some cells are so constituted that polarization takes place faster than the means intended to prevent it can act. In other words, the polarization gradually gains on the preventive means and so gradually reduces the current by increasing the resistance of the cell and lowering its electromotive force. In cells of this kind, however, the arrangement is such that if the cell is allowed to rest, that is, if the external circuit is opened, the depolarizing agency will gradually act to remove the hydrogen from the unattacked electrode and thus place the cell in good condition for use again.

Of these two types of primary cells the intermittent-current cell is of far greater use in telephony than the constant-current cell. This is because the use of primary batteries in telephony is, in the great majority of cases, intermittent, and for that reason a cell which will give a strong current for a few minutes and which after such use will regain practically all of its initial strength and be ready for use again, is more desirable than one which will give a weaker current continuously throughout a long period of time.

Since the cells which are adapted to give constant current are commonly used in connection with circuits that are continuously closed, they are called *closed-circuit cells.* The other cells, which are better adapted for intermittent current, are commonly used on circuits which stand open most of the time and are closed only occasionally when their current is desired. For this reason these are termed *open-circuit cells.*

Open-Circuit Cells. LeClanché Cell:—By far the most important primary cell for telephone work is the so-called LeClanché cell. This assumes a large variety of forms, but always employs zinc as the negatively charged element, carbon as the positively charged element, and a solution of sal ammoniac as the electrolyte. This cell employs a chemical method of taking care of polarization, the depolarizing agent being peroxide of manganese, which is closely associated with the carbon element.

The original form of the LeClanché cell, a form in which it was very largely used up to within a short time ago, is shown in Fig. 61. In this the carbon element is placed within a cylindrical jar of porous clay, the walls of this jar being of such consistency as to allow moisture slowly to permeate through it. Within this porous cup, as it is called, a plate or disk of carbon is placed, and around this the depolarizing agent, consisting of black oxide of manganese. This is usually mixed with broken carbon, so as to increase the effective area of the carbon element in contact with the depolarizing agent, and also to reduce the total internal resistance of the cell. The zinc electrode usually consisted merely in a rod of zinc, as shown, with a suitable terminal at its upper end.

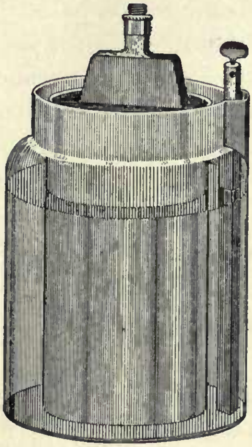


Fig. 61. LeClanché Cell

The chemical action taking place within the LeClanché cell is, briefly, as follows: Sal ammoniac is chemically known as chloride of ammonium and is a combination of chlorine and ammonia. In the action which is assumed to accompany the passage of current in this cell, the sal ammoniac is decomposed, the chlorine leaving the ammonia to unite with an atom of the zinc plate, forming chloride of zinc and setting free ammonia and hydrogen. The ammonia is immediately dissolved in the water of the cell, and the hydrogen enters the porous cup and would speedily polarize the cell by adhering to the carbon plate but for the fact that it encounters the peroxide of manganese. This material is exceedingly rich in oxygen and it therefore readily gives up a part of its oxygen, which forms water by combination with the already liberated hydrogen and leaves what is termed a *sesquioxide* of manganese. This absorption or combination of the hydrogen prevents immediate polarization, but hydrogen is evolved during the operation of the cell more rapidly than it can combine wth the oxygen of the manganese, thereby leading to polarization more rapidly than the depolarizer can prevent it when the cell is heavily worked. When, however, the cell is left with its external circuit open for a time, depolarization ensues by the gradual combination of the hydrogen with the oxygen of the peroxide of manganese, and as a result the cell recuperates and in a short time attains its normal electromotive force.

The electromotive force of this cell when new is about 1.47 volts. The internal resistance of the cell of the type shown in Fig. 61 is approximately 1 ohm, ordinarily less rather than more.

A more recent form of LeClanché cell is shown in cross-section in Fig. 62. This uses practically the same materials and has the same chemical action as the old disk LeClanché cell shown in Fig. 61. It dispenses, however, with the porous cup and instead employs a carbon electrode, which in itself forms a cup for the depolarizing agent.

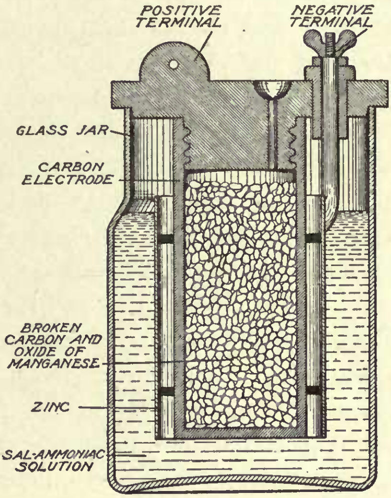


Fig. 62. Carbon Cylinder LeClanché Cell

The carbon electrode is in the form of a corrugated hollow cylinder which engages by means of an internal screw thread a corresponding screw thread on the outer side of the carbon cover. Within this cylinder is contained a mixture of broken carbon and peroxide of manganese. The zinc electrode is in the form of a hollow cylinder almost surrounding the carbon electrode and separated therefrom by means of heavy rubber bands stretched around the carbon. The rod, forming the terminal of the zinc, passes through a porcelain bushing on the cover plate to obviate short circuits. This type of cell has an electromotive force of about 1.55 volts and recuperates very quickly after severe use. It also has considerably lower internal resistance than the type of LeClanché cell employing a porous cup, and, therefore, is capable of generating a considerably larger current.

Cells of this general type have assumed a variety of forms. In some the carbon electrode, together with the broken carbon and peroxide of manganese, were packed into a canvas bag which was suspended in the electrolyte and usually surrounded by the zinc electrode. In other forms the carbon electrode has moulded with it the manganese depolarizer.

In order to prevent the salts within the cell from creeping over the edge of the containing glass jar and also over the upper portion of the carbon electrode, it is common practice to immerse the upper end of the carbon element and also the upper edge of the glass jar in hot paraffin.

In setting up the LeClanché cell, place not more than four ounces of white sal ammoniac in the jar, fill the jar one-third full of water, and stir until the sal ammoniac is all dissolved. Then put the carbon and zinc elements in place. A little water poured in the vent hole of the porous jar or carbon cylinder will tend to hasten the action.

An excess of sal ammoniac should not be used, as a saturated solution tends to deposit crystals on the zinc; on the other hand, the solution should not be allowed to become too weak, as in that case the chloride of zinc will form on the zinc. Both of these causes materially increase the resistance of the cell.

A great advantage of the LeClanché cell is that when not in use there is but little material waste. It contains no highly corrosive chemicals. Such cells require little attention, and the addition of water now and then to replace the loss due to evaporation is about all that is required until the elements become exhausted. They give a relatively high electromotive force and have a moderately low internal resistance, so that they are capable of giving rather large currents for short intervals of time. If properly made, they recuperate quickly after polarization due to heavy use.

Dry Cell. All the forms of cells so far considered may be quite properly termed *wet cells* because of the fact that a free liquid electrolyte is used. This term is employed in contradistinction to the later developed cell, commonly termed the *dry cell.* This term "dry cell" is in some respects a misnomer, since it is not dry and if it were dry it would not work. It is essential to the operation of these cells that they shall be moist within, and when such moisture is dissipated the cell is no longer usable, as there is no further useful chemical action.

The dry cells are all of the LeClanché type, the liquid electrolyte of that type being replaced by a semi-solid substance that is capable of retaining moisture for a considerable period.

As in the ordinary wet LeClanché cell, the electrodes are of carbon and zinc, the zinc element being in the form of a cylindrical cup and forming the retaining vessel of the cell, while the carbon element is in the form of a rod or plate and occupies a central position with regard to the zinc, being held out of contact with the zinc, however, at all points.

A cross-section of an excellent form of dry cell is shown in Fig. 63. The outer casing is of zinc, formed in the shape of a cylindrical cup, and serves not only as the retaining vessel, but as the negatively charged electrode. The outer surface of the zinc is completely covered on its sides and bottom with heavy pasteboard so as to insulate it from bodies with which it may come in contact, and particularly from the zinc cups of other cells used in the same battery. The positively charged electrode is a carbon rod corrugated longitudinally, as shown, in order to obtain greater surface. This rod is held in the center of the zinc cup out of contact therewith, and the intervening space is filled with a mixture of peroxide of manganese, powdered carbon, and sal ammoniac. Several thicknesses of blotting paper constitute a lining for the inner portion of the zinc electrode and serve to prevent the manganese mixture from coming directly into contact therewith. The cell is sealed with pitch, which is placed on a layer of sand and sawdust mixed in about equal parts.

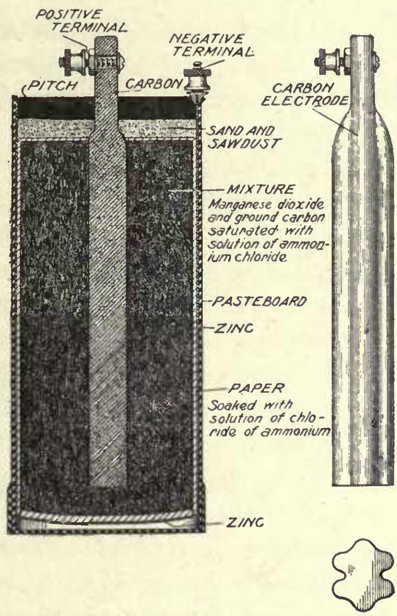


Fig. 63. Dry Cell

The electrolyte in such cells varies largely as to quantities and proportions of the materials employed in various types of cells, and also varies in the method in which the elements are introduced into the container.

The following list and approximate proportions of material will serve as a fair example of the filling mixture in well-known types of cells.

Manganese dioxide	45 per cent
Carbon or graphite, or both	45 per cent
Sal ammoniac	7 per cent
Zinc chloride	3 per cent

Water is added to the above and a sufficient amount of mixture is taken for each cell to fill the zinc cup about seven-eighths full when the carbon is in place. The most suitable quantity of water depends upon the original dryness and fineness of material and upon the quality of the paper lining.

In some forms of dry batteries, starch or other paste is added to improve the contact of the electrolyte with the zinc and promote a more even distribution of action throughout the electrolyte. Mercury, too, is often added to effect amalgamation of the zinc.

As in the ordinary wet type of LeClanché cell, the purpose of the manganese is to act as a depolarizer; the carbon or graphite being added to give conductivity to the manganese and to form a large electrode surface. It is important that the sal ammoniac, which is the active agent of the cell, should be free from lumps in order to mix properly with the manganese and carbon.

A small local action takes place in the dry cell, caused by the dissimilar metals necessarily employed in soldering up the zinc cup and in soldering the terminal rod of zinc to the zinc cup proper. This action, however, is slight in the better grades of cells. As a result of this, and also of the gradual drying out of the moisture within the cell, these cells gradually deteriorate even when not in use—this is commonly called *shelf-wear.* Shelf-wear is much more serious in the very small sizes of dry cells than in the larger ones.

Dry cells are made in a large number of shapes and sizes. The most useful form, however, is the ordinary cylindrical type. These are made in sizes varying from one and one-half inches high and three-quarters inch in diameter to eight inches high and three and three-quarters inches in diameter. The most used and standard size of dry cell is of cylindrical form six inches high and two and three-quarters inches in diameter. The dry cell when new and in good condition has an open-circuit voltage of from 1.5 to 1.6 volts. Perhaps 1.55 represents the usual average.

A cell of the two and three-quarters by six-inch size will give throughout its useful life probably thirty ampere hours as a maximum, but this varies greatly with the condition of use and the make of cell. Its effective voltage during its useful life averages about one volt, and if during this life it gives a total discharge of thirty ampere hours, the fair energy rating of the cell will be thirty watt-hours. This may not be taken as an accurate figure, however, as the watt-hour capacity of a cell depends very largely, not only on the make of the cell, but on the rate of its discharge.

An examination of Fig. 63 shows that the dry cell has all of the essential elements of the LeClanché cell. The materials of which the electrodes are made are the same and the porous cup of the disk LeClanché cell is represented in the dry cell by the blotting-paper cylinder, which separates the zinc from the carbon electrode. The positively charged electrode must not be considered as merely the carbon plate or rod alone, but rather the carbon rod with its surrounding mixture of peroxide of manganese and broken carbon. Such being the case, it is obvious that the separation between the electrodes is very small, while the surface presented by both electrodes is very large. As a result, the internal resistance of the cell is small and the current which it will give on a short circuit is correspondingly large. A good cell of the two and three-quarters by six-inch size will give eighteen or twenty amperes on short-circuit, when new.

As the action of the cell proceeds, zinc chloride and ammonia are formed, and there being insufficient water to dissolve the ammonia, there results the formation of double chlorides of zinc and ammonium. These double chlorides are less soluble than the chlorides and finally occupy the pores of the paper lining between the electrolyte and the zinc and greatly increase the internal resistance of the cell. This increase of resistance is further contributed to by the gradual drying out of the cell as its age increases.

Within the last few years dry batteries have been so perfected mechanically, chemically, and electrically that they have far greater outputs and better recuperative power than any of the other types of LeClanché batteries, while in point of convenience and economy, resulting from their small size and non-break-able, non-spillable features and low cost, they leave no room for comparison.

Closed-Circuit Cells. Gravity-Cell:—Coming now to the consideration of closed-circuit or constant-current cells, the most important is the well-known gravity, or blue-stone, cell, devised by Daniell. It is largely used in telegraphy, and often in telephony in such cases as require a constantly flowing current of small quantity. Such a cell is shown in Fig. 64.

The elements of the gravity cell are electrodes of copper and zinc. The solution in which the copper plate is immersed is primarily a solution of copper sulphate, commonly known as blue-stone, in water. The zinc plate after the cell is in action is immersed in a solution of sulphate of zinc which is formed around it.

The glass jar is usually cylindrical, the standard sizes being 5 inches diameter and 7 inches deep; and also 6 inches diameter and 8 inches deep. The copper electrode is of sheet copper of the form shown, and it is partly covered with crystals of blue-stone or copper sulphate. Frequently, in later forms of cells, the copper electrode consists merely of a straight, thick, rectangular bar of copper laid horizontally, directly on top of the blue-stone crystals. In all cases a rubber-insulated wire is attached by riveting to the copper electrode, and passes up through the electrolyte to form the positive terminal.

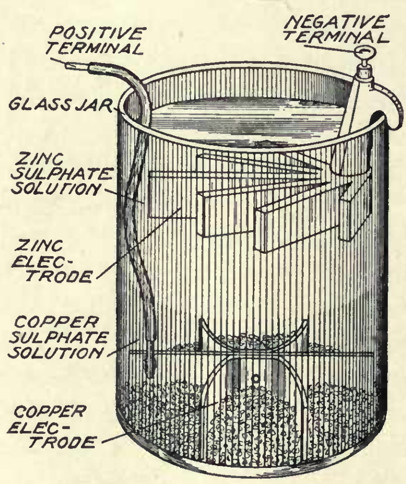


Fig. 64. Gravity Cell

The zinc is, as a rule, of crowfoot form, as shown, whence this cell derives the commonly applied name of *crowfoot cell.* This is essentially a two-fluid cell, for in its action zinc sulphate is formed, and this being lighter than copper sulphate rises to the top of the jar and surrounds the zinc. Gravity, therefore, serves to keep the two fluids separate.

In the action of the cell, when the external circuit is closed, sulphuric acid is formed which attacks the zinc to form sulphate of zinc and to liberate hydrogen, which follows its tendency to attach itself to the copper plate. But in so doing the hydrogen necessarily passes through the solution of sulphate of copper surrounding the copper plate. The hydrogen immediately combines with the SO_4 radical, forming therewith sulphuric acid, and liberating metallic copper. This sulphuric acid, being lighter than the copper sulphate, rises to the surface of the zinc and attacks the zinc, thus forming more sulphate of zinc. The metallic copper so formed is deposited on the copper plate, thereby keeping the surface bright and clean. Since hydrogen is thus diverted from the copper plate, polarization does not ensue.

The zinc sulphate being colorless, while the copper sulphate is of a dark blue color, the separating line of the two liquids is easily distinguishable. This line is called the *blue line* and care should be taken that it does not reach the zinc and cause a deposit of copper to be placed thereon.

As has been stated, these two liquids do not mix readily, but they will eventually mingle unless the action of the cell is sufficient to use up the copper sulphate as speedily as it is dissolved. Thus it will be seen that while the cell is free from polarization and local action, there is, nevertheless, a deteriorating effect if the cell is allowed to remain long on open circuit. Therefore, it should be used when a constant current is required.

Prevention of Creeping:—Much trouble has been experienced in gravity cells due to the creeping of the salts over the edge of the jar. Frequently the upper edges of the jars are coated by dipping in hot paraffin wax in the hope of preventing this. Sometimes oil is poured on top of the fluid in the jar to prevent the creeping of the salts and the evaporation of the electrolyte. The following account of experiments performed by Mr. William Reid, of Chicago, throws light on the relative advantages of these and other methods of preventing creeping.

The experiment was made with gravity cells having 5-inch by 7-inch glass jars. Four cells were made up and operated in a rather dry, warm place, although perhaps under no more severe local conditions than would be found in most telephone exchanges. Cell No. 1 was a plain cell as ordinarily used. Cell No. 2 had the top of the rim of the jar treated with paraffin wax by dipping the rim to about one inch in depth in melted paraffin wax. Cell No. 3 had melted paraffin wax poured over the surface of the liquid forming a seal about $\frac{3}{16}$ inch in thickness. After cooling, a few small holes were bored through the seal to let gases escape. Cell No. 4 had a layer of heavy paraffin oil nearly ½ inch in thickness (about 6 oz. being used) on top of the solutions.

These cells were all run on a load of .22 to .29 amperes for 15½ hours per day for thirty days, after which the following results were noted:

(*a*) The plain cell, or cell No. 1, had to have 26 ounces of water added to it to replace that which had evaporated. The creeping of zinc sulphate salts was very bad.

(*b*) The waxed rim cell, or cell No. 2, evaporated 26 ounces of water and the creeping of zinc sulphate salts was not prevented by the waxed rim. The wax proved of no value.

(*c*) The wax sealed cell, or cell No. 3, showed practically no evaporation and only very slight creeping of zinc sulphate salts. The creeping of salts that took place was only around spots where the edges of the seal were loose from the jar.

(*d*) The paraffin oil sealed cell, or cell No. 4, showed no evaporation and no creeping of salts.

It was concluded by Mr. Reid from the above experiments that the wax applied to the rim of the jar is totally ineffective and has no merits. The wax seal loosens around the edges and does not totally prevent creeping of the zinc sulphate salts, although nearly so. The wax-sealed jar must have holes drilled in it to allow the gases to escape. The method is hardly commercial, as it is difficult to make a neat appearing cell, besides making it almost impossible to manipulate its contents. A coat of paraffin oil approximately ½ inch in thickness (about 6 ounces) gives perfect protection against evaporation and creeping of the zinc sulphate salts. The cell, having the paraffin-oil seal, had a very neat, clean appearance as compared with cells No. 1 and No. 2. It was found that the zinc could be drawn out through the oil, cleaned, and replaced with no appreciable effect on voltage or current.

Setting Up:—In setting up the battery the copper electrode is first unfolded to form a cross and placed in the bottom of the jar. Enough copper sulphate, or blue-stone crystals, is then dropped into the jar to almost cover the copper. The zinc crowfoot is then hung in place, occupying a position about 4 inches above the top of the copper. Clear water is then poured in sufficient to fill the jar within about an inch of the top.

If it is not required to use the cell at once, it may be placed on short circuit for a time and allowed to form its own zinc sulphate. The cell may, however, be made immediately available for use by drawing about one-half pint of a solution of zinc sulphate from a cell already in use and pouring it into the jar, or, when this is not convenient, by putting into the liquid four or five ounces of pulverized sulphate of zinc, or by adding about ten drops of sulphuric acid. When the cell is in proper working condition, one-half inch in thickness of heavy paraffin oil of good quality may be added.

If the blue line gets too low, and if there is in the bottom of the cell a sufficient quantity of sulphate of copper, it may be raised by drawing off a portion of the zinc sulphate with a battery syringe and replacing this with water. If the blue line gets too high, it may be lowered by short-circuiting the cell for a time, or by the addition of more sulphate of zinc solution from another battery. If the copper sulphate becomes exhausted, it should be replenished by dropping in more crystals.

Care should be taken in cold weather to maintain the temperature of the battery above 65° or 70° Fahrenheit. If below this temperature, the internal resistance of a cell increases very rapidly, so much so that even at 50° Fahrenheit the action becomes very much impaired. This follows from the facts that the resistance of a liquid decreases as its temperature rises, and that chemical action is much slower at lower temperatures.

The gravity cell has a practically constant voltage of 1.08 volts. Its internal resistance is comparatively high, seldom falling below 1 ohm and often rising to 6 ohms. At best, therefore, it is only capable of producing about 1 ampere. The gravity cell is perhaps the most common type of cell wherein depolarization is affected by electro-chemical means.

Fuller Cell:—A form of cell that is adapted to very heavy open-circuit work and also closed-circuit work where heavier currents are required than can be supplied by the gravity battery is the Fuller. In this the electrodes are of zinc and carbon, respectively, the zinc usually being in the form of a heavy cone and placed within a porous cup. The electrolyte of the Fuller cell is known as *electropoion fluid*, and consists of a mixture of sodium or potassium bichromate, sulphuric acid, and water.

The various parts of the standard Fuller cell, as once largely employed by the various Bell operating companies, are shown in Fig. 65. In this the jar was made of flint glass, cylindrical in form, six inches in diameter and eight inches deep. It is important that a good grade of glass be used for the jar in this cell, because, on account of the nature of the electrolyte, breakage is disastrous in the effects it may produce on adjacent property. The carbon plate is rectangular in form, about four inches wide, eight and three-quarters inches long, and one-quarter inch thick. The metal terminal at the top of the carbon block is of bronze, both it and the lock nuts and bolts being nickel-plated to minimize corrosion. The upper end of the carbon block is soaked in paraffin so hot as to drive all of the moisture out of the paraffin and out of the pores of the block itself.

The zinc, as is noted from the cut, is in the form of a truncated cone. It is about two and one-eighth inches in diameter at the base and two and one-half inches high. Cast into the zinc is a soft copper wire about No. 12 B. & S. gauge. This wire extends above the top of the jar so as to form a convenient terminal for the cell.

The porous cup is cylindrical in form, about three inches in diameter and seven inches deep. The wooden cover is of kiln-dried white wood thoroughly coated with two coats of asphalt paint. It is provided with a slot for the carbon and a hole for the copper wire extending to the zinc.

The electrolyte for this cell is made as follows:

Sodium bichromate...............	6 oz.
Sulphuric acid....................	17 oz.
Soft water........................	56 oz.

This solution is mixed by dissolving the bichromate of sodium in the water and then adding slowly the sulphuric acid. Potassium bichromate may be substituted for the sodium bichromate.

In setting up this cell, the amalgamated zinc is placed within the porous cup, in the bottom of which are about two teaspoonfuls of mercury, the latter serving to keep the zinc well amalgamated. The porous cup is then placed in the glass jar and a sufficient quantity of the electrolyte is placed in the outer jar to come within about one and one-half inches of the top of the porous cup. About two teaspoonfuls of salt are then placed in the porous cup and sufficient soft water added to bring the level of the liquid within the porous cup even with the level of the electrolyte in the jar surrounding the cup. The carbon is then placed through the slot in the cover, and the wire from the zinc is passed through the hole in the cover provided for it, and the cover is allowed to fall in place. The cell is now ready for immediate use.

The action of this cell is as follows: The sulphuric acid attacks the zinc and forms zinc sulphate, liberating hydrogen. The hydrogen attempts to pass to the carbon plate as usual, but in so doing it meets with the oxygen of the chromic acid and forms water therewith. The remainder of the chromic acid combines with the sulphuric acid to form chromium sulphate.

The mercury placed in the bottom of the porous cup with the zinc keeps the zinc in a state of perpetual amalgamation. This it

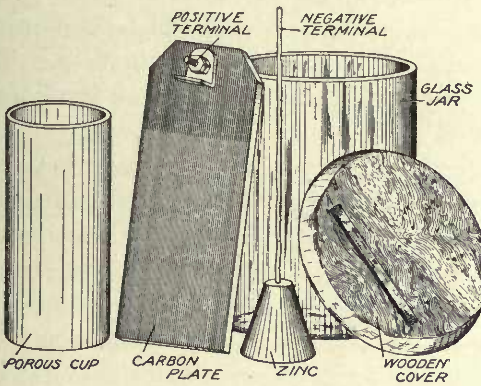


Fig. 65. Fuller Cell

does by capillary action, as the mercury spreads over the entire surface of the zinc. The initial amalgamation, while not absolutely essential, helps in a measure this capillary action.

In another well-known type of the Fuller battery the carbon is a hollow cylinder, surrounding the porous cup. In this type the zinc usually took the form of a long bar having a cross-shaped section, the length of this bar being sufficient to extend the entire depth of the porous cup. This type of cell has the advantage of a somewhat lower internal resistance than the standard form just described.

Should the electrolyte become supersaturated by virtue of the battery being neglected or too heavily overworked, a set of secondary reactions will occur in the cell, resulting in the formation of the yellow crystals upon the carbon. This seriously affects the e. m. f. of the cell and also its internal resistance. Should this occur, some of the solution should be withdrawn and dilute sulphuric acid inserted in its place and the crystals which have formed on the carbon should be carefully washed off. Should the solution lose its orange tint and turn blue, it indicates that more bichromate of potash or bichromate of sodium is needed. This cell gives an electromotive force of 2.1 volts and a very large current when it is in good condition, since its internal resistance is low.

The Fuller cell was once largely used for supplying current to telephone transmitters at subscribers' stations, where very heavy service was demanded, but the advent of the so-called common-battery systems, in some cases, and of the high-resistance transmitter, in other cases, has caused a great lessening in its use. This is fortunate as the cell is a "dirty" one to handle and is expensive to maintain.

The Fuller cell still warrants attention, however, as an available source of current, which may be found useful in certain cases of emergency work, and in supplying special but temporary needs for heavier current than the LeClanché or gravity cell can furnish.

Lalande Cell:—A type of cell, specially adapted to constant-current work, and sometimes used as a central source of current in very small common-battery exchanges is the so-called *copper oxide*, or *Lalande cell*, of which the Edison and the Gordon are types. In all of these the negatively charged element is of zinc, the positively charged element a mass of copper oxide, and the electrolyte a solution of caustic potash in water. In the Edison cell the copper oxide is in the form of a compressed slab which with its connecting copper support forms the electrode. In the Gordon and other cells of this type the copper oxide is contained loosely in a perforated cylinder of sheet copper. The copper oxide serves not only as an electrode, but also as a depolarizing agent, the liberated hydrogen in the electrolyte uniting with the oxygen of the copper oxide to form water, and leaving free metallic copper.

On open circuit the elements are not attacked, therefore there is no waste of material while the cell is not in use. This important feature, and the fact that the internal resistance is low, make this cell well adapted for all forms of heavy open-circuit work. The fact that there is no polarizing action within the cell makes it further adaptable to heavy closed-circuit service.

These cells are intended to be so proportioned that all of their parts become exhausted at once so that when the cell fails, complete renewals are necessary. Therefore, there is never a question as to which of the elements should be renewed.

After the elements and solution are in place about one-fourth of an inch of heavy paraffin oil is poured upon the surface of the solution in order to prevent evaporation. This cell requires little attention and will maintain a constant e. m. f. of about two-thirds of a volt until completely exhausted. It is non-freezable at all ordinary temperatures. Its low voltage is its principal disadvantage.

Standard Cell. Chloride of Silver Cell:—The chloride of silver cell is largely used as a standard for testing purposes. Its compactness and portability and its freedom from local action make it particularly adaptable to use in portable testing outfits where constant electromotive force and very small currents are required.

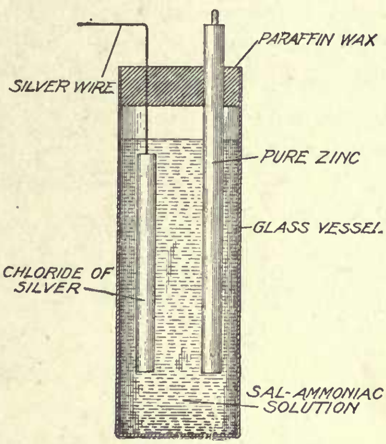


Fig. 66. Chloride of Silver Cell

A cross-section of one form of the cell is shown in Fig. 66. Its elements are a rod of chemically-pure zinc and a rod of chloride of silver immersed in a water solution of sal ammoniac. As ordinarily constructed, the glass jar or tube is usually about $2\frac{1}{2}$ inches long by 1 inch in diameter. After the solution is poured in and the elements are in place the glass tube is hermetically sealed with a plug of paraffin wax.

The e. m. f. of a cell of this type is 1.03 volts and the external resistance varies with the age of the cell, being about 4 ohms at first. Care should be taken not to short-circuit these cells, or use them in any but high-resistance circuits, as they have but little energy and become quickly exhausted if compelled to work in low-resistance circuits.

Conventional Symbol. The conventional symbol for a cell, either of the primary or the secondary type, consists of a long thin line and a short heavy line side by side and parallel. A battery is represented by a number of pairs of such lines, as in Fig. 67. The two lines of each pair are supposed to represent the two electrodes of a cell. Where any significance is to be placed on the polarity of the cell or battery the long thin line is supposed to represent the positively

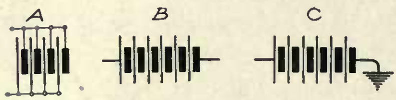


Fig. 67. Battery Symbols

charged plate and the short thick line the negatively charged plate. The number of pairs may indicate the number of cells in the battery. Frequently, however, a few pairs of such lines are employed merely for the purpose of indicating a battery without regard to its polarity or its number of cells.

In Fig. 67 the representation at *A* is that of a battery of a number of cells connected in parallel; that at *B* of a battery with the cells connected in series; and that at *C* of a battery with one of its poles grounded.

CHAPTER VIII

MAGNETO SIGNALING APPARATUS

Method of Signaling. The ordinary apparatus, by which speech is received telephonically, is not capable of making sufficiently loud sounds to attract the attention of people at a distance from the instrument. For this reason it is necessary to employ auxiliary apparatus for the purpose of signaling between stations. In central offices where an attendant is always on hand, the sense of sight is usually appealed to by the use of signals which give a visual indication, but in the case of telephone instruments for use by the public, the sense of hearing is appealed to by employing an audible rather than a visual signal.

Battery Bell. The ordinary vibrating or battery bell, such as is employed for door bells, is sometimes, though not often, employed in telephony. It derives its current from primary batteries or from any direct-current source. The reason why they are not employed to a greater extent in telephony is that telephone signals usually have to be sent over lines of considerable length and the voltage that would be required to furnish current to operate such bells over such lengths of line is higher than would ordinarily be found in the batteries commonly employed in telephone work. Besides this the make-and-break contacts on which the ordinary battery bell depends for its operation are an objectionable feature from the standpoint of maintenance.

Magneto Bell. Fortunately, however, there has been developed a simpler type of electric bell, which operates on smaller currents, and which requires no make-and-break contacts whatever. This simpler form of bell is commonly known as the *polarized,* or *magneto,* bell or *ringer.* It requires for its operation, in its ordinary form, an alternating current, though in its modified forms it may be used with pulsating currents, that is, with periodically recurring impulses of current always in the same direction.

Magneto Generator. In the early days of telephony there was nearly always associated with each polarized bell a magneto generator for furnishing the proper kind of current to ring such bells. Each telephone was therefore equipped, in addition to the transmitter and receiver, with a signal-receiving device in the form of a polarized bell, and with a current generator by which the user was enabled to develop his own currents of suitable kind and voltage for ringing the bells of other stations.

Considering the signaling apparatus of the telephones alone, therefore, each telephone was equipped with a power plant for generating currents used by that station in signaling other stations, the prime mover being the muscles of the user applied to the turning of a crank on the side of the instrument; and also with a current-consuming device in the form of a polarized electromagnetic bell adapted to receive the currents generated at other stations and to convert a portion of their energy into audible signals.

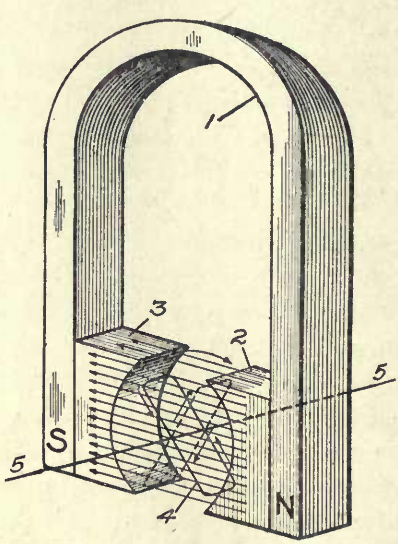


Fig. 68. Principles of Magneto Generator

The magneto generator is about the simplest type of dynamo-electric machine, and it depends upon the same principles of operation as the much larger generators, employed in electric-lighting and street-railway power plants, for instance. Instead of developing the necessary magnetic field by means of electromagnets, as in the case of the ordinary dynamo, the field of the magneto generator is developed by permanent magnets, usually of the horseshoe form. Hence the name *magneto*.

In order to concentrate the magnetic field within the space in which the armature revolves, pole pieces of iron are so arranged in connection with the poles of the permanent magnet as to afford a substantially cylindrical space in which the armature conductors may revolve and through which practically all the magnetic lines of force set up by the permanent magnets will pass. In Fig. 68 there is shown, diagrammatically, a horseshoe magnet with such a pair of pole pieces, between which a loop of wire is adapted to rotate. The magnet *1* is of hardened steel and permanently magnetized. The pole pieces are shown at *2* and *3*, each being of soft iron adapted to make good magnetic contact on its flat side with the inner flat surface of the bar magnet, and being bored out so as to form a cylindrical recess between them as indicated. The direction of the magnetic lines of force set up by the bar magnet through the interpolar space is indicated by the long horizontal arrows, this flow being from the north pole (N) to the south pole (S) of the magnet. At *4* there is shown a loop of wire supposed to revolve in the magnetic field of force on the axis *5-5*.

Theory. In order to understand how currents will be generated in this loop of wire *4*, it is only necessary to remember that if a conductor is so moved as to cut across magnetic lines of force, an electromotive force will be set up in the conductor which will tend to make the current flow through it. The magnitude of the electromotive force will depend on the rate at which the conductor cuts through the lines of force, or, in other words, on the number of lines of force that are cut through by the conductor in a given unit of time. Again, the direction of the electromotive force depends on the direction of the cutting, so that if the conductor be moved in one direction across the lines of force, the electromotive force and the current will be in one direction; while if it moves in the opposite direction across the lines of force, the electromotive force and the current will be in the reverse direction.

It is, evident that as the loop of wire *4* revolves in the field of force about the axis *5-5*, the portions of the conductor parallel to the axis will cut through the lines of force, first in one direction and then in the other, thus producing electromotive forces therein, first in one direction and then in the other.

Referring now to Fig. 68, and supposing that the loop *4* is revolving in the direction of the curved arrow shown between the upper edges of the pole pieces, it will be evident that just as the loop stands in the vertical position, its horizontal members will be moving in a horizontal direction, parallel with the lines of force and, therefore, not cutting them at all. The electromotive force and the current will, therefore, be zero at this time.

As the loop advances toward the position shown in dotted lines, the upper portion of the loop that is parallel with the axis will begin to cut downwardly through the lines of force, and likewise the lower portion of the loop that is parallel with the axis will begin to cut upwardly through the lines of force. This will cause electromotive forces in opposite directions to be generated in these portions of the loop, and these will tend to aid each other in causing a current to circulate in the loop in the direction shown by the arrows associated with the dotted representation of the loop. It is evident that as the motion of the loop progresses, the rate of cutting the lines of force will increase and will be a maximum when the loop reaches a horizontal position, or at that time the two portions of the loop that are parallel with the axis will be traveling at right angles to the lines of force. At this point, therefore, the electromotive force and the current will be a maximum.

From this point until the loop again assumes a vertical position, the cutting of the lines of force will still be in the same direction, but at a constantly decreasing rate, until, finally, when the loop is vertical the movement of the parts of the loop that are parallel with the axis will be in the direction of the lines of force and, therefore, no cutting will take place. At this point, therefore, the electromotive force and the current in the loop again will be zero. We have seen, therefore, that in this half revolution of the loop from the time when it was in a vertical position to a time when it was again in a vertical position but upside down, the electromotive force varied from zero to a maximum and back to zero, and the current did the same.

It is easy to see that, as the loop moves through the next half revolution, an exactly similar rise and fall of electromotive force and current will take place; but this will be in the opposite direction, since that portion of the loop which was going down through the lines of force is now going up, and the portion which was previously going up is now going down.

The law concerning the generation of electromotive force and current in a conductor that is cutting through lines of magnetic force, may be stated in another way, when the conductor is bent into the form of a loop, as in the case under consideration: Thus, *if the number of lines of force which pass through a conducting loop be varied, electromotive forces will be generated in the loop.* This will be true whether the number of lines passing through the loop be varied by moving the loop within the field of force or by varying the field of force itself. In any case, *if the number of lines of force be increased, the current will flow in one way, and if it be diminished the current will flow in the other way.* The amount of the current will depend, other things being equal, on the rate at which the lines of force through the loop are being varied, regardless of the method by which the variation is made to take place. One revolution of the loop, therefore, results in a complete cycle of alternating current consisting of one positive followed by one negative impulse.

The diagram of Fig. 68 is merely intended to illustrate the principle involved. In the practical construction of magneto generators more than one bar magnet is used, and, in addition, the conductors in the armature are so arranged as to include a great many loops of wire. Furthermore, the conductors in the armature are wound around an iron core so that the path through the armature loops or turns, may present such low reluctance to the passage of lines of force as to greatly increase the number of such lines and also to cause practically all of them to go through the loops in the armature conductor.

Armature. The iron upon which the armature conductors are wound is called the *core*. The core of an ordinary armature is shown in Fig. 69. This is usually made of soft gray cast iron, turned so as to form bearing surfaces at *1* and *2*, upon which the entire armature may rotate, and also turned so that the surfaces *3* will be truly cylindrical with respect to the axis through the center of the shaft. The armature conductors are put on by winding the space between the two parallel faces *4* as full of insulated wire as space will admit. One end of the armature winding is soldered to the pin *5* and, therefore, makes contact with the frame of the generator, while the other end of the winding is soldered to the pin *6*, which engages the stud *7*, carried in an insulating bushing in a longitudinal hole in the end of the armature shaft. It is thus seen that the frame of the machine will form one terminal of the armature winding, while the insulated stud *7* will form the other terminal.

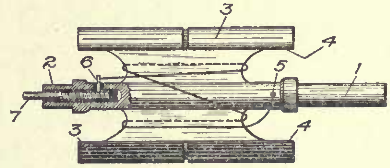


Fig. 69. Generator Armature

Another form of armature largely employed in recent magneto generators is illustrated in Fig. 70. In this the shaft on which the armature revolves does not form an integral part of the armature core

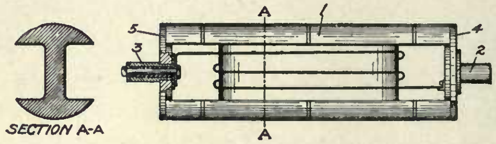


Fig. 70. Generator Armature

but consists of two cylindrical studs *2* and *3* projecting from the centers of disks *4* and *5*, which are screwed to the ends of the core *1*. This **H** type of armature core, as it is called, while containing somewhat more parts than the simpler type shown in Fig. 69, possesses distinct advantages in the matter of winding. By virtue of its simpler form of winding space, it is easier to insulate and easier to wind, and furthermore, since the shaft does not run through the winding space, it is capable of holding a considerably greater number of turns of wire. The ends of the armature winding are connected, one directly to the frame and the other to an insulated pin, as is shown in the illustration.

The method commonly employed of associating the pole pieces with each other and with the permanent magnets is shown in Fig.

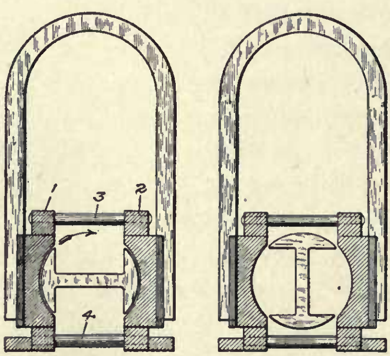


Fig. 71. Generator Field and Armature

71. It is very important that the space in which the armature revolves shall be truly cylindrical, and that the bearings for the armature shall be so aligned as to make the axis of rotation of the armature coincide with the axis of the cylindrical surface of the

pole pieces. A rigid structure is, therefore, required and this is frequently secured, as shown in Fig. 71, by joining the two pole pieces *1* and *2* together by means of heavy brass rods *3* and *4*, the rods being shouldered and their reduced ends passed through holes in flanges extending from the pole pieces, and riveted. The bearing plates in which the armature is journaled are then secured to the ends of these pole pieces, as will be shown in subsequent illustrations. This assures proper rigidity between the pole pieces and also between the pole pieces and the armature bearings.

The reason why this degree of rigidity is required is that it is necessary to work with very small air gaps between the armature core and its pole pieces and unless these generators are mechanically well made they are likely to alter their adjustment and thus allow the armature faces to scrape or rub against the pole pieces. In Fig. 71 one of the permanent horseshoe magnets is shown, its ends resting in grooves on the outer faces of the pole pieces and usually clamped thereto by means of heavy iron machine screws.

With this structure in mind, the theory of the magneto generator developed in connection with Fig. 68 may be carried a little further. When the armature lies in the position shown at the left of Fig. 71, so that the center position of the core is horizontal, a good path is afforded for the lines of force passing from one pole to the other. Practically all of these lines will pass through the iron of the core rather than through the air, and, therefore, practically all of them will pass through the convolutions of the armature winding.

When the armature has advanced, say 45 degrees, in its rotation in the direction of the curved arrow, the lower right-hand portion of the armature flange will still lie opposite the lower face of the right-hand pole piece and the upper left-hand portion of the armature flange will still lie opposite the upper face of the left-hand pole piece. As a result there will still be a good path for the lines of force through the iron of the core and comparatively little change in the number of lines passing through the armature winding. As the corners of the armature flange pass away from the corners of the pole pieces, however, there is a sudden change in condition which may be best understood by reference to the right-hand portion of Fig. 71. The lines of force now no longer find path through the center portion of the armature core—that lying at right angles to their direction of flow.

Two other paths are at this time provided through the now horizontal armature flanges which serve almost to connect the two pole pieces. The lines of force are thus shunted out of the path through the armature coils and there is a sudden decrease from a large number of lines through the turns of the winding to almost none. As the armature continues in its rotation the two paths through the flanges are broken, and the path through the center of the armature core and, therefore, through the coils themselves, is reëstablished.

As a result of this consideration it will be seen that in actual practice the change in the number of lines passing through the armature winding is not of the gradual nature that would be indicated by a consideration of Fig. 68 alone, but rather, is abrupt, as the corners

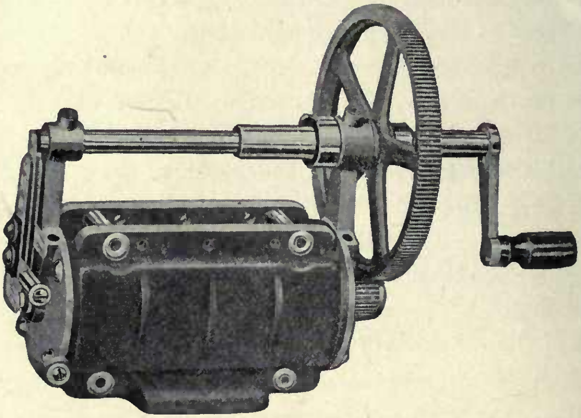


Fig. 72. Generator with Magnets Removed

of the armature flanges leave the corners of the pole pieces. This abrupt change produces a sudden rise in electromotive force just at these points in the rotation, and, therefore, the electromotive force and the current curves of these magneto generators is not usually of the smooth sine-wave type but rather of a form resembling the sine wave with distinct humps added to each half cycle.

As is to be expected from any two-pole alternating generator, there is one cycle of current for each revolution of the armature. Under ordinary conditions a person is able to turn the generator handle at the rate of about two hundred revolutions a minute, and as the ratio of gearing is about five to one, this results in about one thousand revolutions per minute of the generator, and, therefore, in a current of about one thousand cycles per minute, this varying widely according to the person who is doing the turning.

The end plates which support the bearings for the armature are usually extended upwardly, as shown in Fig. 72, so as to afford bearings for the crank shaft. The crank shaft carries a large spur gear which meshes with a pinion in the end of the armature shaft, so that the user may cause the armature to revolve rapidly. The construction shown in Fig. 72 is typical of that of a modern magneto generator, it being understood that the permanent magnets are removed for clearness of illustration.

Fig. 73 is a view of a completely assembled generator such as is used for service requiring a comparatively heavy output. Other

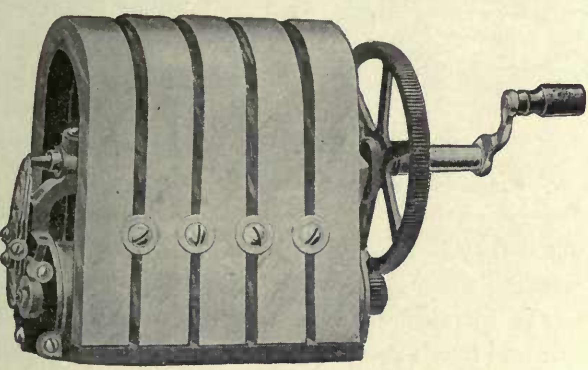


Fig. 73. Five-Bar Generator

types of generators having two, three, or four permanent magnets instead of five, as shown in this figure, are also standard.

Referring again to Fig. 69, it will be remembered that one end of the armature winding shown diagrammatically in that figure, is terminated in the pin *5*, while the other terminates in the pin *7*. When the armature is assembled in the frame of the generator it is evident that the frame itself is in metallic connection with one end of the armature winding, since the pin *5* is in metallic contact with the armature casting and this is in contact with the frame of the generator through the bearings. The frame of the machine is, therefore, one terminal of the generator. When the generator is assembled a spring of one form or another always rests against the terminal pin *7* of the armature so as to form a terminal for the armature winding of such a nature as to permit the armature to rotate freely. Such spring, therefore, forms the other terminal of the generator.

Automatic Shunt. Under nearly all conditions of practice it is desirable to have the generator automatically perform some switching function when it is operated. As an example, when the generator is connected so that its armature is in series in a telephone line, it is quite obvious that the presence of the resistance and the impedance of the armature winding would be objectionable if left in the circuit through which the voice currents had to pass. For this reason, what is termed an *automatic shunt* is employed on generators designed for series work; this shunt is so arranged that it will automatically shunt or short-circuit the armature winding when it is at rest and also break this shunt when the generator is operated, so as to allow the current to pass to line.

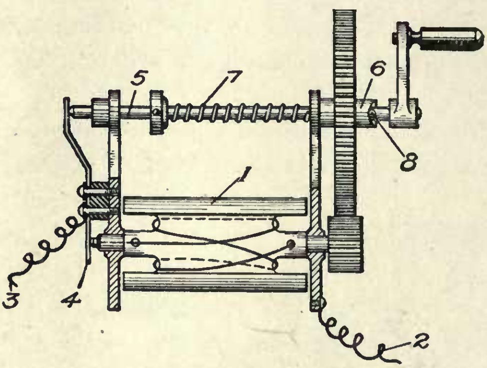


Fig 74. Generator Shunt Switch

A simple and much-used arrangement for this purpose is shown in Fig. 74, where *1* is the armature; *2* is a wire leading from the frame of the generator and forming one terminal of the generator circuit; and *3* is a wire forming the other terminal of the generator circuit, this wire being attached to the spring *4*, which rests against the center pin of the armature so as to make contact with the opposite end of the armature winding to that which is connected with the frame. The circuit through the armature may be traced from the terminal wire *2* through the frame; thence through the bearings to the armature *1* and through the pin to the right-hand side of the armature winding. Continuing the circuit through the winding itself, it passes to the center pin projecting from the left-hand end of the armature shaft; thence to the spring *4* which rests against this pin; and thence to the terminal wire *3*.

Normally, this path is shunted by what is practically a short circuit, which may be traced from the terminal *2* through the frame of the generator to the crank shaft *5;* thence to the upper end of the spring *4* and out by the terminal wire *3*. This is the condition which ordinarily exists and which results in the removal of the resistance and the impedance on the armature winding from any circuit in which the generator is placed, as long as the generator is not operated.

An arrangement is provided, however, whereby the crank shaft *5* will be withdrawn automatically from engaging with the upper end of the spring *4,* thus breaking the shunt around the armature circuit, whenever the generator crank is turned. In order to accomplish this the crank shaft *5* is capable of partial rotation and of slight longitudinal movement within the hub of the large gear wheel. A spring *7* usually presses the crank shaft toward the left and into engagement with the spring *4*. A pin *8* carried by the crank shaft, rests in a **V**-shaped notch in the end of the hub *6* and as a result, when the crank is turned the pin rides on the surface of this notch before the large gear wheel starts to turn, and thus moves the crank shaft *5* to the right and breaks the contact between it and the spring *4*. Thus, as long as the generator is being operated, its armature is connected in the circuit of the line, but as soon as it becomes idle the armature is automatically short-circuited. Such devices as this are termed *automatic shunts.*

In still other cases it is desirable to have the generator circuit normally open so that it will not affect in any way the electrical characteristics of the line while the line is being used for talking. In this case the arrangement is made so that the generator will automatically be placed in proper circuit relation with the line when it is operated.

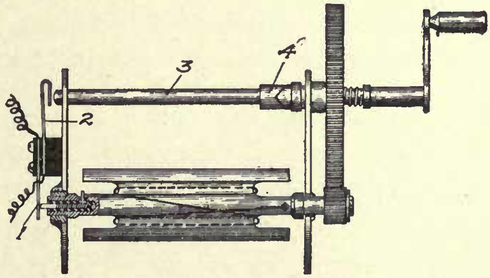


Fig. 75. Generator Cut-In Switch

A common arrangement for doing this is shown in Fig. 75, wherein the spring *1* normally rests against the contact pin of the armature and forms one terminal of the armature circuit. The spring *2* is adapted to form the other terminal of the armature circuit but it is normally insulated from everything. The circuit of the generator is, therefore, open between the spring *2* and the shaft *3*.

but as soon as the generator is operated the crank shaft is bodily moved to the left by means of the V-shaped notch in the driving collar *4* and is thus made to engage the spring *2*. The circuit of the generator is then completed from the spring *1* through the armature pin to the armature winding; thence to the frame of the machine and through shaft *3* to the spring *2*. Such devices as this are largely used in connection with so-called "bridging" telephones in which the generators and bells are adapted to be connected in multiple across the line.

A better arrangement for accomplishing the automatic switching on the part of the generator is to make no use of the crank shaft as a part of the conducting path as is the case in both Figs. 74 and 75, but to make the crank shaft, by its longitudinal movement, impart the necessary motion to a switch spring which, in turn, is made to engage or disengage a corresponding contact spring. An arrangement of this kind that is in common use is shown in Fig. 76. This needs no further explanation than to say that the crank shaft is provided on its end with an insulating stud *1*, against which a switching spring *2* bears. This spring normally rests against another switch spring *3*, but when the generator crank shaft moves to the right upon the turning of the crank, the spring *2* disengages spring *3* and engages spring *4*, thus completing the circuit of the generator armature. It is seen that this operation accomplishes the breaking of one circuit and the making of another, a function that will be referred to later on in this work.

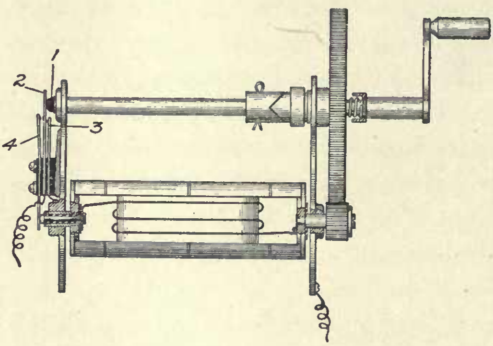


Fig. 76. Generator Cut-In Switch

Pulsating Current. Sometimes it is desirable to have a generator capable of developing a pulsating current instead of an alternating current; that is, a current which will consist of impulses all in one direction rather than of impulses alternating in direction. It is obvious that this may be accomplished if the circuit of the generator be broken during each half revolution so that its circuit is completed only when current is being generated in one direction.

Such an arrangement is indicated diagrammatically in Fig. 77. Instead of having one terminal of the armature winding brought out through the frame of the generator as is ordinarily done, both terminals are brought out to a commuting device carried on the end of the armature shaft. Thus, one end of the loop representing the armature winding is shown connected directly to the armature pin *1*, against which bears a spring *2*, in the usual manner. The other end of the armature winding is carried directly to a disk *3*, mounted *on* but insulated *from* the shaft and revolving therewith. One-half of the circumferential surface of this disk is of insulating material *4* and a spring *5* rests against this disk and bears alternately upon the conducting portion *3* or the insulating portion *4*, according to the position of the armature in its revolution. It is obvious that when the generator armature is in the position shown the circuit through it is from the spring *2* to the pin *1*; thence to one terminal of the armature loop; thence through the loop and back to the disk *3* and out by the spring *5*. If, however, the armature were turned slightly, the spring *5* would rest on the insulating portion *4* and the circuit would be broken.

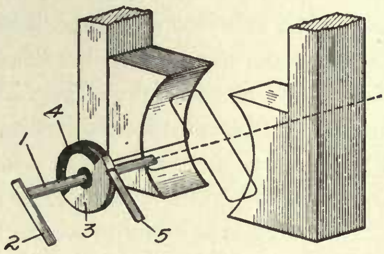


Fig. 77. Pulsating-Current Commutator

It is obvious that if the brush *5* is so disposed as to make contact with the disk *3* only during that portion of the revolution while positive current is being generated, the generator will produce positive pulsations of current, all the negative ones being cut out. If, on the other hand, the spring *5* may be made to bear on the opposite side of the disk, then it is evident that the positive impulses would all be cut out and the generator would develop only negative impulses. Such a generator is termed a "direct-current" generator or a "pulsating-current" generator.

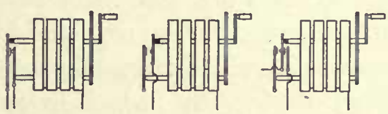


Fig. 78. Generator Symbols

The symbols for magneto or hand generators usually embody a simplified side view, showing the crank and the gears on one side and the shunting or other switching device on the other. Thus in Fig. 78 are shown three such symbols, differing from each other only in the details of the switching device. The one at the left shows the simple shunt, adapted to short-circuit the generator at all times save when it is in operation. The one in the center shows the cut-in, of which another form is described in connection with Fig. 75; while the symbol at the right of Fig. 78 is of the make-and-break device, discussed in connection with Fig. 76. In such diagrammatic representations of generators it is usual to somewhat exaggerate the size of the switching springs, in order to make clear their action in respect to the circuit connections in which the generator is used.

Polarized Ringer. The polarized bell or ringer is, as has been stated, the device which is adapted to respond to the currents sent out by the magneto generator. In order that the alternately opposite currents may cause the armature to move alternately in opposite directions, these bells are polarized, *i. e.*, given a definite magnetic set, so to speak; so the effect of the currents in the coils is not to create magnetism in normally neutral iron, but rather to alter the magnetism in iron already magnetized.

Western Electric Ringer. A typical form of polarized bell is shown in Fig. 79, this being the standard bell or ringer of the Western Electric Company. The two electromagnets are mounted side by side, as shown, by attaching their cores to a yoke piece *1* of soft iron. This yoke piece also carries the standards *2* upon which the gongs are mounted. The method of mounting is such that the standards may be adjusted slightly so as to bring the gongs closer *to* or farther *from* the tapper.

The soft iron yoke piece *1* also carries two brass posts *3* which, in turn, carry another yoke *4* of brass. In this yoke *4* is pivoted, by means of trunnion screws, the armature *5*, this extending on each side of the pivot so that its ends lie opposite the free poles of the electromagnets. From the center of the armature projects the tapper rod carrying the ball or striker which plays between the two gongs.

In order that the armature and cores may be normally polarized, a permanent magnet *6* is secured to the center of the yoke piece *1*. This bends around back of the electromagnets and comes into close proximity to the armature *5*. By this means one end of each of the electromagnet cores is given one polarity—say north—while the armature is given the other polarity—say south. The two coils of the electromagnet are connected together in series in such a way that current in a given direction will act to produce a north pole in one of the free poles and a south pole in the other. If it be assumed that the permanent magnet maintains the armature normally of south polarity and that the current through the coils is of such direction as to make the left-hand core north and the right-hand core south, then it is evident that the left-hand end of the armature will be attracted and the right-hand end repelled. This will throw the tapper rod to the right and sound the right-hand bell. A reversal in current will obviously produce the opposite effect and cause the tapper to strike the left-hand bell.

An important feature in polarized bells is the adjustment between the armature and the pole pieces. This is secured in the

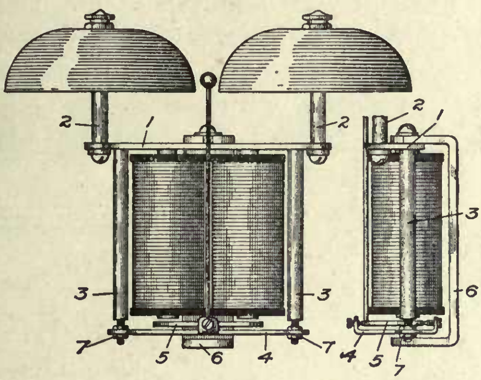


Fig. 79. Polarized Bell

Western Electric bell by means of the nuts *7*, by which the yoke *4* is secured to the standards *3*. By moving these nuts up or down on the standards the armature may be brought closer *to* or farther *from* the poles, and the device affords ready means for clamping the parts into any position to which they may have been adjusted.

Kellogg Ringer. Another typical ringer is that of the Kellogg Switchboard and Supply Company, shown in Fig. 80. This differs from that of the Western Electric Company mainly in the details by which the armature adjustment is obtained. The armature supporting yoke *1* is attached directly to the cores of the magnets, no supporting side rods being employed. Instead of providing means whereby the armature may be adjusted toward or from the poles, the reverse practice is employed, that is, of making the poles themselves extensible. This is done by means of the iron screws *2* which form extensions of the cores and which may be made to approach or recede from the armature by turning them in such direction as to screw them in or out of the core ends.

Biased Bell. The pulsating-current generator has already been discussed and its principle of operation pointed out in connection with Fig. 77. The companion piece to this generator is the so-called biased ringer. This is really nothing but a common alternating-current polarized ringer with a light spring so arranged as to hold the armature normally in one of its extreme positions so that the tapper will rest against one of the gongs. Such a ringer is shown in Fig. 81 and needs no further explanation. It is obvious that if a current flows in the coils of such a ringer in a direction tending to move the tapper toward the left, then no sound will result because the

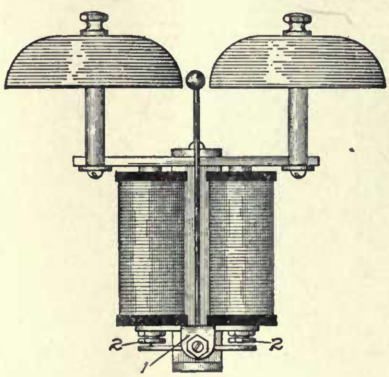


Fig. 80. Polarized Bell

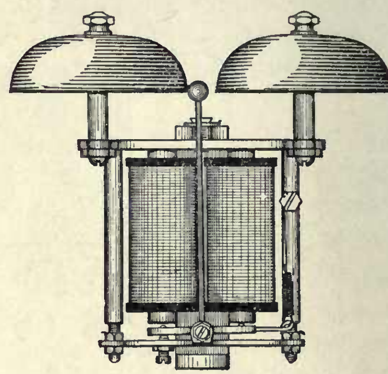


Fig. 81. Biased Bell

tapper is already moved as far as it can be in that direction. If, however, currents in the opposite direction are caused to flow through the windings, then the electromagnetic attraction on the armature will overcome the pull of the spring and the tapper will move over and strike the right-hand gong. A cessation of the current will allow the spring to exert itself and throw the tapper back into engagement with the left-hand gong. A series of such pulsations in the proper direction will, therefore, cause the tapper to play between the two gongs and ring the bell as usual. A series of currents in a wrong direction will, however, produce no effect.

Conventional Symbols. In Fig. 82 are shown six conventional symbols of polarized bells. The three at the top, consisting merely of two circles representing the magnets in plan view, are perhaps to be preferred as they are well standardized, easy to draw, and rather suggestive. The three at the bottom, showing the ringer as a whole in side elevation, are somewhat more specific, but are objectionable in that they take more space and are not so easily drawn.

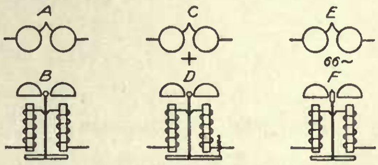


Fig. 82. Ringer Symbols

Symbols *A* or *B* may be used for designating any ordinary polarized ringer. Symbols *C* and *D* are interchangeably used to indicate a biased ringer. If the bell is designed to operate only on positive impulses, then the plus sign is placed opposite the symbol, while a minus sign so placed indicates that the bell is to be operated only by negative impulses.

Some specific types of ringers are designed to operate only on a given frequency of current. That is, they are so designed as to be responsive to currents having a frequency of sixty cycles per second, for instance, and to be unresponsive to currents of any other frequency. Either symbols *E* or *F* may be used to designate such ringers, and if it is desired to indicate the particular frequency of the ringer this is done by adding the proper numeral followed by a short reversed curve sign indicating frequency. Thus 50 ~ would indicate a frequency of fifty cycles per second.

CHAPTER IX

THE HOOK SWITCH

Purpose. In complete telephone instruments, comprising both talking and signaling apparatus, it is obviously desirable that the two sets of apparatus, for talking and signaling respectively, shall not be connected with the line at the same time. A certain switching device is, therefore, necessary in order that the signaling apparatus alone may be left operatively connected with the line while the instrument is not being used in the transmission of speech, and in order that the signaling apparatus may be cut out when the talking apparatus is brought into play.

In instruments employing batteries for the supply of transmitter current, another switching function is the closing of the battery circuit through the transmitter and the induction coil when the instrument is in use for talking, since to leave the battery circuit closed all the time would be an obvious waste of battery energy.

In the early forms of telephones these switching operations were performed by a manually operated switch, the position of which the user was obliged to change before and after each use of the telephone. The objection to this was not so much in the manual labor imposed on the user as in the tax on his memory. It was found to be practically a necessity to make this switching function automatic, principally because of the liability of the user to forget to move the switch to the proper position after using the telephone, resulting not only in the rapid waste of the battery elements but also in the inoperative condition of the signal-receiving bell. The solution of this problem, a vexing one at first, was found in the so-called automatic hook switch or switch hook, by which the circuits of the instrument were made automatically to assume their proper conditions by the mere act, on the part of the user, of removing the receiver from, or placing it upon, a conveniently arranged hook or fork projecting from the side of the telephone casing.

Automatic Operation. It may be taken as a fundamental principle in the design of any piece of telephone apparatus that is to be generally used by the public, that the necessary acts which a person must perform in order to use the device must, as far as possible, follow as a natural result from some other act which it is perfectly obvious to the user that he must perform. So in the case of the switch hook, the user of a telephone knows that he must take the receiver from its normal support and hold it to his ear; and likewise, when he is through with it, that he must dispose of it by hanging it upon a support obviously provided for that purpose.

In its usual form a forked hook is provided for supporting the receiver in a convenient place. This hook is at the free end of a pivoted lever, which is normally pressed upward by a spring when the receiver is not supported on it. When, however, the receiver is supported on it, the lever is depressed by its weight. The motion of the lever is mechanically imparted to the members of the switch proper, the contacts of which are usually enclosed so as to be out of reach of the user. This switch is so arranged that when the hook is depressed the circuits are held in such condition that the talking apparatus will be cut out, the battery circuit opened, and the signaling apparatus connected with the line. On the other hand, when the hook is in its raised position, the signaling apparatus is cut out, the talking apparatus switched into proper working relation with the line, and the battery circuit closed through the transmitter.

In the so-called common-battery telephones, where no magneto generator or local battery is included in the equipment at the subscriber's station, the mere raising of the hook serves another important function. It acts, not only to complete the circuit through the substation talking apparatus, but, by virtue of the closure of the line circuit, permits a current to flow over the line from the central-office battery which energizes a signal associated with the line at the central office. This use of the hook switch in the case of the common-battery telephone is a good illustration of the principle just laid down as to making all the functions which the subscriber has to perform depend, as far as possible, on acts which his common sense alone tells him he must do. Thus, in the common-battery telephone the subscriber has only to place the receiver at his ear and ask for what he wants. This operation automatically displays a signal at the central office and he does nothing further until the operator inquires for the number that he wants. He has then nothing to do but wait until the called-for party responds, and after the conversation his own personal convenience demands that he shall dispose of the receiver in some way, so he hangs it up on the most convenient object, the hook switch, and thereby not only places the apparatus at his telephone in proper condition to receive another call, but also conveys to the central office the signal for disconnection.

Likewise in the case of telephones operating in connection with automatic exchanges, the hook switch performs a number of functions automatically, of which the subscriber has no conception; and while, in automatic telephones, there are more acts required of the user than in the manual, yet a study of these acts will show that they all follow in a way naturally suggested to the user, so that he need have but the barest fundamental knowledge in order to properly make use of the instrument. In all cases, in properly designed apparatus, the arrangement is such that the failure of the subscriber to do a certain required act will do no damage to the apparatus or to the system, and, therefore, will inconvenience only himself.

Design. The hook switch is in reality a two-position switch, and while at present it is a simple affair, yet its development to its high state of perfection has been slow, and its imperfections in the past have been the cause of much annoyance.

Several important points must be borne in mind in the design of the hook switch. The spring provided to lift the hook must be sufficiently strong to accomplish this purpose and yet must not be strong enough to prevent the weight of the receiver from moving the switch to its other position. The movement of this spring must be somewhat limited in order that it will not break when used a great many times, and also it must be of such material and shape that it will not lose its elasticity with use. The shape and material of the restoring spring are, of course, determined to a considerable extent by the length of the lever arm which acts on the spring, and on the space which is available for the spring.

The various contacts by which the circuit changes are brought about upon the movement of the hook-switch lever usually take the form of springs of German silver or phosphor-bronze, hard rolled so as to have the necessary resiliency, and these are usually tipped with platinum at the points of contact so as to assure the necessary character of surface at the points where the electric circuits are made or broken. A slight sliding movement between each pair of contacts as they are brought together is considered desirable, in that it tends to rub off any dirt that may have accumulated, yet this sliding movement should not be great, as the surfaces will then cut each other and, therefore, reduce the life of the switch.

Contact Material. On account of the high cost of platinum, much experimental work has been done to find a substitute metal suitable for the contact points in hook switches and similar uses in the manufacture of telephone apparatus. Platinum is unquestionably the best known material, on account of its non-corrosive and heat-resisting qualities. Hard silver is the next best and is found in some first-class apparatus. The various cheap alloys intended as substitutes for platinum or silver in contact points may be dismissed as worthless, so far as the writers' somewhat extensive investigations have shown.

In the more recent forms of hook switches, the switch lever itself does not form a part of the electrical circuit, but serves merely as the means by which the springs that are concerned in the switching functions are moved into their alternate coöperative relations. One advantage in thus insulating the switch lever from the current-carrying portions of the apparatus and circuits is that, since it necessarily projects from the box or cabinet, it is thus liable to come in contact with the person of the user. By insulating it, all liability of the user receiving shocks by contact with it is eliminated.

Wall Telephone Hooks. *Kellogg.* A typical form of hook switch, as employed in the ordinary wall telephone sets, is shown in Fig. 83, this being the standard hook of the Kellogg Switchboard and Supply Company. In this the lever *1* is pivoted at the point *3* in a bracket *5* that forms the base of all the working parts and the means of securing the entire hook switch to the box or framework of the telephone. This switch lever is normally pressed upward by a spring *2,* mounted on the bracket *5,* and engaging the under side of the hook lever at the point *4.* Attached to the lever arm *1* is an insulated pin *6.* The contact springs by which the various electrical circuits are made and broken are shown at *7, 8, 9, 10,* and *11,* these being mounted in one group with insulated bushings between them; the entire group is secured by machine screws to a lug projecting horizontally from the bracket *5*. The center spring *9* is provided with a forked extension which embraces the pin *6* on the hook lever. It is obvious that an up-and-down motion of the hook lever will move the long spring *9* in such manner as to cause electrical contact either between it and the two upper springs *7* and *8*, or between it and the two lower springs *10* and *11*. The hook is shown in its raised position, which

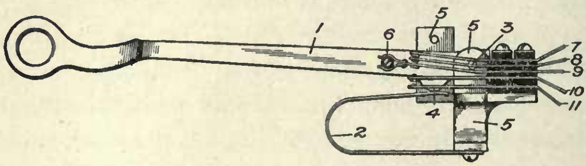


Fig. 83. Long Lever Hook Switch

is the position required for talking. When lowered the two springs *7* and *8* are disengaged from the long spring *9* and from each other, and the three springs *9*, *10*, and *11* are brought into electrical engagement, thus establishing the necessary signaling conditions.

The right-hand ends of the contact springs are shown projecting beyond the insulating supports. This is for the purpose of facilitating making electrical joints between these springs and the various wires which lead from them. These projecting ends are commonly referred to as ears, and are usually provided with holes or notches into which the connecting wire is fastened by soldering.

Western Electric. Fig. 84 shows the type of hook switch quite extensively employed by the Western Electric Company in wall telephone sets where the space is somewhat limited and a compact arrangement is desired. It will readily be seen that the principle on which this hook switch operates is similar to that employed in Fig. 83, although the mechanical arrangement of the parts differs radically. The hook lever *1* is pivoted at *3* on a bracket *2*, which serves to support all the other parts of the switch. The contact springs are shown at *4*, *5*, and *6*, and this latter spring *6* is so designed as to make it serve as an actuating spring for the hook. This is accomplished by having the curved end of this spring press against the lug *7* of the hook and thus tend to raise the hook when it is relieved of the weight of the receiver. The two shorter springs *8* and *9* have no electrical function but merely serve as supports against which the springs *4* and *5* may rest when the receiver is on the hook, these springs *4* and *5* being given a light normal tension toward the stop springs *8* and *9*. It is obvious that in the particular arrangement of the springs in this switch no contacts are closed when the receiver is on the hook.

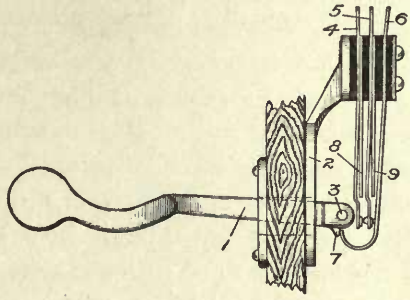


Fig. 84. Short Lever Hook Switch

Concerning this latter feature, it will be noted that the particular form of Kellogg hook switch, shown in Fig. 83, makes two contacts and breaks two when it is raised. Similarly the Western Electric Company's makes two contacts but does not break any when raised. From such considerations it is customary to speak of a hook such as that shown in Fig. 83 as having two make and two break contacts, and such a hook as that shown in Fig. 84 as having two make contacts.

It will be seen from either of these switches that the modification of the spring arrangement, so as to make them include a varying number of make-and-break contacts, is a simple matter, and switches of almost any type are readily modified in this respect.

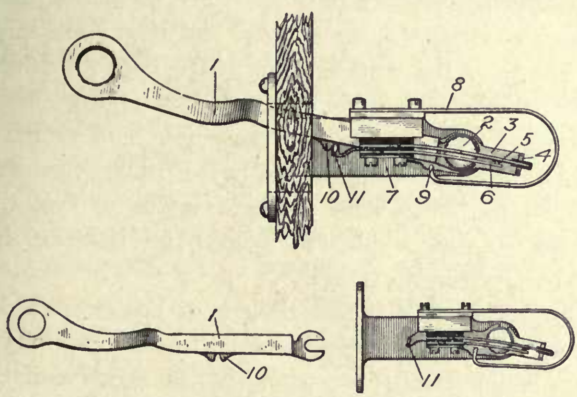


Fig. 85. Removable Lever Hook Switch

Dean. In Fig. 85 is shown a decidedly unique hook switch for wall telephone sets which forms the standard equipment of the Dean Electric Company. The hook lever *1* is pivoted at *2*, an auxiliary lever *3* also being pivoted at the same point. The auxiliary lever *3* carries at its rear end a slotted lug *4*, which engages the long contact spring *5*, and serves to move it up and down so as to engage and disengage the spring *6*, these two springs being mounted on a base lug extending from the base plate *7*, upon which the entire hook-switch mechanism is mounted. The curved spring *8*, also mounted on this same base, engages the auxiliary lever *3* at the point *9* and normally serves to press this up so as to maintain the contact springs *5* in engagement with contact spring *6*. The switch springs are moved entirely by the auxiliary lever *3*, but in order that this lever *3* may be moved as required by the hook lever *1*, this lever is provided with a notched lug *10* on its lower side, which notch is engaged by a forwardly projecting lug *11* that is integral with the auxiliary lever *3*. The switch lever may be bodily removed from the remaining parts of the hook switch by depressing the lug *11* with the finger, so that it disengages the notch in lug *10*, and then drawing the hook lever out of engagement with the pivot stud *2*, as shown in the lower portion of the figure. It will be noted that the pivotal end of the hook lever is made with a slot instead of a hole as is the customary practice.

The advantage of being able to remove the hook switch bodily from the other portions arises mainly in connection with the shipment or transportation of instruments. The projecting hooks cause the instruments to take up more room and thus make larger packing boxes necessary than would otherwise be used. Moreover, in handling the telephones in store houses or transporting them to the places where they are to be used, the projecting hook switch is particularly liable to become damaged. It is for convenience under such conditions that the Dean hook switch is made so that the switch lever may be removed bodily and placed, for instance, inside the telephone box for transportation.

Desk-Stand Hooks. The problem of hook-switch design for portable desk telephones, while presenting the same general characteristics, differs in the details of construction on account of the necessarily restricted space available for the switch contacts in the desk telephone.

Western Electric. In Fig. 86 is shown an excellent example of hook-switch design as applied to the requirements of the ordinary portable desk set. This figure is a cross-sectional view of the base and standard of a familiar type of desk telephone. The base itself is of stamped metal construction, as indicated, and the standard which supports the transmitter and the switch hook for the receiver is composed of a black enameled or nickel-plated brass tube *1*, attached to the base by a screw-threaded joint, as shown. The switch lever *2* is pivoted at *3* in a brass plug *4*, closing the upper end of the tube forming the standard. This brass plug supports also the transmitter, which is not shown in this figure. Attached to the plug *4* by the screw *5* is a heavy strip *6*, which reaches down through the tube to the base plate of the standard and is held therein by a screw *7*. The plug *4*, carrying with it the switch-hook lever *2* and the brass strip *6*, may be lifted bodily out of the standard *1* by taking out the screw *7* which holds the strip *6* in place, as is clearly indicated. On the strip *6* there is mounted the group of switch springs by which the circuit changes of the instrument are brought about when the hook is raised or lowered. The spring *8* is longer than the others, and projects upwardly far enough to engage the lug on the switch-hook lever *2*. This spring, which is so bent as to close the contacts at the right when not prevented by the switch lever, also serves as an actuating spring to raise the lever *2* when the receiver is removed from it. This spring, when the receiver is removed from the hook, engages the two springs at the right, as shown, or when the receiver is placed on the hook, breaks contact with the two right-hand springs and makes contact respectively with the left-hand spring and also with the contact *9* which forms the transmitter terminal.

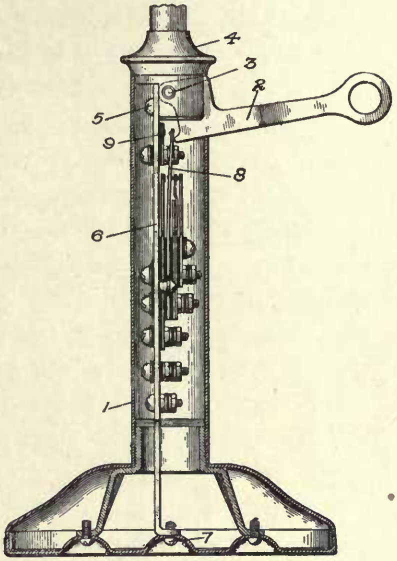


Fig. 86. Desk-Stand Hook Switch

It is seen from an inspection of this switch hook that it has two make and two break contacts. The various contact springs are connected with the several binding posts shown, these forming the connectors for the flexible cord conductors leading into the base and up through the standard of the desk stand. By means of the conductors in this cord the circuits are led to the other parts of the instrument, such as the induction coil, call bell, and generator, if there is one, which, in the case of the Western Electric Company's desk set, are all mounted separately from the portable desk stand proper.

This hook switch is accessible in an easy manner and yet not subject to the tampering of idle or mischievous persons. By taking out the screw 7 the entire hook switch may be lifted out of the tube forming the standard, the cords leading to the various binding posts being slid along through the tube. By this means the connections to the hook switch, as well as the contact of the switch itself, are readily inspected or repaired by those whose duty it is to perform such operations.

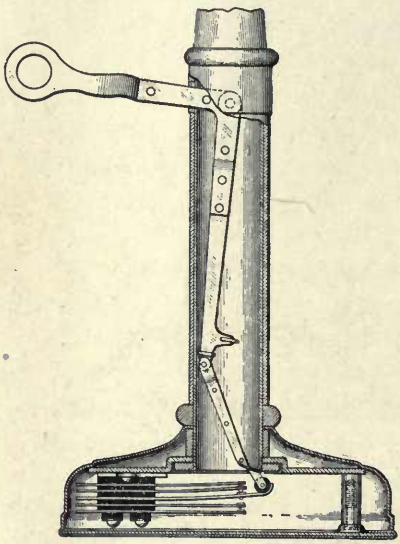


Fig. 87. Desk-Stand Hook Switch

Kellogg. In Fig. 87 is shown a sectional view of the desk-stand hook switch of the Kellogg Switchboard and Supply Company. In this it will be seen that instead of placing the switch-hook springs within the standard or tube, as in the case of the Western Electric Company, they are mounted in the base where they are readily accessible by merely taking off the base plate from the bottom of the stand. The hook lever operates on the long spring of the group of switch springs by means of a toggle joint in an obvious manner. This switch spring itself serves by its own strength to raise the hook lever when released from the weight of the receiver.

In this switch, the hook lever, and in fact the entire exposed metal portions of the instrument, are insulated from all of the contact springs and, therefore, there is little liability of shocks on the part of the person using the instrument.

Conventional Symbols. The hook switch plays a very important part in the operation of telephone circuits; for this reason readily understood conventional symbols, by which they may be conveniently represented in drawings of circuits, are desirable. In Fig. 88 are shown several symbols such as would apply to almost any circuit, regardless of the actual mechanical details of the particular hook switch which happened to be employed. Thus diagram *A* in Fig. 88 shows a hook switch having a single make contact and this diagram might be used to refer to the hook switch of the Dean Electric Company shown in Fig. 85, in which only a single contact is made when the receiver is removed, and none is made when it is on the hook. Similarly, diagram *B* might be used to represent the hook switch of the Kellogg Company, shown in Fig. 83, the arrangement being for two make and two break contacts. Likewise diagram *C* might be used to represent the hook switch of the Western Electric Company, shown in Fig. 84, which, as before stated, has two make contacts only. Diagram *D* shows another modification in which contacts made by the hook switch, when the receiver is removed, control two separate circuits. Assuming that the solid black portion represents insulation, it is obvious that the contacts are divided into two groups, one insulated from the other.

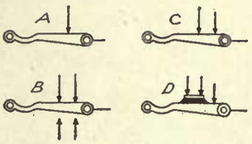


Fig. 88. Hook Switch Symbols

CHAPTER X

ELECTROMAGNETS AND INDUCTIVE COILS

Electromagnet. The physical thing which we call an electromagnet, consisting of a coil or helix of wire, the turns of which are insulated from each other, and within which is usually included an iron core, is by far the most useful of all the so-called translating devices employed in telephony. In performing the ordinary functions of an electromagnet it translates the energy of an electrical current into the energy of mechanical motion. An almost equally important function is the converse of this, that is, the translation of the energy of mechanical motion into that of an electrical current. In addition to these primary functions which underlie the art of telephony, the electromagnetic coil or helix serves a wide field of usefulness in cases where no mechanical motion is involved. As impedance coils, they serve to exert important influences on the flow of currents in circuits, and as induction coils, they serve to translate the energy of a current flowing in one circuit into the energy of a current flowing in another circuit, the translation usually, but not always, being accompanied by a change in voltage.

When a current flows through the convolutions of an ordinary helix, the helix will exhibit the properties of a magnet even though the substance forming the core of the helix is of non-magnetic material, such as air, or wood, or brass. If, however, a mass of iron, such as a rod or a bundle of soft iron wires, for instance, is substituted as a core, the magnetic properties will be enormously increased. The reason for this is, that a given magnetizing force will set up in iron a vastly greater number of lines of magnetic force than in air or in any other non-magnetic material.

Magnetizing Force. The magnetizing force of a given helix is that force which tends to drive magnetic lines of force through the magnetic circuit interlinked with the helix. It is called *magnetomotive force* and is analogous to electromotive force, that is, the force which tends to drive an electric current through a circuit.

The magnetizing force of a given helix depends on the product of the current strength and the number of turns of wire in the helix. Thus, when the current strength is measured in amperes, this magnetizing force is expressed as ampere-turns, being the product of the number of amperes flowing by the number of turns. The magnetizing force exerted by a given current, therefore, is independent of anything except the number of turns, and the material within the core or the shape of the core has no effect upon it.

Magnetic Flux. The total magnetization resulting from a magnetizing force is called the magnetic flux, and is analogous to current. The intensity of a magnetic flux is expressed by the number of magnetic lines of force in a square centimeter or square inch.

While the magnetomotive force or magnetizing force of a given helix is independent of the material of the core, the flux which it sets up is largely dependent on the material and shape of the core—not only upon this but on the material that lies in the return path for the flux outside of the core. We may say, therefore, that the amount of flux set up by a given current in a given coil or helix is dependent on the material in the magnetic path or magnetic circuit, and on the shape and length of that circuit. If the magnetic circuit be of air or brass or wood or any other non-magnetic material, the amount of flux set up by a given magnetizing force will be relatively small, while it will be very much greater if the magnetic circuit be composed in part or wholly of iron or steel, which are highly magnetic substances.

Permeability. The quality of material, which permits of a given magnetizing force setting up a greater or less number of lines of force within it, is called its permeability. More accurately, the permeability is the ratio existing between the amount of magnetization and the magnetizing force which produces such magnetization.

The permeability of a substance is usually represented by the Greek letter μ (pronounced *mu*). The intensity of the magnetizing force is commonly symbolized by **H**, and since the permeability of air is always taken as unity, we may express the intensity of magnetizing force by the number of lines of force per square centimeter which it sets up in air.

Now, if the space on which the given magnetizing force **H** were acting were filled with iron instead of air, then, owing to the greater permeability of iron, there would be set up a very much greater number of lines of force per square centimeter, and this number of lines of force per square centimeter in the iron is the measure of the magnetization produced and is commonly expressed by the letter B.

From this we have

$$\mu = \frac{B}{H}$$

Thus, when we say that the permeability of a given specimen of wrought iron under given conditions is 2,000, we mean that 2,000 times as many lines of force would be induced in a unit cross-section of this sample as would be induced by the same magnetizing force in a corresponding unit cross-section of air. Evidently for air B = H, hence μ becomes unity.

The permeability of air is always a constant. This means that whether the magnetic density of the lines of force through the air be great or small the number of lines will always be proportional to the magnetizing force. Unfortunately for easy calculations in electromagnetic work, however, this is not true of the permeability of iron. For small magnetic densities the permeability is very great, but for large densities, that is, under conditions where the number of lines of force existing in the iron is great, the permeability becomes smaller, and an increase in the magnetizing force does not produce a corresponding increase in the total flux through the iron.

Magnetization Curves. This quality of iron is best shown by the curves of Fig. 89, which illustrate the degree of magnetization set up in various kinds of iron by different magnetizing forces. In these curves the ordinates represent the total magnetization B, while the abscissas represent the magnetizing force H. It is seen from an inspection of these curves that as the magnetizing force H increases, the intensity of flux also increases, but at a gradually lessening rate, indicating a reduction in permeability at the higher densities. These curves are also instructive as showing the great differences that exist between the permeability of the different kinds of iron; and also as showing how, when the magnetizing force becomes very great, the iron approaches what is called *saturation*, that is, a point at which the further increase in magnetizing force will result in no further magnetization of the core.

From the data of the curves of Fig. 89, which are commonly called *magnetization curves,* it is easy to determine other data from which so-called permeability curves may be plotted. In permeability curves the total magnetization of the given pieces of iron are plotted as abscissas, while the corresponding permeabilities are plotted as ordinates.

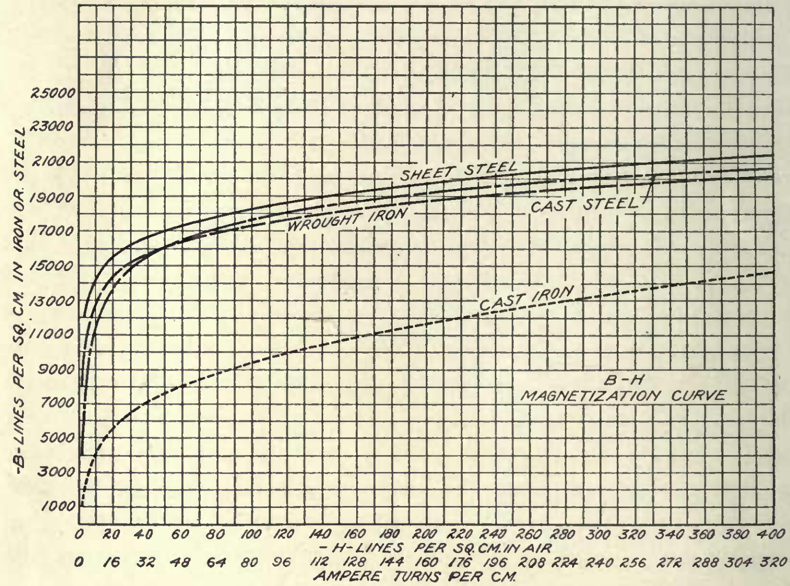


Fig. 89. Magnetization Curve

Direction of Lines of Force. The lines of force set up within the core of a helix always have a certain direction. This direction always depends upon the direction of the flow of current around the core. An easy way to remember the direction is to consider the helix as grasped in the right hand with the fingers partially encircling it and the thumb pointing along its axis. Then, if the current through the convolutions of the helix be in the direction in which the fingers of the hand are pointed around the helix, the magnetic lines of force will proceed through the core of the helix along the direction in which the thumb is pointed.

In the case of a simple bar electromagnet, such as is shown in Fig. 90, the lines of force emerging from one end of the bar must pass back through the air to the other end of the bar, as indicated by dotted lines and arrows. The path followed by the magnetic lines of force is called the *magnetic circuit,* and, therefore, the magnetic circuit of the magnet shown in Fig. 90 is composed partly of iron and partly of air. From what has been said concerning the relative permeability of air and of iron, it will be obvious that the presence of such a long air path in the magnetic circuit will greatly reduce the number of lines of force that a given magnetizing force can set up. The presence of an air gap in a magnetic circuit has much the same effect on the total flow of lines of force as the presence of a piece of bad conductor in a circuit composed otherwise of good conductor, in the case of the flow of electric current.

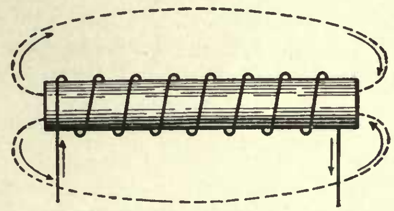


Fig. 90. Bar Electromagnet

Reluctance. As the property which opposes the flow of electric current in an electrical circuit is called *resistance,* so the property which opposes the flow of magnetic lines of force in a magnetic circuit is called *reluctance.* In the case of the electric circuit, the resistance is the reciprocal of the conductivity; in the case of the magnetic circuit, the reluctance is the reciprocal of the permeability. As in the case of an electrical circuit, the amount of flow of current is equal to the electromotive force divided by the resistance; so in a magnetic circuit, the magnetic flux is equal to the magnetizing force or magnetomotive force divided by the reluctance.

Types of Low-Reluctance Circuits. As the pull of an electromagnet upon its armature depends on the total number of lines of force passing from the core to the armature—that is, on the total flux—and as the total flux depends for a given magnetizing force on the reluctance of the magnetic circuit, it is obvious that the design of the electromagnetic circuit is of great importance in influencing the action of the magnet. Obviously, anything that will reduce the amount of air or other non-magnetic material that is in the magnetic circuit will tend to reduce the reluctance, and, therefore, to increase the total magnetization resulting from a given magnetizing force.

Horseshoe Form. One of the easiest and most common ways of reducing reluctance in a circuit is to bend the ordinary bar electromagnet into horseshoe form. In order to make clear the direction of current flow, attention is called to Fig. 91. This is intended to represent a simple bar of iron with a winding of one direction throughout its length. The gap in the middle of the bar, which divides the winding into two parts, is intended merely to mark the fact that the winding need not cover the whole length of the bar and still will be able to magnetize the bar when the current passes through it.

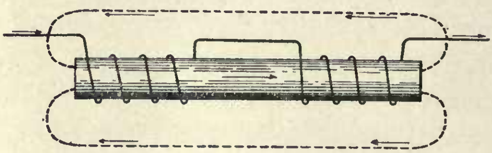


Fig. 91. Bar Electromagnet

In Fig. 92 a similar bar is shown with similar winding upon it, but bent into U-form, exactly as if it had been grasped in the hand and bent without further change. The magnetic polarity of the two ends of the bar remain the same as before for the same direction of current, and it is obvious that the portion of the magnetic circuit which extends through air has been very greatly shortened by the bending. As a result, the magnetic reluctance of the circuit has been greatly decreased and the strength of the magnet correspondingly increased.

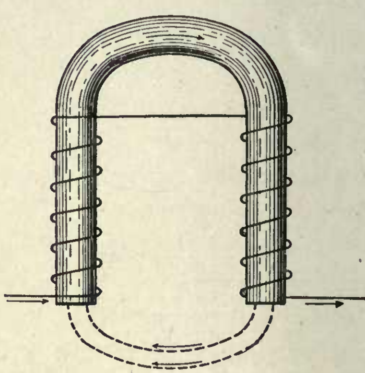


Fig. 92. Horseshoe Electromagnet

If the armature of the electromagnet shown in Fig. 92 is long enough to extend entirely across the air gap from the south to the north pole, then the air gap in the magnetic circuit is still further shortened, and is now represented only by the small gap between the ends of the armature and the ends of the core. Such a magnet, with an armature closely approaching the poles, is called a *closed-circuit magnet*, since

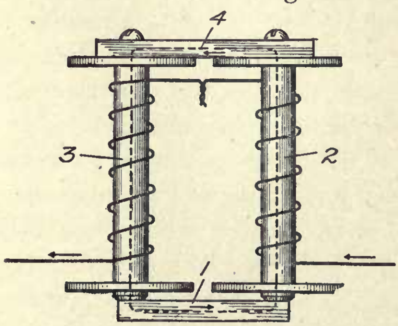


Fig. 93. Horseshoe Electromagnet

the only gap in the iron of the magnetic circuit is that across which the magnet pulls in attracting its armature.

In Fig. 93 is shown the electrical and magnetic counterpart of Fig. 92. The fact that the magnetic circuit is not a single iron bar but is made up of two cores and one backpiece rigidly secured together, has no bearing upon the principle, but only shows that a modification of construction is possible. In the construction of Fig. 93 the armature *1* is shown as being pulled directly against the two cores *2* and *3*, these two cores being joined by a yoke *4*, which, like the armature and the core, is of magnetic material. The path of the lines of force is indicated by dotted lines. This is a very important form of electromagnet and is largely used in telephony.

Iron-Clad Form. Another way of forming a closed-circuit magnet that is widely used in telephony is to enclose the helix or winding in a shell of magnetic material which joins the core at one end. This construction results in what is known as the *tubular* or *iron-clad* electromagnet, which is shown in section and in end view in Fig. 94. In this the core *1* is a straight bar of iron and it lies centrally within a cylindrical shell *2*, also of iron. The bar is usually held in place within the shell by a screw, as shown. The lines of force set up in the core by the current flowing through the coil, pass to the center of the bottom of the iron shell and thence return through the metal of the shell, through the air gap between the edges of the shell and the armature, and then concentrate at the center of the armature and pass back to the end of the core. This is a highly efficient form of closed-circuit magnet, since the magnetic circuit is of low reluctance.

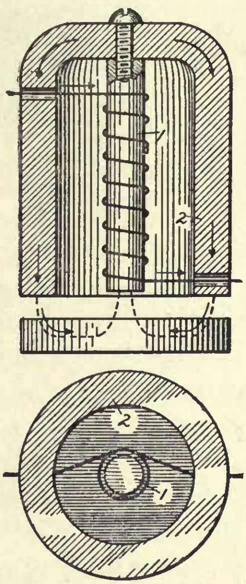


Fig. 94. Iron-Clad Electromagnet

Such forms of magnets are frequently used where it is necessary to mount a large number of them closely together and where it is desired that the current flowing in one magnet shall produce no inductive effect in the coils of the adjacent magnets. The reason why mutual induction between adjacent magnets is obviated in the case of the iron-clad or tubular magnet is that practically all stray field is eliminated, since the return path for the magnetic lines is so completely provided for by the presence of the iron shell.

Special Horseshoe Form. In Fig. 95 is shown a type of relay commonly employed in telephone circuits. The purpose of illustrating it in this chapter is not to discuss relays, but rather to show an adaptation of an electromagnet wherein low reluctance of the magnetic circuit is secured by providing a return leg for the magnetic lines developed in the core, thus forming in effect a horseshoe magnet with a winding on one of its limbs only. To the end of the core *1* there is secured an L-shaped piece of soft iron *2*. This extends upwardly and then forwardly throughout the entire length of the magnet core. An L-shaped armature *3* rests on the front edge

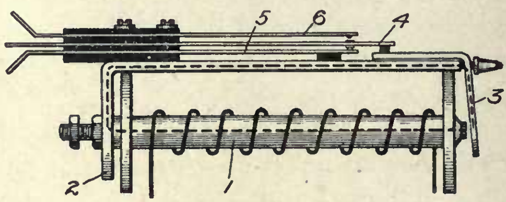


Fig. 95. Electromagnet of Relay

of the piece *2* so that a slight rocking motion will be permitted on the "knife-edge" bearing thus afforded. It is seen from the dotted lines that the magnetic circuit is almost a closed one. The only gap is that between the lower end of the armature *3* and the front end of the core. When the coil is energized, this gap is closed by the attraction of the armature. As a result, the rearwardly projecting end of the armature *3* is raised and this raises the spring *4* and causes it to break the normally existing contact with the spring *5* and to establish another contact with the spring *6*. Thus the energy developed within the coil of the magnet is made to move certain parts which in turn operate the switching devices to produce changes in electrical circuits. These relays and other adaptations of the electromagnet will be discussed more fully later on.

There are almost numberless forms of electromagnets, but we have illustrated here examples of the principal types employed in telephony, and the modifications of these types will be readily understood in view of the general principles laid down.

Direction of Armature Motion. It may be said in general that the armature of an electromagnet always moves or tends to move, when the coil is energized, in such a way as to reduce the reluctance of the magnetic circuit through the coil. Thus, in all of the forms of electromagnets discussed, the armature, when attracted, moves in such a direction as to shorten the air gap and to introduce the iron of the armature as much as possible into the path of the magnetic lines, thus reducing the reluctance. In the case of a solenoid type of electromagnet, or the coil and plunger type, which is a better name than solenoid, the coil, when energized, acts in effect to suck the iron core or plunger within itself so as to include more and more of the iron within the most densely occupied portion of the magnetic circuit.

Differential Electromagnet. Frequently in telephony, the electromagnets are provided with more than one winding. One purpose

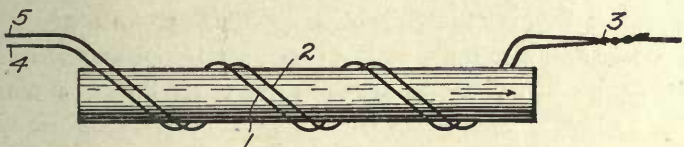


Fig. 96. Parallel Differential Electromagnet

of the double-wound electromagnet is to produce the so-called differential action between the two windings, *i. e.*, making one of the windings develop magnetization in the opposite direction from that of the other, so that the two will neutralize each other, or at least exert different and opposite influences. The principle of the differential electromagnet may be illustrated in connection with Fig. 96. Here two wires *1* and *2* are shown wrapped in the same direction about an iron core, the ends of the wire being joined together at *3*. Obviously, if one of these windings only is employed and a current sent through it, as by connecting the terminals of a battery with the points *4* and *3*, for instance, the core will be magnetized as in an ordinary magnet. Likewise, the core will be energized if a current be sent from *5* to *3*. Assuming that the two windings are of equal resistance and number of turns, the effects so produced, when either the coil *1* or the coil *2* is energized, will be equal. If the battery be connected between the terminals *4* and *5* with the positive pole, say, at *5*, then the current will proceed through the winding *2* and tend to generate magnetism in the core in the direction of the arrow. After traversing the winding *2,* however, it will then begin to traverse the other winding *1* and will pass around the core in the opposite direction throughout the length of that winding. This will tend to set up magnetism in the core in the opposite direction to that indicated by the arrow. Since the two currents are equal and also the number of turns in each winding, it is obvious that the two magnetizing influences will be exactly equal and opposite and no magnetic effect will be produced. Such a winding, as is shown in Fig. 96, where the two wires are laid on side by side, is called a *parallel differential winding.*

Another way of winding magnets differentially is to put one winding on one end of the core and the other winding on the other end of the core and connect these so as to cause the currents through them to flow around the core in opposite directions. Such a construction is shown in Fig. 97 and is called a *tandem differential winding.* The tandem arrangement, while often good enough for practical purposes, cannot result in the complete neutralization of magnetic effect. This is true because of the leakage of some of the lines of force from

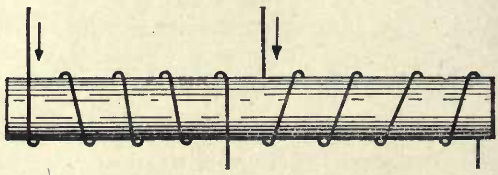


Fig. 97. Tandem Differential Electromagnet

intermediate points in the length of the core through the air, resulting in some of the lines passing through more of the turns of one coil than of the other. Complete neutralization can only be attained by first twisting the two wires together with a uniform lay and then winding them simultaneously on the core.

Mechanical Details. We will now consider the actual mechanical construction of the electromagnet. This is a very important feature of telephone work, because, not only must the proper electrical and magnetic effects be produced, but also the whole structure of the magnet must be such that it will not easily get out of order and not be affected by moisture, heat, careless handling, or other adverse conditions.

The most usual form of magnet construction employed in telephony is shown in Fig. 98. On the core, which is of soft Norway iron, usually cylindrical in form, are forced two washers of either fiber or hard rubber. Fiber is ordinarily to be preferred because it is tougher and less liable to breakage. Around the core, between the two heads, are then wrapped several layers of paper or specially prepared cloth in order that the wire forming the winding may be thoroughly insulated from the core. One end of the wire is then passed through a hole in one of the spool heads or washers, near the core, and the wire is then wound on in layers. Sometimes a thickness of paper is placed around each layer of wire in order to further guard against the breaking down of the insulation between layers. When the last layer is wound on, the end of the wire is passed out through a hole in the head, thus leaving both ends projecting.

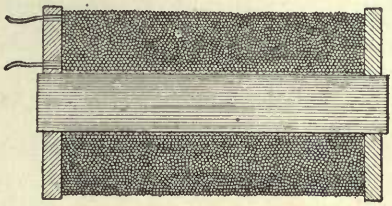


Fig. 98. Construction of Electromagnet

Magnet Wire. The wire used in winding magnets is, of course, an important part of the electromagnet. It is always necessary that the adjacent turns of the wire be insulated from each other so that the current shall be forced to pass around the core through all the length of wire in each turn rather than allowing it to take the shorter and easier path from one turn to the next, as would be the case if the turns were not insulated. For this purpose the wire is usually covered with a coating of some insulating material. There are, however, methods of winding magnet coils with bare wire and taking care of the insulation between the turns in another way, as will be pointed out.

Insulated wire for the purpose of winding magnet coils is termed *magnet wire*. Copper is the material almost universally employed for the conductor. Its high conductivity, great ductility, and low cost are the factors which make it superior to all other metals. However, in special cases, where exceedingly high conductivity is required with a limited winding space, silver wire is sometimes employed, and on the other hand, where very high resistance is desired within a limited winding space, either iron or German silver or some other high-resistance alloy is used.

Wire Gauges. Wire for electrical purposes is drawn to a number of different standard gauges. Each of the so-called wire gauges consists of a series of graded sizes of wire, ranging from approximately one-half an inch in diameter down to about the fineness of a lady's hair. In certain branches of telephone work, such as line construction, the existence of the several wire gauges or standards is very

TABLE III

Copper Wire Table

Giving weights, lengths, and resistances of wire @ 68° F., of Matthiessen's Standard Conductivity.

A. W. G. B. & S.	Diameter Mils	Area Circular Mils	Resistance		Length		Weight	
			Ohms per Pound	Ohms per Foot	Feet per Pound	Feet per Ohm	Pounds per Foot	Pounds per Ohm
0000	460.	211,600.	0.00007639	0.0000489	1.561	20,440.	0.6405	13,090.
000	409.6	167,800.	0.0001215	0.0000617	1.969	16,210.	0.5080	8,232.
00	364.8	133,100.	0.0001931	0.0000778	2.482	12,850.	0.4028	5,177.
0	324.9	105,500.	0.0003071	0.0000981	3.130	10,190.	0.3195	3,256.
1	289.3	83,690.	0.0004883	0.0001237	3.947	8,083.	0.2533	2,048.
2	257.6	66,370.	0.0007765	0.0001560	4.977	6,410.	0.2009	1,288.
3	229.4	52,630.	0.001235	0.0001967	6.276	5,084.	0.1593	810.0
4	204.3	41,740.	0.001963	0.0002480	7.914	4,031.	0.1264	509.4
5	181.9	33,100.	0.003122	0.0003128	9.980	3,197.	0.1002	320.4
6	162.0	26,250.	0.004963	0.0003944	12.58	2,535.	0.07946	201.5
7	144.3	20,820.	0.007892	0.0004973	15.87	2,011.	0.06302	126.7
8	128.5	16,510.	0.01255	0.0006271	20.01	1,595.	0.04998	79.69
9	114.4	13,090.	0.01995	0.0007908	25.23	1,265.	0.03963	50.12
10	101.9	10,380.	0.03173	0.0009972	31.82	1,003.	0.03143	31.52
11	90.74	8,234.	0.05045	0.001257	40.12	795.3	0.02493	19.82
12	80.81	6,530.	0.08022	0.001586	50.59	630.7	0.01977	12.47
13	71.96	5,178.	0.1276	0.001999	63.79	500.1	0.01568	7.840
14	64.08	4,107.	0.2028	0.002521	80.44	396.6	0.01243	4.931
15	57.07	3,257.	0.3225	0.003179	101.4	314.5	0.009858	3.101
16	50.82	2,583.	0.5128	0.004009	127.9	249.4	0.007818	1.950
17	45.26	2,048.	0.8153	0.005055	161.3	197.8	0.006200	1.226
18	40.30	1,624.	1.296	0.006374	203.4	156.9	0.004917	0.7713
19	35.89	1,288.	2.061	0.008038	256.5	124.4	0.003899	0.4851
20	31.96	1,022.	3.278	0.01014	323.4	98.66	0.003092	0.3051
21	28.46	810.1	5.212	0.01278	407.8	78.24	0.002452	0.1919
22	25.35	642.4	8.287	0.01612	514.2	62.05	0.001945	0.1207
23	22.57	509.5	13.18	0.02032	648.4	49.21	0.001542	0.07589
24	20.10	404.0	20.95	0.02563	817.6	39.02	0.001223	0.04773
25	17.90	320.4	33.32	0.03231	1,031.	30.95	0.0009699	0.03002
26	15.94	254.1	52.97	0.04075	1,300.	24.54	0.0007692	0.1187
27	14.2	201.5	84.23	0.05138	1,639.	19.46	0.0006100	0.01888
28	12.64	159.8	133.9	0.06479	2,067.	15.43	0.0004837	0.007466
29	11.26	126.7	213.0	0.08170	2,607.	12.24	0.0003836	0.004696
30	10.03	100.5	338.6	0.1030	3,287.	9.707	0.0003042	0.002953
31	8.928	79.70	538.4	0.1299	4,145.	7.698	0.0002413	0.001857
32	7.950	63.21	856.2	0.1638	5,227.	6.105	0.0001913	0.001168
33	7.080	50.13	1,361.	0.2066	6,591.	4.841	0.0001517	0.0007346
34	6.305	39.75	2,165.	0.2605	8,311.	3.839	0.0001203	0.0004620
35	5.615	31.52	3,441.	0.3284	10,480.	3.045	0.00009543	0.0002905
36	5.0	25.0	5,473.	0.4142	13,210.	2.414	0.00007568	0.0001827
37	4.453	19.83	8,702.	0.5222	16,660.	1.915	0.00006001	0.0001149
38	3.965	15.72	13,870.	0.6585	21,010.	1.519	0.00004759	0.00007210
39	3.531	12.47	22,000.	0.8304	26,500.	1.204	0.00003774	0.00004545
40	3.145	9.888	34,980.	1.047	33,410.	0.9550	0.00002993	0.00002858

likely to lead to confusion. Fortunately, however, so far as magnet wire is concerned, the so-called Brown and Sharpe, or American, wire gauge is almost universally employed in this country. The abbreviations for this gauge are B. & S. or A. W. G.

In the Brown and Sharpe gauge the sizes, beginning with the largest, are numbered 0000, 000, 00, 0, 1, 2, and so on up to 40. Sizes larger than about No. 16 B. & S. gauge are seldom used as magnet wire in telephony, but for the purpose of making the list complete, Table III is given, including all of the sizes of the B. & S. gauge.

In Table III there is given for each gauge number the diameter of the wire in mils (thousandths of an inch); the cross-sectional area in circular mils (a unit area equal to that of a circle having a diameter of one one-thousandth of an inch); the resistance of the wire in various units of length and weight; the length of the wire in terms of resistance and of weight; and the weight of the wire in terms of its length and resistance.

It is to be understood that in Table III the wire referred to is bare wire and is of pure copper. It is not commercially practicable to use absolutely pure copper, and the ordinary magnet wire has a conductivity equal to about 98 per cent of that of pure copper. The figures given in this table are sufficiently accurate for all ordinary practical purposes.

Silk and Cotton Insulation. The insulating material usually employed for covering magnet wire is of silk or cotton. Of these, silk is by far the better material for all ordinary purposes, since it has a much higher insulating property than cotton, and is very much thinner. Cotton, however, is largely employed, particularly in the larger sizes of magnet wire. Both of these materials possess the disadvantage of being hygroscopic, that is, of readily absorbing moisture. This disadvantage is overcome in many cases by saturating the coil after it is wound in some melted insulating compound, such as wax or varnish or asphaltum, which will solidify on cooling. Where the coils are to be so saturated the best practice is to place them in a vacuum chamber and exhaust the air, after which the hot insulating compound is admitted and is thus drawn into the innermost recesses of the winding space.

Silk-insulated wire, as regularly produced, has either one or two layers of silk. This is referred to commercially as single silk wire or as double silk wire. The single silk has a single layer of silk fibers wrapped about it, while the double silk has a double layer, the two layers being put on in reverse direction. The same holds true of cotton insulated wire. Frequently, also, there is a combination of the two, consisting of a single or a double wrapping of silk next to the wire with an outer wrapping of cotton. Where this is done the cotton serves principally as a mechanical protection for the silk, the principal insulating properties residing in the silk.

Enamel. A later development in the insulation of magnet wire has resulted in the so-called enamel wire. In this, instead of coating the wire with some fibrous material such as silk or cotton, the wire is heated and run through a bath of fluid insulating material or liquid enamel, which adheres to the wire in a very thin coating. The wire is then run through baking ovens, so that the enamel is baked on. This process is repeated several times so that a number of these thin layers of the enamel are laid on and baked in succession.

The characteristics sought in good enamel insulation for magnet wire may be thus briefly set forth: It is desirable for the insulation to possess the highest insulating qualities; to have a glossy, flawless surface; to be hard without being brittle; to adhere tenaciously and stand all reasonable handling without cracking or flaking; to have a coefficient of elasticity greater than the wire itself; to withstand high temperatures; to be moisture-proof and inert to corrosive agencies; and not to "dry out" or become brittle over a long period of time.

Space Utilization. The utilization of the winding space in an electromagnet is an important factor in design, since obviously the copper or other conductor is the only part of the winding that is effective in setting up magnetizing force. The space occupied by the insulation is, in this sense, waste space. An ideally perfect winding may be conceived as one in which the space is all occupied by wire; and this would necessarily involve the conception of wire of square cross-section and insulation of infinite thinness. In such a winding there would be no waste of space and a maximum amount of metal employed as a conductor. Of course, such a condition is not possible to attain and in practice some insulating material must be introduced between the layers of wire and between the adjacent convolutions of wire. The ratio of the space occupied by the conductor to the total space occupied by the winding, that is, by the conductor and the insulation, is called the *coefficient of space utilization of the coil.* For the ideal coil just conceived the coefficient of space utilization would be 1. Ordinarily the coefficient of space utilization is greater for coarse wire than for fine wire, since obviously the ratio of the diameter of the wire to the thickness of the insulation increases as the size of the wire grows larger.

The chief advantage of enamel insulation for magnet wire is its thinness, and the high coefficient of space utilization which may be secured by its use. In good enamel wire the insulation will average about one-quarter the thickness of the standard single silk insulation, and the dielectric strength is equal or greater. Where economy of winding space is desirable the advantages of this may readily be seen. For instance, in a given coil wound with No. 36 single silk wire about one-half of the winding space is taken up with the insulation, whereas when the same coil is wound with No. 36 enameled wire only about one-fifth of the winding space is taken up by the insulation. Thus the coefficient of space utilization is increased from .50 to .80. The practical result of this is that, in the case of any given winding space where No. 36 wire is used, about 60 per cent more turns can be put on with enameled wire than with single silk insulation, and of course this ratio greatly increases when the comparison is made with double silk insulation or with cotton insulation. Again, where it is desired to reduce the winding space and keep the same number of turns, an equal number of turns may be had with a corresponding reduction of winding space where enameled wire is used in place of silk or cotton.

In the matter of heat-resisting properties the enameled wire possesses a great advantage over silk and cotton. Cotton or silk insulation will char at about 260° Fahrenheit, while good enameled wire will stand 400° to 500° Fahrenheit without deterioration of the insulation. It is in the matter of liability to injury in rough or careless handling, or in winding coils having irregular shapes, that enamel wire is decidedly inferior to silk or cotton-covered wire. It is likely to be damaged if it is allowed to strike against the sharp corners of the magnet spool during winding, or run over the edge of a hard surface while it is being fed on to the spool. Coils having other than round cores, or having sharp corners on their spool heads, should not ordinarily be wound with enamel wire.

The dielectric strength of enamel insulation is much greater than that of either silk or cotton insulation of equal thickness. This is a distinct advantage and frequently a combination of the two kinds of insulation results in a superior wire. If wire insulated with enamel is given a single wrapping of silk or of cotton, the insulating and dielectric properties of the enamel is secured, while the presence of the silk and cotton affords not only an additional safeguard against bare spots in the enamel but also a certain degree of mechanical protection to the enamel.

Winding Methods. In winding a coil, the spool, after being properly prepared, is placed upon a spindle which may be made to revolve rapidly. Ordinarily the wire is guided on by hand; sometimes, however, machinery is used, the wire being run over a tool which moves to and fro along the length of the spool, just fast enough to lay the wire on at the proper rate. The movement of this tool is much the same as that of the tool in a screw cutting lathe.

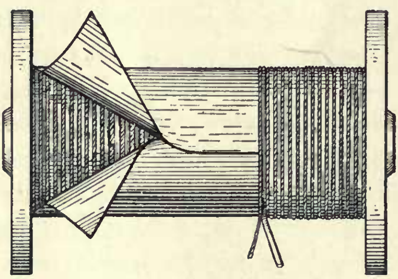


Fig. 99 Electromagnet with Bare Wire

Unless high voltages are to be encountered, it is ordinarily not necessary to separate the layers of wire with paper, in the case of silk- or cotton-insulated magnet wire; although where especially high insulation resistance is needed this is often done. It is necessary to separate the successive layers of a magnet that is wound with enamel wire, by sheets of paper or thin oiled cloth.

In Fig. 99 is shown a method, that has been used with some success, of winding magnets with bare wire. In this the various adjacent turns are separated from each other by a fine thread of silk or cotton wound on beside the wire. Each layer of wire and thread as it is placed on the core is completely insulated from the subsequent layer by a layer of paper. This is essentially a machine-wound coil, and machines for winding it have been so perfected that several coils are wound simultaneously, the paper being fed in automatically at the end of each layer.

Another method of winding the bare wire omits the silk thread and depends on the permanent positioning of the wire as it is placed on the coil, due to the slight sinking into the layer of paper on which it is wound. In this case the feed of the wire at each turn of the spool is slightly greater than the diameter of the wire, so that a small distance will be left between each pair of adjacent turns.

Upon the completion of the winding of a coil, regardless of what method is used, it is customary to place a layer of bookbinders' cloth over the coil so as to afford a certain mechanical protection for the insulated wire.

Winding Terminals. The matter of bringing out the terminal ends of the winding is one that has received a great deal of attention in the construction of electromagnets and coils for various purposes. Where the winding is of fine wire, it is always well to reinforce its ends by a short piece of larger wire. Where this is done the larger wire is given several turns around the body of the coil, so that the finer wire with which it connects may be relieved of all strain which may be exerted upon it from the protruding ends of the wire. Great care is necessary in the bringing out of the inner terminal—*i. e.*, the terminal which connects with the inner layer—that the terminal wire shall not come in contact with any of the subsequent layers that are wound on.

Where economy of space is necessary, a convenient method of terminating the winding of the coil consists in fastening rigid terminals to the spool head. This, in the case of a fiber spool head, may be done by driving heavy metal terminals into the fiber. The connections of the two wires leading from the winding are then made with these heavy rigid terminals by means of solder. A coil having such terminals is shown in its finished condition in Fig. 100.

Fig. 100. Electromagnet with Terminals

Winding Data. The two things principally affecting the manufacture of electromagnets for telephone purposes are *the number of turns in a winding* and *the resistance of the wound wire.* The latter governs the amount of current which may flow through the coil with a given difference of potential at its end, while the former controls the amount of magnetism produced in the core by the current flow-

TABLE IV

Winding Data for Insulated Wires—Silk and Cotton Covering

A.W.G. B. & S.	Diameter Mils	Area Circular Mils	Diameter over Insulation: Single Cotton	Diameter over Insulation: Double Cotton	Diameter over Insulation: Single Silk	Diameter over Insulation: Double Silk	Turns per Linear Inch: Single Cotton	Turns per Linear Inch: Double Cotton	Turns per Linear Inch: Single Silk	Turns per Linear Inch: Double Silk	Turns per Square Inch: Single Cotton	Turns per Square Inch: Double Cotton	Turns per Square Inch: Single Silk	Turns per Square Inch: Double Silk	Ohms per Cubic Inch: Single Cotton	Ohms per Cubic Inch: Double Cotton	Ohms per Cubic Inch: Single Silk
20	31.961	1021.20	37.861	42.161	34.261	36.161	25.7	22.5	27.70	26.22	660.5	506.3	767.3	687.5	.646	.533	8.01
21	28.462	810.10	34.362	38.662	30.762	32.662	28.3	24.5	30.97	29.07	800.9	600.2	959.1	845.0	.981	.795	1.261
22	25.347	642.70	31.247	35.547	27.647	29.547	31.0	26.7	34.39	32.11	961.0	712.9	1182.7	1031.0	1.502	1.188	1.956
23	22.571	509.45	28.471	32.771	24.871	26.771	34.4	28.97	38.19	35.53	1183.0	839.2	1458.5	1262.4	2.359	1.772	3.049
24	20.100	404.01	26.000	30.300	22.401	24.300	36.9	31.35	42.37	39.14	1321.6	982.8	1795.2	1532.0	3.528	2.595	4.739
25	17.900	320.40	23.800	28.100	20.200	22.100	38.0	33.92	47.02	42.94	1444.0	1150.8	2210.9	1843.8	5.831	3.802	7.489
26	15.940	254.01	21.840	26.140	18.240	20.140	42.0	36.29	52.06	46.81	1764.0	1317.0	2710.3	2191.2	6.941	5.552	9.031
27	14.195	201.50	20.095	24.395	16.495	18.395	48.0	38.95	57.67	51.59	2304.0	1517.2	3326.0	2661.6	10.814	8.078	13.92
28	12.641	159.79	18.541	22.841	14.941	16.841	53.0	41.61	63.36	56.43	2809.0	1731.0	4014.5	3184.5	17.617	11.54	26.86
29	11.257	126.72	17.157	21.457	13.557	15.457	56.5	44.27	70.11	61.56	3192.3	1959.9	4915.5	3789.8	25.500	16.47	41.29
30	10.025	100.50	15.925	20.225	12.325	14.225	59.66	46.93	77.14	66.79	3559.2	2202.5	5950.2	4461.0	34.800	23.43	62.98
31	8.928	79.71	14.828	19.128	11.228	13.128	64.125	49.78	84.64	72.39	4112.2	2478.0	7164.0	5240.0	48.5	32.83	95.70
32	7.950	63.20	13.850	18.150	10.250	12.150	68.600	52.34	92.72	78.19	4692.5	2739.5	8597.5	6114.0	73.8	46.19	144.70
33	7.080	50.13	12.980	17.280	9.380	11.280	73.050	55.10	101.65	84.17	5333.5	3036.1	10332.0	7085.0	104.5	64.30	217.8
34	6.304	39.74	12.204	16.504	8.504	10.504	77.900	57.57	112.11	90.44	6068.5	3314.2	12570.0	8179.5	151.4	70.58	342.1
35	5.614	31.52	11.514	15.814	7.914	9.814	82.600	60.04	119.7	96.90	6773.3	3605.0	14327.0	9389.5	202.0	125.9	489.0
36	5.000	25.00	10.900	15.200	7.300	9.200	87.100	62.51	130.15	103.55	7586.5	3907.5	16940.0	10722.0	298.8	166.3	721.1
37	4.453	19.83	10.353	14.653	6.753	8.653	91.870	64.70	140.6	110.20	8440.0	4186.1	19770.0	12145.0	418.0	225.6	1062.0
38	3.965	15.72	9.865	14.165	6.265	8.165	95.000	66.80	151.05	116.85	9025.0	4462.2	22820.0	13655.0	567.0	305.5	1557.0
39	3.531	12.47	9.431	13.731	5.831	7.731	100.700	68.80	163.04	122.55	10140.5	4733.6	26700.0	15018.0	811.0	409.8	2266.0
40	3.144	9.89	9.044	13.344	5.344	7.344	106.000	71.20	177.65	129.20	11236.0	5069.8	31559.0	16692.0	1113.0	545.5	3400.0

ing. While a coil is being wound, it is a simple matter to count the turns by any simple form of revolution counter. When the coil has been completed it is a simple matter to measure its resistance. But it is not so simple to determine in advance how many turns of a given size wire may be placed on a given spool, and still less simple to know what the resistance of the wire on that spool will be when the desired turns shall have been wound.

If the length and the depth of the winding space of the coil as well as the diameter of the core are known, it is not difficult to determine how much bare copper wire of a given size may be wound on it, but it is more difficult to know these facts concerning copper wire which has been covered with cotton or silk. Yet something may be done, and tables have been prepared for standard wire sizes with definite thicknesses of silk and cotton insulation. As a result of facts collected from a large number of actually wound coils, the number of turns per linear inch and per square inch of B. & S. gauge wires from No. 20 to No. 40 have been tabulated, and these, supplemented by a tabulation of the number of ohms per cubic inch of winding space for wires of three different kinds of insulation, are given in Table IV.

Bearing in mind that the calculations of Table IV are all based upon the "diameter over insulation," which it states at the outset for each of four different kinds of covering, it is evident what is meant by "turns per linear inch." The columns referring to "turns per square inch" mean the number of turns, the ends of which would be exposed in one square inch if the wound coil were cut in a plane passing through the axis of the core. Knowing the distance between the head, and the depth to which the coil is to be wound, it is easy to select a size of wire which will give the required number of turns in the provided space. It is to be noted that the depth of winding space is one-half of the difference between the core diameter and the complete diameter of the wound coil. The resistance of the entire volume of wound wire may be determined in advance by knowing the total cubic contents of the winding space and multiplying this by the ohms per cubic inch of the selected wire; that is, one must multiply in inches the distance between the heads of the spool by the difference between the squares of the diameters of the core and the winding space, and this in turn by .7854. This result, times the ohms per cubic inch, as given in the table, gives the resistance of the winding.

There is a considerable variation in the method of applying silk insulation to the finer wires, and it is in the finer sizes that the errors, if any, pile up most rapidly. Yet the table throughout is based on data taken from many samples of actual coil winding by the present process of winding small coils. It should be said further that the table does not take into account the placing of any layers of paper between the successive layers of the wires. This table has been compared with many examples and has been used in calculating windings in advance, and is found to be as close an approximation as is afforded by any of the formulas on the subject, and with the further advantage that it is not so cumbersome to apply.

Winding Calculations. In experimental work, involving the winding of coils, it is frequently necessary to try one winding to determine its effect in a given circuit arrangement, and from the knowledge so gained to substitute another just fitted to the conditions. It is in such a substitution that the table is of most value. Assume a case in which are required a spool and core of a given size with a winding of, say No. 25 single silk-covered wire, of a resistance of 50 ohms. Assume also that the circuit regulations required that this spool should be rewound so as to have a resistance of, say 1,000 ohms. What size single silk-covered wire shall be used? Manifestly, the winding space remains the same, or nearly so. The resistance is to be increased from 50 to 1,000 ohms, or twenty times its first value. Therefore, the wire to be used must show in the table twenty times as many ohms per cubic inch as are shown in No. 25, the known first size. This amount would be twenty times 7.489, which is 149.8, but there is no size giving this exact resistance. No. 32, however, is very nearly of that resistance and if wound to exactly the same depth would give about 970 ohms. A few turns more would provide the additional thirty ohms.

Similarly, in a coil known to possess a certain number of turns, the table will give the size to be selected for rewinding to a greater or smaller number of turns. In this case, as in the case of substituting a winding of different resistance, it is unnecessary to measure and calculate upon the dimensions of the spool and core. Assume a spool wound with No. 30 double silk-covered wire, which requires to be wound with a size to double the number of turns. The exact size to do this would have 8922. turns per square inch and would be between No. 34 and No. 35. A choice of these two wires may be made, using an increased winding depth with the smaller wire and a shallower winding depth for the larger wire.

Impedance Coils. In telephony electromagnets frequently serve, as already stated, to perform other functions than the producing of motion by attracting or releasing their armatures. They are required to act as impedance coils to present a barrier to the passage of alternating or other rapidly fluctuating currents, and at the same time to allow the comparatively free passage of steady currents. Where it is desired that an electromagnet coil shall possess high impedance, it is usual to employ a laminated instead of a solid core. This is done by building up a core of suitable size by laying together thin sheets of soft iron, or by forming a bundle of soft iron wires. The use of laminated cores is for the purpose of preventing eddy currents, which, if allowed to flow, would not only be wasteful of energy but would also tend to defeat the desired high impedance. Sometimes in iron-clad impedance coils, the iron shell is slotted longitudinally to break up the flow of eddy currents in the shell.

Frequently electromagnetic coils have only the function of offering impedance, where no requirements exist for converting any part of the electric energy into mechanical work. Where this is the case, such coils are termed *impedance,* or *retardation,* or *choke coils,* since they are employed to impede or to retard or to choke back the flow of rapidly varying current. The distinction, therefore, between an impedance coil and the coil of an ordinary electromagnet is one of function, since structurally they may be the same, and the same principles of design and construction apply largely to each.

Number of Turns. It should be remembered that an impedance coil obstructs the passage of fluctuating current, not so much by ohmic resistance as by offering an opposing or counter-electromotive force. Other things being equal, the counter-electromotive force of self-induction increases directly as the number of turns on a coil and directly as the number of lines of force threading the coil, and this latter factor depends also on the reluctance of the magnetic circuit. Therefore, to secure high impedance we need many turns or low reluctance, or both. Often, owing to requirements for direct-current carrying capacity and limitations of space, a very large number of turns is not permissible, in which case sufficiently high impedance to such rapid fluctuations as those of voice currents may be had by employing a magnetic circuit of very low reluctance, usually a completely closed circuit.

Kind of Iron. An important factor in the design of impedance coils is the grade of iron used in the magnetic circuit. Obviously, it should be of the highest permeability and, furthermore, there should be ample cross-section of core to prevent even an approach to saturation. The iron should, if possible, be worked at that density of magnetization at which it has the highest permeability in order to obtain the maximum impedance effects.

Types. Open-Circuit:—Where very feeble currents are being dealt with, and particularly where there is no flow of direct current, an open magnetic circuit is much used. An impedance coil having an open magnetic circuit is shown in section in Fig. 101, Fig. 102 showing its external appearance and illustrating particularly the method of bringing out the terminals of the winding.

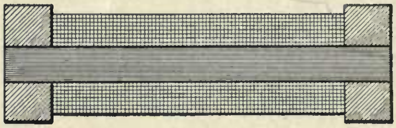


Fig 101. Section of Open-Circuit Impedance Coil

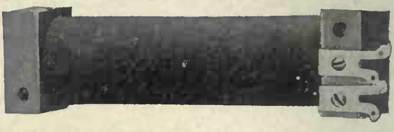


Fig. 102. Open-Circuit Impedance Coil

Closed-Circuit:—A type of retardation coil which is largely used in systems of simultaneous telegraphy and telephony, known as *composite systems*, is shown in Fig. 103. In the construction of this coil the core is made of a bundle of fine iron wires first bent into U-shape, and then after the coils are in place, the free ends of the core are brought together to form a closed magnetic circuit. The coils have a large number of turns of rather

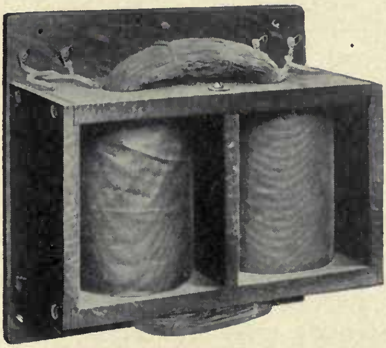


Fig. 103. Closed-Circuit Impedance Coil

coarse wire. The conditions surrounding the use of this coil are those which require very high impedance and rather large current-carrying capacity, and fortunately the added requirement, that it shall be placed in a very small space, does not exist.

Toroidal:—Another type of retardation coil, called the toroidal type due to the fact that its core is a torus formed by winding a continuous length of fine iron wire, is shown in diagram in Fig. 104. The two windings of this coil may be connected in series to form in effect a single winding, or it may be used as a "split-winding" coil, the two windings being in series but having some other element, such as a battery, connected between them in the circuit. Evidently such a coil, however connected, is well adapted for high impedance, on account of the low reluctance of its core.

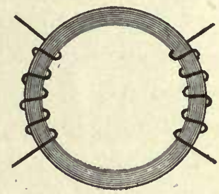


Fig. 104. Symbol of Toroidal Impedance Coil

This coil is usually mounted on a base-board, the coil being enclosed in a protecting iron case, as shown in Fig. 105. The terminal wires of both windings of each coil are brought out to terminal punchings on one end of the base-board to facilitate the making of the necessary circuit connections.

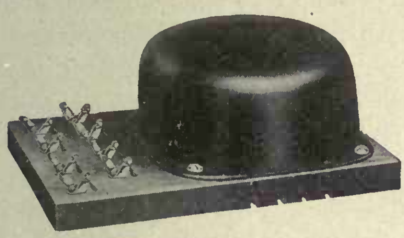


Fig. 105. Toroidal Impedance Coil

The usual diagrammatic symbol for an impedance coil is shown in Fig. 106. This is the same as for an ordinary bar magnet, except that the parallel lines through the core may be taken as indicating that the core is laminated, thus conveying the idea of high impedance. The symbol of Fig. 104 is a good one for the toroidal type of impedance coil.

Fig. 106. Symbol of Impedance Coil

Induction Coil. An induction coil consists of two or more windings of wire interlinked by a common magnetic circuit. In an induction coil having two windings, any change in the strength of the current flowing in one of the windings, called the *primary*, will cause corresponding changes in the magnetic flux threading the magnetic circuit, and, therefore, changes in flux through the other winding, called the *secondary*. This, by the laws of electromagnetic induction, will produce corresponding electromotive forces in the secondary winding and, therefore, corresponding currents in that winding if its circuit be closed.

Current and Voltage Ratios. In a well-designed induction coil the energy in the secondary, *i. e.*, the induced current, is for all practical purposes equal to that of the primary current, yet the values of the voltage and the amperage of the induced current may vary widely from the values of the voltage and the amperage of the primary current. With simple periodic currents, such as the commercial alternating lighting currents, the ratio between the voltage in the primary and that in the secondary will be equal to the ratio of the number of turns in the primary to the number of turns in the secondary. Since the energy in the two circuits will be practically the same, it follows *that the ratio between the current in the primary and that in the secondary will be equal to the ratio of the number of turns in the secondary to the number of turns in the primary.* In telephony, where the currents are not simple periodic currents, and where the variations in current strength take place at different rates, such a law as that just stated does not hold for all cases; but it may be stated in general that *the induced currents will be of higher voltage and smaller current strength than those of the primary in all coils where the secondary winding has a greater number of turns than the primary*, and *vice versâ*.

Functions. The function of the induction coil in telephony is, therefore, mainly one of transformation, that is, either of stepping up the voltage of a current, or in other cases stepping it down. The induction coil, however, does serve another purpose in cases where no change in voltage and current strength is desired, that is, it serves as a means for electrically separating two circuits so far as any conductive relation exists, and yet of allowing the free transmission by induction from one of these circuits to the other. This is a function that in telephony is scarcely of less importance than the purely transforming function.

Design. Induction coils, as employed in telephony, may be divided into two general types: first, those having an open magnetic circuit; and, second, those having a closed magnetic circuit. In the design of either type it is important that the core should be thoroughly laminated, and this is done usually by forming it of a bundle of soft Swedish or Norway iron wire about .02 of an inch in diameter. The diameter and the length of the coil, and the relation between the number of turns in the primary and in the secondary, and the mechanical construction of the coil, are all matters which are subject to very wide variation in practice. While the proper relationship of these factors is of great importance, yet they may not be readily determined except by actual experiment with various coils, owing to the extreme complexity of the action which takes place in them and to the difficulty of obtaining fundamental data as to the existing facts. It may be stated, therefore, that the design of induction coils is nearly always carried out by "cut-and-try" methods, bringing to bear, of course, such scientific and practical knowledge as the experimenter may possess.

Fig. 107. Induction Coil

Use and Advantage. The use and advantages of the induction coil in so-called local-battery telephone sets have already been explained in previous chapters. Such induction coils are nearly always of the open magnetic circuit type, consisting of a long, straight core comprised of a bundle of small annealed iron wires, on which is wound a primary of comparatively coarse wire and having a small

Fig. 108. Section of Induction Coil

number of turns, and over which is wound a secondary of comparatively fine wire and having a very much larger number of turns. A view of such a coil mounted on a base is shown in Fig. 107, and a sectional view of a similar coil is shown in Fig. 108. The method of bringing out the winding terminals is clearly indicated in this figure, the terminal wires *2* and *4* being those of the primary winding and *1* and *3* those of the secondary winding. It is customary to bring out these wires and attach them by solder to suitable terminal clips. In the case of the coil shown in Fig. 108 these clips are mounted on the wooden heads of the coil, while in the design shown in Fig. 107 they are mounted on the base, as is clearly indicated.

Repeating Coil. The so-called repeating coil used in telephony is really nothing but an induction coil. It is used in a variety of ways and usually has for its purpose the inductive association of two circuits that are conductively separated. Usually the repeating coil has a one to one ratio of turns, that is, there are the same number of turns in the primary as in the secondary. However, this is not always the case, since sometimes they are made to have an unequal number of turns, in which case they are called *step-up* or *step-down* repeating coils, according to whether the primary has a smaller or a greater number of turns than the secondary. Repeating coils are almost universally of the closed magnetic circuit type.

Ringing and Talking Considerations. Since repeating coils often serve to connect two telephones, it follows that it is sometimes necessary to ring through them as well as talk through them. By this is meant that it is necessary that the coil shall be so designed as to be capable of transforming the heavy ringing currents as well as the very much smaller telephone or voice currents. Ringing currents ordinarily have a frequency ranging from about 16 to 75 cycles per second, while voice currents have frequencies ranging from a few hundred up to perhaps ten thousand per second. Ordinarily, therefore, the best form of repeating coil for transforming voice currents is not the best for transforming the heavy ringing currents and *vice versâ.* If the comparatively heavy ringing currents alone were to be considered, the repeating coil might well be of heavy construction with a large amount of iron in its magnetic circuit. On the other hand, for carrying voice currents alone it is usually made with a small amount of iron and with small windings, in order to prevent waste of energy in the core, and to give a high degree of responsiveness with the least amount of distortion of wave form, so that the voice currents will retain as far as possible their original characteristics. When, therefore, a coil is required to carry both ringing and talking currents, a compromise must be effected.

Types. The form of repeating coil largely used for both ringing and talking through is shown in Fig. 109. This coil comprises a soft iron core made up of a bundle of wires about .02 inch in diameter, the ends of which are left of sufficient length to be bent back around the windings after they are in place and thus form a completely

Fig. 109. Repeating Coil

closed magnetic path for the core. The windings of this particular coil are four in number, and contain about 2,400 turns each, and have a resistance of about 60 ohms. In this coil, when connected for local battery work, the windings are connected in pairs in series, thus forming effectively two windings having about 120 ohms resistance each. The whole coil is enclosed in a protecting case of iron. The terminals are brought out to suitable clips on the wooden base, as shown. An external perspective view of this coil is shown in Fig. 110. By bringing out each terminal of each winding, eight

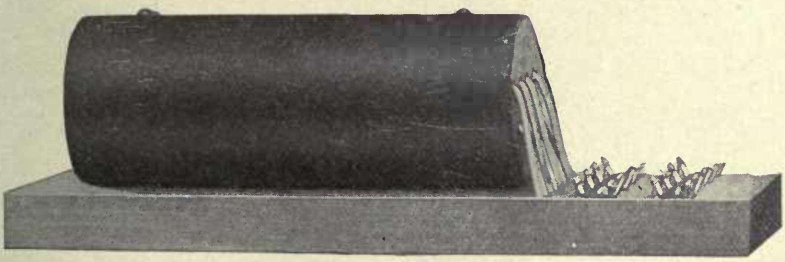


Fig. 110. Repeating Coil

in all, as shown in this figure, great latitude of connection is provided for, since the windings may be connected in circuit in any desirable way, either by connecting them together in pairs to form virtually a primary and a secondary, or, as is frequently the case, to split the primary and the secondary, connecting a battery between each pair of windings.

Fig. 111 illustrates in section a commercial type of coil designed for talking through only. This coil is provided with four windings of 1,357 turns each, and when used for local battery work the coils are connected in pairs in series, thus giving a resistance of about 190 ohms in each half of the repeating coil. The core of this coil consists of a bundle of soft iron wires, and the shell which forms the return path for the magnetic lines is of very soft sheet iron. This shell is drawn into cup shape and its open end is closed, after the coil is inserted, by the insertion of a soft iron head, as indicated. As in the case of the coil shown in Figs. 109 and 110, eight terminals are brought out on this coil, thus providing the necessary flexibility of connection.

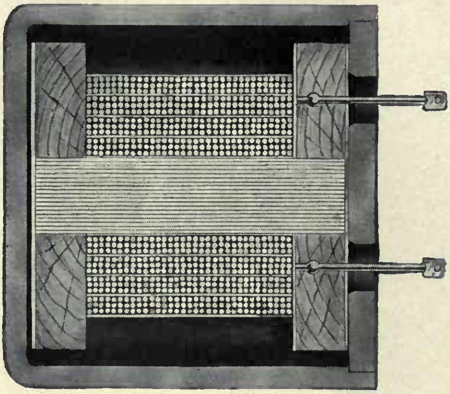


Fig. 111. Repeating Coil

Still another type of repeating coil is illustrated in diagram in Fig. 112, and in view in Fig. 113. This coil, like the impedance coil shown in Fig. 104, comprises a core made up of a bundle of soft iron wires wound into the form of a ring. It is usually provided with two primary windings placed opposite each other upon the core, and with two secondary windings, one over each primary. In practice these two primary windings are connected in one circuit and

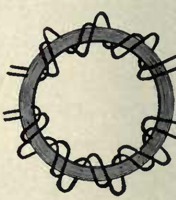


Fig. 112. Diagram of Toroidal Repeating Coil

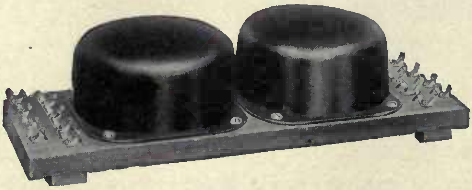


Fig. 113. Toroidal Repeating Coil

the two secondaries in another. This is the standard repeating coil now used by the Bell companies in their common-battery cord circuits.

Conventional Symbols. The ordinary symbol for the induction coil used in local battery work is shown in Fig. 114. This consists merely of a pair of parallel zig-zag lines. The primary winding is usually indicated by a heavy line having a fewer number of zig-zags, and the secondary by a finer line having a greater number of zig-zags. In this way the fact that the primary is of large wire and of comparatively few turns is indicated. This diagrammatic symbol may be modified to suit almost any conditions, and where a tertiary as well as a secondary winding is provided it may be shown by merely adding another zig-zag line.

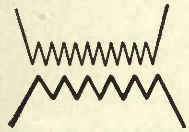


Fig. 114. Symbol of Induction Coil

The repeating coil is indicated symbolically in the two diagrams of Fig. 115. Where there is no necessity for indicating the internal connections of the coil, the symbol shown in the left of this figure is usually employed. Where, however, the coil consists of four windings rather than two and the method of connecting them is to be indicated, the symbol at the right hand is employed. In Fig. 116 another way of indicating a four-winding repeating coil or induction coil is shown. Sometimes such windings may be combined by connection to form merely a primary and a secondary winding, and in other cases the four windings all act separately, in which case one may be considered the primary and the others, respectively, the secondary, tertiary, and quaternary.

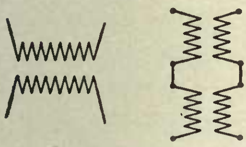


Fig. 115. Repeating-Coil Symbols

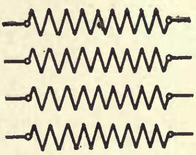


Fig. 116. Symbol of Four-Winding Repeating Coil

Where the toroidal type of repeating coil is employed, the diagram of Fig. 112, already referred to, is a good symbolic representation.

CHAPTER XI

NON-INDUCTIVE RESISTANCE DEVICES

It is often desired to introduce simple ohmic resistance into telephone circuits, in order to limit the current flow, or to create specific differences of potential at given points in the circuit.

Temperature Coefficient. The design or selection of resistance devices for various purposes frequently involves the consideration of the effect of temperature on the resistance of the conductor employed. The resistance of conductors is subject to change by changes in temperature. While nearly all metals show an increase, carbon shows a decrease in its resistance when heated.

The temperature coefficient of a conductor is a factor by which the resistance of the conductor at a given temperature must be multiplied in order to determine the change in resistance of that conductor brought about by a rise in temperature of one degree.

TABLE V

Temperature Coefficients

Pure Metals	Temperature Coefficients	
	Centigrade	Fahrenheit
Silver (annealed)	0.00400	0.00222
Copper (annealed)	0.00428	0.00242
Gold (99.9%)	0.00377	0.00210
Aluminum (99%)	0.00423	0.00235
Zinc	0.00406	0.00226
Platinum (annealed)	0.00247	0.00137
Iron	0.00625	0.00347
Nickel	0.0062	0.00345
Tin	0.00440	0.00245
Lead	0.00411	0.00228
Antimony	0.00389	0.00216
Mercury	0.00072	0.00044
Bismuth	0.00354	0.00197

Positive and Negative Coefficients. Those conductors, in which a rise in temperature produces an increase in resistance, are said to have positive temperature coefficients, while those in which a rise in temperature produces a lowering of resistance are said to have negative temperature coefficients.

The temperature coefficients of pure metals are always positive and for some of the more familiar metals, have values, according to Foster, as in Table V.

Iron, it will be noticed, has the highest temperature coefficient of all. Carbon, on the other hand, has a large negative coefficient, as proved by the fact that the filament of an ordinary incandescent lamp has nearly twice the resistance when cold as when heated to full candle-power.

Certain alloys have been produced which have very low temperature coefficients, and these are of value in producing resistance units which have practically the same resistance for all ordinary temperatures. Some of these alloys also have very high resistance as compared with copper and are of value in enabling one to obtain a high resistance in small space.

One of the most valuable resistance wires is of an alloy known as *German silver.* The so-called eighteen per cent alloy has approximately 18.3 times the resistance of copper and a temperature coefficient of .00016 per degree Fahrenheit. The thirty per cent alloy has approximately 28 times the resistance of copper and a temperature coefficient of .00024 per degree Fahrenheit.

For facilitating the design of resistance coils of German silver wire, Tables VI and VII are given, containing information as to length, resistance, and weight of the eighteen per cent and the thirty per cent alloys, respectively, for all sizes of wire smaller than No. 20 B. & S. gauge.

Special resistance alloys may be obtained having temperature coefficients as low as .000003 per degree Fahrenheit. Other alloys of nickel and steel are adapted for use where the wire must carry heavy currents and be raised to comparatively high temperatures thereby; for such use non-corrosive properties are specially to be desired. Such wire may be obtained having a resistance of about fifty times that of copper.

TABLE VI

18 Per Cent German Silver Wire

No. B. & S. Gauge	Diameter Inches	Weight Pounds per Foot	Length Feet per Pound	Resistance Ohms per Foot
21	.02846	.002389	418.6	.2333
22	.02535	.001894	527.9	.2941
23	.02257	.001502	665.8	.3710
24	.02010	.001191	839.5	.4678
25	.01790	.0009449	1058.	.5899
26	.01594	.0007493	1335.	.7438
27	.01419	.0005943	1683.	.9386
28	.01264	.0004711	2123.	1.183
29	.01126	.0003735	2677.	1.491
30	.01003	.0002962	3376.	1.879
31	.008928	.0002350	4255.	2.371
32	.007950	.0001864	5366.	2.990
33	.007080	.0001478	6766.	3.771
34	.006304	.0001172	8532.	4.756
35	.005614	.00009295	10758.	5.997
36	.005000	.00007369	13569.	7.560
37	.004453	.00005845	17108.	9.532
38	.003965	.00004636	21569.	12.02
39	.003531	.00003675	27209.	15.16
40	.003145	.00002917	34282.	19.11

Inductive Neutrality. Where the resistance unit is required to be strictly non-inductive, and is to be in the form of a coil, special designs must be employed to give the desired inductive neutrality.

Provisions Against Heating. In cases where a considerable amount of heat is to be generated in the resistance, due to the necessity of carrying large currents, special precautions must be taken as to the heat-resisting properties of the structure, and also as to the provision of sufficient radiating surface or its equivalent to provide for the dissipation of the heat generated.

Types. *Mica Card Unit.* One of the most common resistance coils used in practice is shown in Fig. 117. This comprises a coil of fine, bare German silver wire wound on a card of mica, the windings being so spaced that the loops are not in contact with each other. The winding is protected by two cards of mica and the whole is bound in place by metal strips, to which the ends of the winding

TABLE VII

30 Per Cent German Silver Wire

No. B. & S. Gauge	Diameter Inches	Weight Pounds per Foot	Length Feet per Pound	Resistance Ohms per Foot
21	.02846	.002405	415.8	.3581
22	.02535	.001907	524.4	.4513
23	.02257	.001512	661.3	.5693
24	.02010	.001199	833.9	.7178
25	.01790	.0009513	1051.	.9051
26	.01594	.0007544	1326.	1.141
27	.01419	.0005983	1671.	1.440
28	.01264	.0004743	2108.	1.815
29	.01126	.0003761	2659.	2.287
30	.01003	.0002982	3353.	2.883
31	.008928	.0002366	4227.	3.638
32	.007950	.0001876	5330.	4.588
33	.007080	.0001488	6721.	5.786
34	.006304	.0001180	8475.	7.297
35	.005614	.00009358	10686.	9.201
36	.005000	.00007419	13478.	11.60
37	.004453	.00005885	16994.	14.63
38	.003965	.00004668	21424.	18.45
39	.003531	.00003700	27026.	23.26
40	.003145	.00002937	34053.	29.32

are attached. Binding posts are provided on the extended portions of the terminals to assist in mounting the resistance on a supporting frame, and the posts terminate in soldering terminals by which the resistance is connected into the circuit.

Differentially-Wound Unit. Another type of resistance coil is that in which the winding is placed upon an insulating core of heat-resisting material and wound so as to overcome inductive effects. In order to accomplish this, the wire to be bound on the core is doubled back on itself at its middle portion to form two strands, and these are wound simultaneously on the core, thus forming two spirals of equal number of turns. The current in traversing the entire coil must flow through one spiral in one direction with relation to the core, and in the opposite direction in the other spiral, thereby nullifying the inductive effects of one spiral by those of the other. This is called a *non-inductive winding* and is in reality an example of differential winding.

Lamp Filament. An excellent type of non-inductive resistance is the ordinary carbon-filament incandescent lamp. This is used largely in the circuits of batteries, generators, and other sources of supply to prevent overload in case of short circuits on the line. These are cheap, durable, have large current-carrying capacities, and are not likely to set things afire when overheated. An additional advantage incident to their use for this purpose is that an overload on a circuit in which they are placed is visibly indicated by the glowing of the lamp

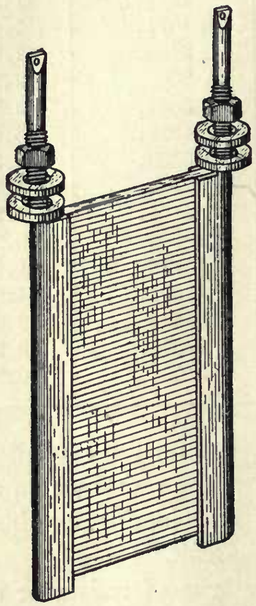


Fig. 117. Mica Card Resistance

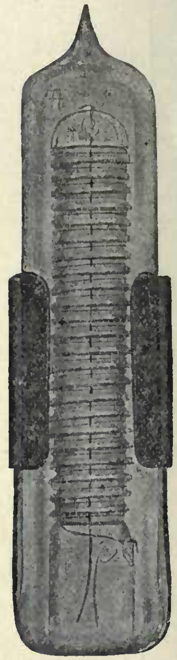


Fig. 118. Iron-Wire Ballast

Obviously, the carbon-filament incandescent lamp, when used as a resistance, has, on account of the negative temperature coefficient of carbon, the property of presenting the highest resistance to the circuit when carrying no current, and of presenting a lower and lower resistance as the current and consequent heating increases. For some conditions of practice this is not to be desired, and the opposite characteristic of presenting low resistance to small currents and comparatively high resistance to large currents would best meet the conditions of practice.

Iron-Wire Ballast. Claude D. Enochs took advantage of the very high positive temperature coefficient of iron to produce a resistance device having these characteristics. His arrangement possesses the compactness of the carbon-filament lamp and is shown in Fig. 118. The resistance element proper is an iron wire, wound on a central stem of glass, and this is included in an exhausted bulb so as to avoid oxidation. Such a resistance is comparatively low when cold, but when traversed by currents sufficient to heat it considerably will offer a very large increase of resistance to oppose the further increase of current. In a sense, it is a self-adjusting resistance, tending towards the equalization of the flow of current in the circuit in which it is placed.

CHAPTER XII

CONDENSERS

Charge. A conducting body insulated from all other bodies will receive and hold a certain amount of electricity (a charge), if subjected to an electrical potential. Thus, referring to Fig. 119, if a metal plate, insulated from other bodies, be connected with, say, the positive pole of a battery, the negative pole of which is grounded, a current will flow into the plate until the plate is raised to the same potential as that of the battery pole to which it is connected. The amount of electricity that will flow into the plate will depend, other things being equal, on the potential of the source from which it is charged; in fact, it is proportional to the potential of the source from which it is charged. This amount of electricity is a measure of the capacity of the plate, just as the amount of water that a bath-tub will hold is a measure of the capacity of the bath-tub.

Capacity. Instead of measuring the amount of electricity by the quart or pound, as in the case of material things, the unit of electrical quantity is the *coulomb.* The unit of capacity of an insulated conductor is the *farad,* and a given insulated conductor is said to have unit capacity, that is, the capacity of one farad, when it will receive a charge of one coulomb of electricity at a potential of one volt.

Referring to Fig. 119, the potential of the negative terminal of the battery may be said to be zero, since it is connected to the earth. If the battery shown be supposed to have exactly one volt potential, then the plate would be said to have the capacity of one farad if one coulomb of electricity flowed from the battery to the plate before the plate was raised to the same potential as that of the positive pole, that is, to a potential of one volt above the potential of the earth; it being assumed that the plate was also at zero potential before the connection was made. Another conception of this quantity may be had by remembering that a coulomb is such a quantity of current as will result from one ampere flowing one second.

The capacity of a conductor depends, among other things, on its area. If the plate of Fig. 119 should be made twice as large in area, other things remaining the same, it would have twice the capacity. But there are other factors governing the capacity of a conductor. Consider the diagram of Fig. 120, which is supposed to represent two such plates as are shown in Fig. 119, placed opposite each other and connected respectively with the positive and the negative poles of the battery. When the connection between the plates and the battery is made, the two plates become charged to a difference of potential equal to the electromotive force of the battery. In order to obtain these charges, assume that the plates were each at zero potential before the connection was made; then current flows from the battery into the plates until they each assume the potential of the corresponding battery terminal. If the two plates be brought closer together, it will be found that more current will now flow into each of them, although the difference of potential between the two plates must obviously remain the same, since each of them is still connected to the battery.

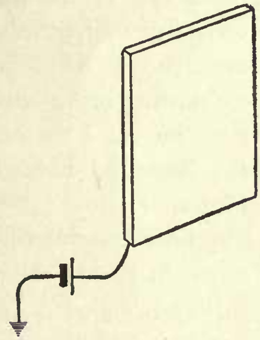


Fig. 119. Condenser Plate

Theory. Due to the proximity of the plates, the positive electricity on plate A is drawn by the negative charge on plate B towards plate B, and likewise the negative electricity on plate B is drawn to the side towards plate A by the positive charge on that plate. These two charges so drawn towards each other will, so to speak, bind each other, and they are referred to as *bound charges.* The charge on the right-hand side of plate A and on the left-hand side of plate B will, however, be free charges, since there is nothing to attract them, and these are, therefore, neutralized by a further flow of electricity from the battery to the plate.

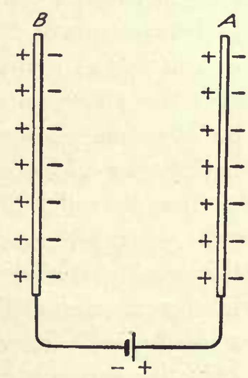


Fig. 120. Theory of Condenser

Obviously, the closer together the plates are the stronger will be the attractive influence of the two charges on each other. From this it follows that in the case of plate A, when the two plates are being moved closer together, more positive electricity will flow into plate A to neutralize the increasing free negative charges on the right-hand side of the plate. As the plates are moved closer together still, a new distribution of charges will take place, resulting in more positive electricity flowing into plate A and more negative electricity flowing into plate B. The closer proximity of the plates, therefore, increases the capacity of the plates for holding charges, due to the increased inductive action across the dielectric separating the plates.

Condenser Defined. A condenser is a device consisting of two adjacent plates of conducting material, separated by an insulating material, called a *dielectric*. The purpose is to increase by the proximity of the plates, each to the other, the amount of electricity which each plate will receive and hold when subjected to a given potential.

Dielectric. We have already seen that the capacity of a condenser depends upon the area of its plates, and also upon their distance apart. There is still another factor on which the capacity of a condenser depends, *i. e.*, on the character of the insulating medium separating its plates. The inductive action which takes place between a charged conductor and other conductors nearby it, as between plate A and plate B of Fig. 120, is called *electrostatic induction*, and it plays an important part in telephony. It is found that the ability of a given charged conductor to induce charges on other neighboring conductors varies largely with the insulating medium or dielectric that separates them. This quality of a dielectric, by which it enables inductive action to take place between two separated conductors, is called *inductive capacity*. Usually this quality of dielectrics is measured in terms of the same quality in dry air, this being taken as unity. When so expressed, it is termed *specific inductive capacity*. To be more accurate the specific inductive capacity of a dielectric is the ratio between the capacity of a condenser having that substance as a dielectric, to the capacity of the same condenser using dry air at zero degrees Centigrade and at a pressure of 14.7 pounds per square inch as the dielectric. To illustrate, if two condensers having plates of equal size and equal distance apart are constructed, one using air as the dielectric and the other using hard crown glass as the dielectric, the one using glass will have a capacity of 6.96 times that of the one using air. From this we say that crown glass has a specific inductive capacity of 6.96.

Various authorities differ rather widely as to the specific inductive capacity of many common substances. The values given in Table VIII have been chosen from the Smithsonian Physical Tables.

TABLE VIII

Specific Inductive Capacities

Dielectric	Referred to Air as 1
Vacuum	.99941
Hydrogen	.99967
Carbonic Acid	1.00036
Dry Paper	1.25 to 1.75
Paraffin	1.95 to 2.32
Ebonite	1.9 to 3.48
Sulphur	2.24 to 3.90
Shellac	2.95 to 3.73
Gutta-percha	3.3 to 4.9
Plate Glass	3.31 to 7.5
Porcelain	4.38
Mica	4.6 to 8.0
Glass—Light Flint	6.61
Glass—Hard Crown	6.96
Selenium	10.2

This data is interesting as showing the wide divergence in specific inductive capacities of various materials, and also showing the wide divergence in different observations of the same material. Undoubtedly, this latter is due mainly to the fact that various materials differ largely in themselves, as in the case of paraffin, for instance, which exhibits widely different specific inductive capacities according to the difference in rapidity with which it is cooled in changing from a liquid to a solid state.

We see then that the capacity of a condenser varies as the area of its plates, as the specific inductive capacity of the dielectric employed, and also inversely as the distance between the plates.

Obviously, therefore, in making a condenser of large capacity, it is important to have as large an area of the plate as possible; to have them as close together as possible; to have the dielectric a good insulating medium so that there will be practically no leakage between the plates; and to have the dielectric of as high a specific inductive capacity as economy and suitability of material in other respects will permit.

Dielectric Materials. *Mica.* Of all dielectrics mica is the most suitable for condensers, since it has very high insulation resistance and also high specific inductive capacity, and furthermore may be obtained in very thin sheets. High-grade condensers, such as are used for measurements and standardization purposes, usually have mica for the dielectric.

Dry Paper. The demands of telephonic practice are, however, such as to require condensers of very cheap construction with large capacity in a small space. For this purpose thin bond paper, sat-

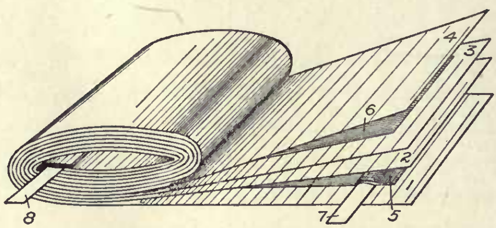


Fig. 121. Rolled Condenser

urated with paraffin, has been founa to be the best dielectric. The conductors in condensers are almost always of tinfoil, this being an ideal material on account of its cheapness and its thinness. Before telephony made such urgent demands for a cheap compact condenser, the customary way of making them was to lay up alternate sheets of dielectric material, either of oiled paper or mica and tinfoil, the sheets of tinfoil being cut somewhat smaller than the sheets of dielectric material in order that the proper insulation might be secured at the edges. After a sufficient number of such plates were built up the alternate sheets of tinfoil were connected together to form one composite plate of the condenser, while the other sheets were similarly connected together to form the other plate. Obviously, in this way a very large area of plates could be secured with a minimum degree of separation.

There has been developed for use in telephony, however, and its use has since extended into other arts requiring condensers, what is called the *rolled condenser*. This is formed by rolling together in a flat roll four sheets of thin bond paper, *1*, *2*, *3*, and *4*, and two somewhat narrower strips of tinfoil, *5* and *6*, Fig. 121. The strips of tinfoil and paper are fed on to the roll in continuous lengths and in such manner that two sheets of paper will lie between the two strips of tinfoil in all cases. Thin sheet metal terminals *7* and *8* are rolled into the condenser as it is being wound, and as these project beyond the edges of the paper they form convenient terminals for the condenser after it is finished. After it is rolled, the roll is boiled in hot paraffin so as to thoroughly impregnate it and expel all moisture. It is then squeezed in a press and allowed to cool while under pressure. In this way the surplus paraffin is expelled and the plates are brought very close together. It then appears as in Fig. 122. The condenser is now sealed in a metallic case, usually rectangular in form, and presents the appearance shown in Fig. 123.

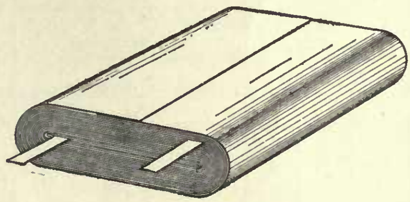


Fig. 122. Rolled Condenser

A later method of condenser making which has not yet been thoroughly proven in practice, but which bids fair to produce good results, varies from the method just described in that a paper is used which in itself is coated with a very thin conducting material. This conducting material is of metallic nature and in reality forms a part of the paper. To form a condenser of this the sheets are merely rolled together and then boiled in paraffin and compressed as before.

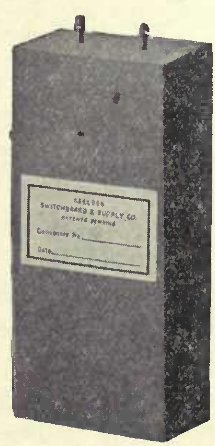


Fig. 123. Rolled Condenser

Sizes. The condensers ordinarily used in telephone practice range in capacity from about $\frac{1}{4}$ microfarad to 2 microfarads. When larger capacities than 2 microfarads are desired, they may be obtained by connecting several of the smaller size

TABLE IX

Condenser Data

Capacity	Shape	Dimensions in Inches		
		Height	Width	Thickness
2 m. f.	Rectangular	$9\frac{1}{6}$	$4\frac{3}{4}$	$\frac{11}{16}$
1 m. f.	"	$9\frac{1}{6}$	$4\frac{3}{4}$	$\frac{11}{16}$
1 m. f.	"	$4\frac{3}{4}$	$2\frac{3}{32}$	$\frac{13}{16}$
$\frac{1}{2}$ m. f.	"	$2\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$
1 m. f.	"	$4\frac{13}{16}$	$2\frac{1}{32}$	$\frac{25}{32}$
$\frac{1}{2}$ m. f.	"	$4\frac{3}{4}$	$2\frac{3}{32}$	$\frac{13}{16}$
$\frac{3}{10}$ m. f.	"	$4\frac{3}{4}$	$2\frac{3}{32}$	$\frac{13}{16}$
1 m. f.	"	$2\frac{3}{4}$	3	1

condensers in multiple. Table IX gives the capacity, shape, and dimensions of a variety of condensers selected from those regularly on the market.

Conventional Symbols. The conventional symbols usually employed to represent condensers in telephone diagrams are shown in Fig. 124. These all convey the idea of the adjacent conducting plates separated by insulating material.

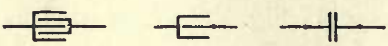


Fig. 124. Condenser Symbols

Functions. Obviously, when placed in a circuit a condenser offers a complete barrier to the flow of direct current, since no conducting path exists between its terminals, the dielectric offering a very high insulation resistance. If, however, the condenser is connected across the terminals of a source of alternating current, this current flows first in one direction and then in the other, the electromotive force in the circuit increasing from zero to a maximum in one direction, and then decreasing back to zero and to a maximum in the other direction, and so on. With a condenser connected so as to be subjected to such alternating electromotive forces, as the electromotive force begins to rise the electromotive force at the condenser terminals will also rise and a current will, therefore, flow into the condenser. When the electromotive force reaches its maximum, the condenser will have received its full charge for that potential, and the current flow into it will cease. When the electromotive force begins to fall, the condenser can no longer retain its charge and a current will, therefore, flow out of it. Apparently, therefore, there is a flow of current through the condenser the same as if it were a conductor.

Means for Assorting Currents. In conclusion, it is obvious that the telephone engineer has within his reach in the various coils—whether non-inductive or inductive, or whether having one or several windings—and in the condenser, a variety of tools by which he may achieve a great many useful ends in his circuit work. Obviously, the condenser affords a means for transmitting voice currents or fluctuating currents, and for excluding steady currents. Likewise the impedance coil affords a means for readily transmitting steady currents but practically excluding voice currents or fluctuating currents. By the use of these very simple devices it is possible to sift out the voice currents from a circuit containing both steady and fluctuating currents, or it is possible in the same manner to sift out the steady currents and to leave the voice currents alone to traverse the circuit.

Great use is made in the design of telephone circuits of the fact that the electromagnets, which accomplish the useful mechanical results in causing the movement of parts, possess the quality of impedance. Thus, the magnets which operate various signaling relays at the central office are often used also as impedance coils in portions of the circuit through which it is desired to have only steady currents pass. If, on the other hand, it is necessary to place a relay magnet, having considerable impedance, directly in a talking circuit, the bad effects of this on the voice currents may be eliminated by shunting this coil with a condenser, or with a comparatively high non-inductive resistance. The voice currents will flow around the high impedance of the relay coil through the condenser or resistance, while the steady currents, which are the ones which must be depended upon to operate the relay, are still forced in whole or in part to pass through the relay coil where they belong.

In a similar way the induction coil affords a means for keeping two circuits completely isolated so far as the direct flow of current between them is concerned, and yet of readily transmitting, by electromagnetic induction, currents from one of these circuits to the other. Here is a means of isolation so far as direct current is concerned, with complete communication for alternating current.

CHAPTER XIII

CURRENT SUPPLY TO TRANSMITTERS

The methods by which current is supplied to the transmitter of a telephone for energizing it, may be classified under two divisions: first, those where the battery or other source of current is located at the station with the transmitter which it supplies; and second, those where the battery or other source of current is located at a distant point from the transmitter, the battery in such cases serving as a common source of current for the supply of transmitters at a number of stations.

The advantages of putting the transmitter and the battery which supplies it with current in a local circuit with the primary of an induction coil, and placing the secondary of the induction coil in the line, have already been pointed out but may be briefly summarized as follows: When the transmitter is placed directly in the *line circuit* and the line is of considerable length, the current which passes through the transmitter is necessarily rather small unless a battery of high potential is used; and, furthermore, the total change in resistance which the transmitter is capable of producing is but a small proportion of the total resistance of the line, and, therefore, the current changes produced by the transmitter are relatively small. On the other hand, when the transmitter is placed in a *local circuit* with the battery, this circuit may be of small resistance and the current relatively large, even though supplied by a low-voltage battery; so that the transmitter is capable of producing relatively large changes in a relatively large current.

To draw a comparison between these two general classes of transmitter current supply, a number of cases will be considered in connection with the following figures, in each of which two stations connected by a telephone line are shown. Brief reference to the local battery method of supplying current will be made in order to make this chapter contain, as far as possible, all of the commonly used methods of current supply to transmitters.

Local Battery. In Fig. 125 two stations are shown connected by a grounded line wire. The transmitter of each station is included in a low-resistance primary circuit including a battery and the primary winding of an induction coil, the relation between the

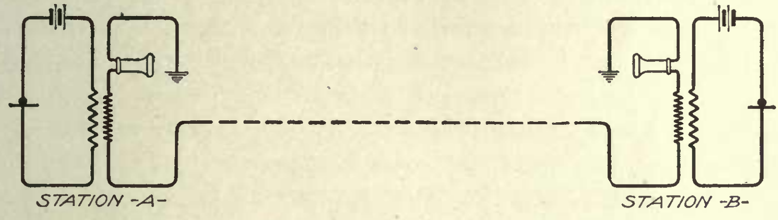


Fig. 125. Local-Battery Stations with Grounded Circuit

primary circuits and the line circuits being established by the inductive action between the primary and the secondary windings of induction coils, the secondary in each case being in the line circuits with the receivers.

Fig. 126 shows exactly the same arrangement but with a metallic circuit rather than a grounded circuit. The student should become accustomed to the replacing of one of the line wires of a metallic cir-

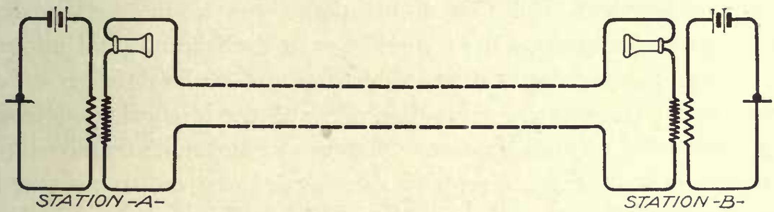


Fig. 126. Local-Battery Stations with Metallic Circuit

cuit by the earth, and to the method, employed in Figs. 125 and 126, of indicating a grounded circuit as distinguished from a metallic circuit.

In Fig. 127 is shown a slight modification of the circuit shown in Fig. 126, which consists of connecting one end of the primary winding to one end of the secondary winding of the induction coil, thus linking together the primary circuit and the line circuit, a portion of each of these circuits being common to a short piece of the local wiring. There is no difference whatever in the action of the circuits shown in Figs. 126 and 127, the latter being shown merely for the purpose of bringing out this fact. It is very common, particularly in local-battery circuits, to connect one end of the primary and the secondary windings, as by doing so it is often possible to save a contact point in the hook switch and also to simplify the wiring.

The advantages to be gained by employing a local battery at each subscriber's station associated with the transmitter in the primary circuit of an induction coil are attended by certain disadvan-

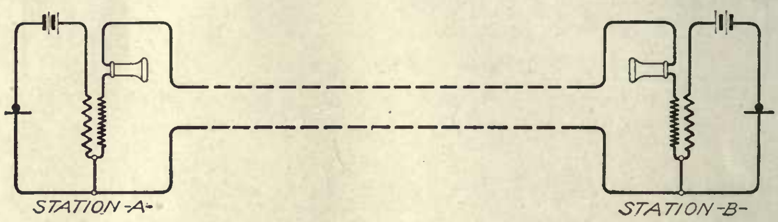


Fig. 127. Local-Battery Stations with Metallic Circuit

tages from a commercial standpoint. The primary battery is not an economical way to generate electric energy. In all its commercial forms it involves the consumption of zinc and zinc is an expensive fuel. The actual amount of current in watts required by a telephone is small, however, and this disadvantage due to the inexpensive method of generating current would not in itself be of great importance. A more serious objection to the use of local batteries at subscribers' stations appears when the subject is considered from the standpoint of maintenance. Batteries, whether of the so-called "dry" or "wet" type, gradually deteriorate, even when not used, and in cases where the telephone is used many times a day the deterioration is comparatively rapid. This makes necessary the occasional renewals of the batteries with the attendant expense for new batteries or new material, and of labor and transportation in visiting the station. The labor item becomes more serious when the stations are scattered in a sparsely settled community, in which case the visiting of the stations, even for the performance of a task that would require but a few minutes' time, may consume some hours on the part of the employes in getting there and back.

Common Battery. *Advantages.* It would be more economical if all of the current for the subscribers' transmitters could be supplied from a single comparatively efficient generating source instead of from a multitude of inefficient small sources scattered throughout the community served by the exchange. The advantage of such centralization lies not only in more economic generating means, but also in having the common source of current located at one place, where it may be cared for with a minimum amount of expense. Such considerations have resulted in the so-called "common-battery system," wherein the current for all the subscribers' transmitters is furnished from a source located at the central office.

Where such a method of supplying current is practiced, the result has also been, in nearly all cases, the doing away with the subscriber's magneto generators, relying on the central-office source of current to furnish the energy for enabling the subscriber to signal the operator. Such systems, therefore, concentrate all of the sources of energy at the central office and for that reason they are frequently referred to as central-energy systems.

NOTE. In this chapter the central-energy or common-battery system will be considered only in so far as the supply of current for energizing the subscribers' transmitters is concerned, the discussion of the action of signaling being reserved for subsequent chapters.

Series Battery. If but a single pair of lines had to be considered, the arrangement shown in Fig. 128 might be employed. In this the battery is located at the central office and placed in series with the two grounded lines leading from the central office to the two subscribers' stations. The voltage of this battery is made sufficient to furnish the required current over the resistance of the entire line

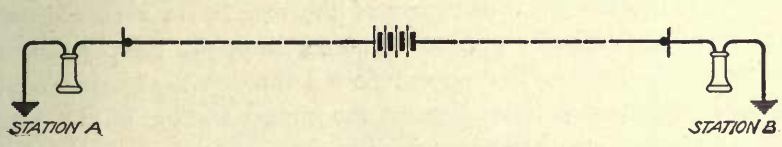


Fig. 128. Battery in Series with Two Lines

circuit with its included instruments. Obviously, changes in resistance in the transmitter at Station A will affect the flow of current in the entire line and the fluctuations resulting from the vibration of the transmitter diaphragm will, therefore, reproduce these sounds in the receiver at Station B, as well as in that at Station A.

An exactly similar arrangement applied to a metallic circuit is shown in Fig. 129. In thus placing the battery in series in the circuit between the two stations, as shown in Figs. 128 and 129, it is obvious that the transmitter at each station is compelled to vary the resistance of the entire circuit comprising the two lines in series, in order to affect the receiver at distant stations. This is in effect making the transmitter circuit twice as long as is necessary, as will be shown in

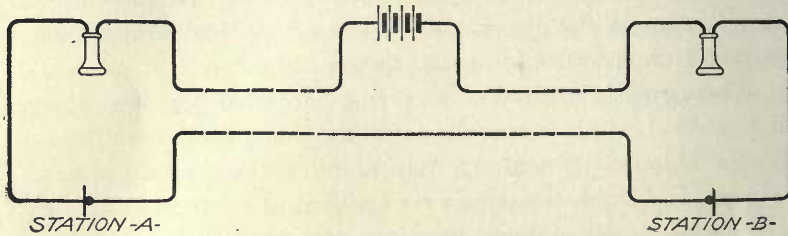


Fig. 129. Battery in Series with Two Lines

the subsequent systems considered. Furthermore, the placing of the battery in series in the circuit of the two combined lines does not lend itself readily to the supply of current from a common source to more than a single pair of lines.

Series Substation Circuit. The arrangement at the substations—consisting in placing the transmitter and the receiver in series in the line circuit, as shown in Figs. 128 and 129—is the simplest possible one, and has been used to a considerable extent, but it has been subject to the serious objection, where receivers having permanent magnets were used, of making it necessary to so connect the receiver in the line circuit that the steady current from the battery would not set up a magnetization in the cores of the receiver in such a direction as to neutralize or oppose the magnetization of the permanent magnets. As long as the current flowed through the receiver coils in such a direction as to supplement the magnetization of the permanent magnets, no harm was usually done, but when the current flowed through the receiver coils in such a way as to neutralize or oppose the magnetizing force of the permanent magnets, the action of the receiver was greatly interfered with. As a result, it was necessary to always connect the receivers in the line circuit in a certain way, and this operation was called *poling*.

In order to obviate the necessity for poling and also to bring about other desirable features, it has been, until recently, almost universal practice to so arrange the receiver that it would be in the circuit of the voice currents passing over the line, but would not be traversed by direct currents, this condition being brought about by various arrangements of condensers, impedance coils, or induction coils, as will be shown later. During the year 1909, however, the adoption by several concerns of the so-called "direct-current" receiver has made it necessary for the direct current to flow through the receiver coils in order to give the proper magnetization to the receiver cores, and this has brought about a return to the very simple form of substation circuit, which includes the receiver and the transmitter directly in the circuit of the line. This illustrates well an occurrence that is frequently observed by those who have opportunity to watch closely the development of an art. At one time the conditions will be such as to call for complicated arrangements, and for years the aim of inventors will be to perfect these arrangements; then, after they are perfected, adopted, and standardized, a new idea, or a slight alteration in the practice in some other respect, will demand a return to the first principles and wipe out the necessity for the things that have been so arduously striven for.

Bridging Battery with Repeating Coil. As pointed out, the placing of the battery in series in the line circuit in the central office is not desirable, and, so far as we are aware, has never been extensively used. The universal practice, therefore, is to place it in a bridge path across the line circuit, and a number of arrangements employing this basic idea are in wide use. In Fig. 130 is shown the standard arrangement of the Western Electric Com-

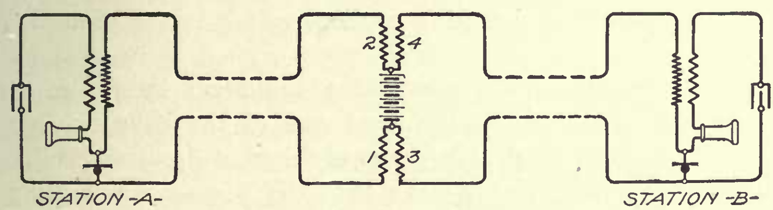


Fig. 130. Bridging Battery with Repeating Coil

pany, employed by practically all the Bell operating companies. In this the battery at the central office is connected in the middle of the two sides of a repeating coil so that the current from the battery is fed out to the two connected lines in multiple.

Referring to the middle portion of this figure showing the central-office apparatus, *1* and *2* may be considered as the two halves of one side of a repeating coil divided so that the battery may be cut into their circuit. Likewise, *3* and *4* may be considered as the two halves of the other side of the repeating coil similarly divided for the same purpose. The windings of this repeating coil are ordinarily alike; that is, *1* and *2* combined have the same resistance, number of turns, and impedance as *3* and *4* combined. The two sides of this coil are alternately used as primary and secondary, *1* and *2* forming the primary when Station A is talking, and *3* and *4*, the secondary; and *vice versâ* when Station B is talking.

As will be seen, the current flowing from the positive pole of the battery will divide and flow through the windings *2* and *4;* thence over the upper limb of each line, through the transmitter at each station, and back over the lower limbs of the line, through the windings *1* and *3*, where the two paths reunite and pass to the negative pole of the battery. It is evident that when neither transmitter is being used the current flowing through both lines will be a steady current and that, therefore, neither line will have an inductive effect on the other. When, however, the transmitter at Station A is used, the variations in the resistance caused by it will cause undulations in the current. These undulations, passing through the windings *1* and *2* of the repeating coil, will cause, by electromagnetic induction, alternating currents to flow in the windings *3* and *4*, and these alternating currents will be superimposed on the steady currents flowing in that line and will affect the receiver at Station B, as will be pointed out. The reverse conditions exist when Station B is talking.

Bell Substation Arrangement. The substation circuits at the stations in Fig. 130 are illustrative of one of the commonly employed methods of preventing the steady current from the battery from flowing through the receiver coil. This particular arrangement is that employed by the common-battery instruments of the various Bell companies. Considering the action at Station B, it is evident that the steady current will pass through the transmitter and through the secondary winding of the induction coil, and that as long as this current is steady no current will flow through the telephone receiver. The receiver, transmitter, and primary winding of the induction coil are, however, included in a local circuit with the condenser. The presence of the condenser precludes the possibility of direct current flowing in this path. Considering Station A as a receiving station, it is evident that the voice currents coming to the station over the line will pass through the secondary winding and will induce alternating currents in the primary winding which will circulate through the local circuit containing the receiver and the condenser, and thus actuate the receiver. The considerations are not so simple when the station is being treated as a transmitting station. Under this condition the steady current passes through the transmitter in an obvious manner. It is clear that if the local circuit containing the receiver did not exist, the circuit would be operative as a transmitting circuit because the transmitter would produce fluctuations in the steady current flowing in the line and thus be able to affect the distant station. The transmitter, therefore, has a direct action on the currents flowing in the line by the variation in resistance which it produces in the line circuit. There is, however, a subsidiary action in this circuit. Obviously, there is a drop of potential across the transmitter terminals due to the flow of steady current. This means that the upper terminal of the condenser will be charged to the same potential as the upper terminal of the transmitter, while the lower terminal of the condenser will be of the same potential as the lower terminal of the transmitter. When, now, the transmitter varies its resistance, a variation in the potential across its terminals will occur; and as a result, a variation in potential across the terminals of the condenser will occur, and this means that alternating currents will flow through the primary winding of the induction coil. The transmitter, therefore, by its action, causes alternating currents to flow through the primary of this induction coil and it causes, by direct action on the circuit of the line, fluctuations in the steady current flowing in the line. The alternating currents flowing in the primary of the coil induce currents in the secondary of the coil which supplement and augment the fluctuations produced by the direct action of the transmitter. This circuit may be looked at, therefore, in the light of combining the direct action which the transmitter produces in the current in the line with the action which the transmitter produces in the local circuit containing the primary of the induction coil, this action being repeated in the line circuit through the secondary of the induction coil.

The receiver in this circuit is placed in the local circuit, and is thus not traversed by the steady currents flowing in the line. There is thus no necessity for poling it. This circuit is very efficient, but is subject to the objection of producing a heavy side tone in the receiver of the transmitting station. By "side tone" is meant the noises which

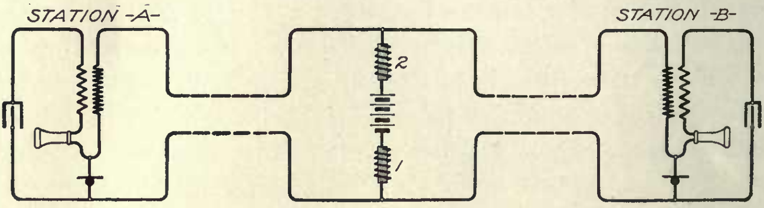


Fig. 131. Bridging Battery with Impedance Coils

are produced in the receiver at a station by virtue of the action of the transmitter at that station. Side tone is objectionable for several reasons: first, it is sometimes annoying to the subscriber; second, and of more importance, the subscriber who is talking, hearing a very loud noise in his own receiver, unconsciously assumes that he is talking too loud and, therefore, lowers his voice, sometimes to such an extent that it will not properly reach the distant station.

Bridging Battery with Impedance Coils. The method of feeding current to the line from the common battery, shown in Fig. 130, is called the "split repeating-coil" method. As distinguished from this is the impedance-coil method which is shown in Fig. 131. In this the battery is bridged across the circuit of the combined lines in series with two impedance coils, *1* and *2*, one on each side of the battery. The steady currents from the battery find ready path through these impedance coils which are of comparatively low ohmic resistance, and the current divides and passes in multiple over the circuits of the two lines. Voice currents, however, originating at either one of the stations, will not pass through the shunt across the line at the central office on account of the high impedance offered by these coils, and as a result they are compelled to pass on to the distant station and affect the receiver there, as desired.

This impedance-coil method seems to present the advantage of greater simplicity over the repeating-coil method shown in Fig. 130, and so far as talking efficiency is concerned, there is little to choose between the two. The repeating-coil method, however, has the advantage over this impedance-coil method, because by it the two lines are practically divided except by the inductive connection between the two windings, and as a result an unbalanced condition of one of the connected lines is not as likely to produce an unbalanced condition in the other as where the two lines are connected straight through, as with the impedance-coil method. The substation arrangement of Fig. 131 is the same as that of Fig. 130.

Double Battery with Impedance Coils. A modification of the impedance-coil method is used in all of the central-office work of the Kellogg Switchboard and Supply Company. This employs a combination of impedance coils and condensers, and in effect isolates the lines conductively from each other as completely as the repeating-coil method. It is characteristic of all the Kellogg common-battery systems that they employ two batteries instead of one, one of these being connected in all cases with the calling line of a pair of connected lines and the other in all cases with the called line. As shown in Fig. 132, the left-hand battery is connected with the line leading to Station A through the impedance coils *1* and *2*. Likewise, the right-hand battery is con-

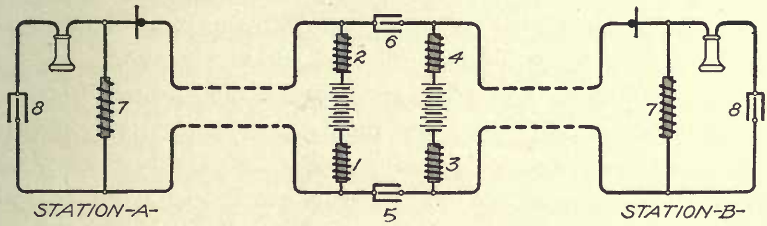


Fig. 132. Double-Battery Kellogg System

nected to the line of Station B through the impedance coils *3* and *4*. These four impedance coils are wound on separate cores and do not have any inductive relation whatsoever with each other. Condensers *5* and *6* are employed to completely isolate the lines conductively. Current from the left-hand battery, therefore, passes only to Station A, and current from the right-hand battery to Station B.

Whenever the transmitter at Station A is actuated the undulations of current which it produces in the line cause a varying difference of potential across the outside terminals of the two impedance coils *1* and *2*. This means that the two left-hand terminals of condensers *5* and *6* are subjected to a varying difference of potential and these, of course, by electrostatic induction, cause the right-hand terminals of these condensers to be subject to a correspondingly varying difference of potential. From this it follows that alternating currents will be impressed upon the right-hand line and these will affect the receiver at Station B.

A rough way of expressing the action of this circuit is to consider it in the same light as that of the impedance-coil circuit shown in Fig. 131, and to consider that the voice currents originating in one line are prevented from passing through the bridge paths at the central office on account of the impedance, and are, therefore, forced to continue on the line, being allowed to pass readily by the condensers in series between the two lines.

Kellogg Substation Arrangement. An interesting form of substation circuit which is employed by the Kellogg Company in all of its common-battery telephones is shown in Fig. 132. In passing, it may be well to state that almost any of the substation circuits shown in this chapter are capable of working with any of the central-office circuits. The different ones are shown for the purpose of giving a knowledge of the various substation circuits that are employed, and, as far as possible, to associate them with the particular central-office arrangements with which they are commonly used.

In this Kellogg substation arrangement the line circuit passes first through the transmitter and then divides, one branch passing through an impedance coil *7* and the other through the receiver and the condenser *8*, in series. The steady current from the central-office battery finds ready path through the transmitter and the impedance coil, but is prevented from passing through the receiver by the barrier set up by the condenser *8*. Voice currents, however, coming over the line to the station, find ready path through the receiver and the condenser but are barred from passing through the impedance coil by virtue of its high impedance.

In considering the action of the station as a transmitting station, the variations set up by the transmitter pass through the condenser and the receiver at the same station, while the steady current which supplies the transmitter passes through the impedance coil. Impedance coils used for this purpose are made of low ohmic resistance but of a comparatively great number of turns, and, therefore, present a good path for steady currents and a difficult path for voice currents. This divided circuit arrangement employed by the Kellogg Company is one of the very simple ways of eliminating direct currents from the receiver path, at the same time allowing the free passage of voice currents.

Dean Substation Arrangement. In marked contrast to the scheme for keeping steady current out of the receiver circuit employed by the Kellogg Company, is that shown in Fig. 133, which has been largely used by the Dean Electric Company, of Elyria, Ohio. The central-office arrangement in this case is that using

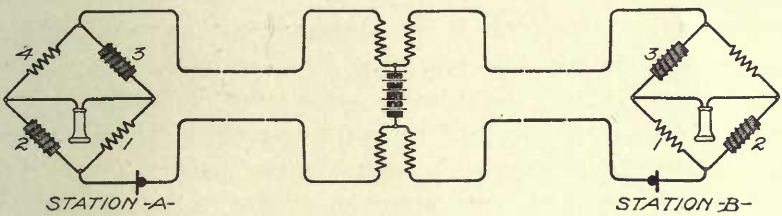


Fig. 133. Dean System

the split repeating coil, which needs no further description. The substation arrangement, however, is unique and is a beautiful example of what can be done in the way of preventing a flow of current through a path without in any way insulating that path or placing any barrier in the way of the current. It is an example of the prevention of the direct flow of current through the receiver by so arranging the circuits that there will always be an equal potential on each side of it, and, therefore, no tendency for current to flow through it.

In this substation arrangement four coils of wire—*1*, *2*, *3*, and *4*—are so arranged as to be connected in the circuit of the line, two in series and two in multiple. The current flowing from the battery at the central office, after passing through the transmitter, divides between the two paths containing, respectively, the coils *1* and *3* and the coils *2* and *4*. The receiver is connected between the junction of the coils *2* and *4* and that of *1* and *3*. The resistances of the coils are so chosen that the drop of potential through the coil *2* will be equal to that through the coil *1*, and likewise that through the coil *4* will be equal to that through the coil *3*. As a result, the receiver will be connected between two points of equal potential, and no direct current will flow through it. How, then, do voice currents find their way through the receiver, as they evidently must, if the circuit is to fulfill any useful function? The coils *2* and *3* are made to have high impedance, while *1* and *4* are so wound as to be non-inductive and, therefore, offer no impedance save that of their ohmic resistance. What is true, therefore, of direct currents does not hold for voice currents, and as a result, the voice currents, instead of taking the divided path which the direct currents pursued, are debarred from the coils *2* and *3* by their high impedance and thus pass through the non-inductive coil *1*, the receiver, and the non-inductive coil *4*.

This circuit employs a Wheatstone-bridge arrangement, adjusted to a state of balance with respect to direct currents, such currents being excluded from the receiver, not because the receiver circuit is in any sense opaque to such direct currents, but because there is no difference of potential between the terminals of the receiver circuit, and, therefore, no tendency for current to flow through the receiver. In order that fluctuating currents may not, for the same reason, be caused to pass by, rather than through, the receiver circuit, the diametrically-opposed arms of the Wheatstone bridge are made to possess, in large degree, self-induction, thereby giving these two arms a high impedance to fluctuating currents. The conditions which exist for direct currents do not, therefore, exist for fluctuating currents, and it is this distinction which allows alternating currents to pass through the receiver and at the same time excludes direct currents therefrom.

In practice, the coils *1*, *2*, *3*, and *4* of the Dean substation circuit are wound on the same core, but coils *1* and *4*—the non-inductive ones—are wound by doubling the wire back on itself so as to neutralize their self-induction.

Stromberg-Carlson. Another modification of the central-office arrangement and also of the subscribers' station circuits, is shown in Fig. 134, this being a simplified representation of the circuits commonly employed by the Stromberg-Carlson Telephone

Manufacturing Company. The battery feed at the central office differs only from that shown in Fig. 132, in that a single battery rather than two batteries is used, the current being supplied to one of the lines through the impedance coils *1* and *2*, and to the other line through the impedance coils *3* and *4*; condensers *5* and *6* serve

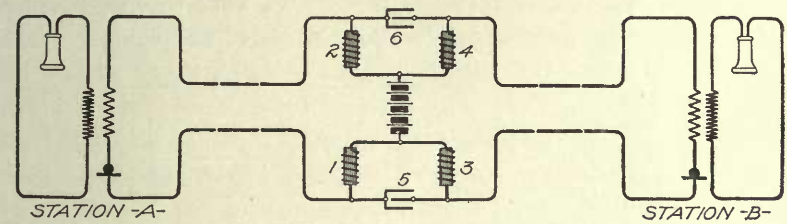


Fig. 134. Stromberg-Carlson System

conductively to isolate the two lines. At the subscriber's station the line circuit passes through the secondary of an induction coil and the transmitter. The receiver is kept entirely in a local circuit so that there is no tendency for direct current to flow through it, but it is receptive to voice currents through the electromagnetic induction between the primary and the secondary of the induction coil.

North. Another arrangement of central-office battery feed is employed by the North Electric Company, and is shown in Fig. 135. In this two batteries are used which supply current respectively to the two connected lines, condensers being employed to conductively isolate the lines. This differs from the Kellogg arrangement

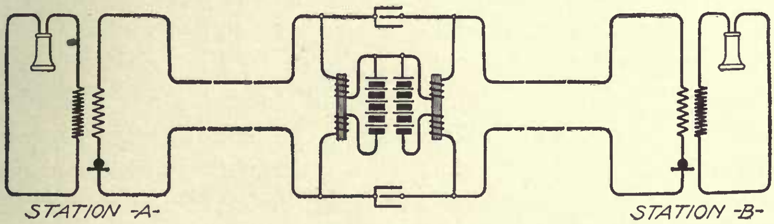


Fig. 135. North Electric Company System

shown in Fig. 132 in that the two coils *1* and *2* are wound on the same core, while the coils *3* and *4* are wound together upon another core. In this case, in order that the inductive action of one of the coils may not neutralize that of the other coil on the same core, the two coils are wound in such relative direction that their magnetizing influence will always be cumulative rather than differential.

The central-office arrangements discussed in Figs. 130 to 135, inclusive, are those which are in principal use in commercial practice in common-battery exchanges.

Current Supply over Limbs of Line in Parallel. As indicating further interesting possibilities in the method of supplying current

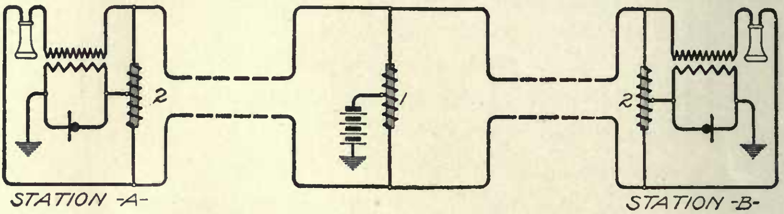


Fig. 136. Current Supply over Parallel Limbs of Line

from a common source to a number of substations, several other systems will be briefly referred to as being of interest, although these have not gone into wide commercial use. The system shown in Fig. 136 is one proposed by Dean in the early days of common-battery working, and this arrangement was put into actual service and gave satisfactory results, but was afterwards supplanted by the Bell equipment operating under the system shown in Fig. 130, which became standardized by that company. In this the current from the common battery at the central office is not fed over the two line wires in series, but in multiple, using a ground return from the subscriber's station to the central office. Across the metallic circuit formed by two connected lines there is bridged, at the central office, an impedance coil *1*, and between the center point of this impedance coil and the ground is connected the common battery. At the subscriber's station is placed an impedance coil *2*, also bridged across the two limbs of the line, and between the center point of this impedance coil and the ground is connected the transmitter, which is shunted by the primary winding of an induction coil. Connected between the two limbs of the line at the substation there is also the receiver and the secondary of an induction coil in series.

The action of this circuit at first seems a little complex, but if taken step by step may readily be understood. The transmitter supply circuit may be traced from the central-office battery through the two halves of the impedance coil *1* in multiple; thence over the two limbs of the line in multiple to Station A, for instance; thence in multiple through the two halves of impedance coil *2*, to the center point of that coil; thence through the two paths offered respectively by the primary of the induction coil and by the transmitter; then to ground and back to the other pole of the central-office battery. By this circuit the transmitter at the substation is supplied with current.

Variations in the resistance of the transmitter when in action, cause complementary variations in the supply current flowing through the primary of the induction coil. These variations induce similar alternating currents in the secondary of this coil, which is in series in the line circuit. The currents, so induced in this secondary, flow in series through one side of the line to the distant station; thence through the secondary and the receiver at that station to the other side of the line and back through that side of the line to the receiver. These currents are not permitted to pass through the bridged paths across the metallic circuit that are offered by the impedance coils *1* and *2*, because they are voice currents and are, therefore, debarred from these paths by virtue of the impedance.

An objection to this form of current supply and to other similar forms, wherein the transmitter current is fed over the two sides of

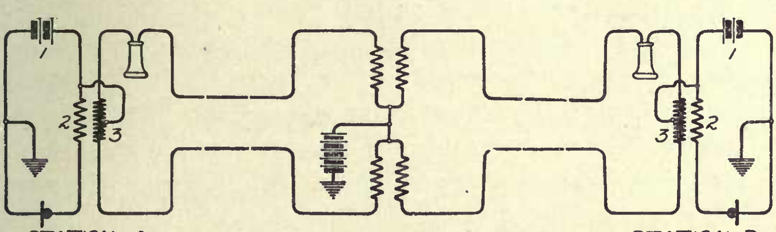


Fig. 137. Current Supply over Parallel Limbs of Line

the line in multiple with a ground return, is that the ground-return circuit formed by the two sides of the line in multiple is subject to inductive disturbances from other lines in the same way as an ordinary grounded line is subject to inductive disturbance. The current-supply circuit is thus subject to external disturbances and such disturbances find their way into the metallic circuit and, therefore, through the instruments by means of the electromagnetic induction between the primary and the secondary coils at the substations.

Another interesting method of current supply from a central-office battery is shown in Fig. 137. This, like the circuit just considered, feeds the energy to the subscriber's station over the two sides of the line in multiple with a ground return. In this case, however, a local circuit is provided at the substation, in which is placed a storage battery *1* and the primary *2* of an induction coil, together with the transmitter. The idea in this is that the current supply from the central office will pass through the storage battery and charge it. Upon the use of the transmitter, this storage battery acts to supply current to the local circuit containing the transmitter and the primary coil *2* in exactly the same manner as in a local battery system. The fluctuating current so produced by the action of the transmitter in this local circuit acts on the secondary winding *3* of the induction coil, and produces therein alternating currents which pass to the central office and are in turn repeated to the distant station.

Supply Many Lines from Common Source. We come now to the consideration of the arrangement by which a single battery may be made to supply current at the central office to a large number of pairs of connected lines simultaneously. Up to this point in this discussion it has been shown only how each battery served a single pair of connected lines and no others.

Repeating Coil:—In Fig. 138 is shown how a single battery supplies current simultaneously to four different pairs of lines, the lines of each pair being connected for conversation. It is seen that the pairs of lines shown in this figure are arranged in each case in accordance with the system shown in Fig. 130. Let us inquire why it is that, although all of these four pairs of lines are connected with a common source of energy and are, therefore, all conductively joined, the stations will be able to communicate in pairs without interference between the pairs. In other words, why is it that voice currents originating at Station A will pass only to the receiver at Station B and not to the receivers at Station C or Station H, for instance? The reason is that separate supply conductors lead from the points such as *1* and *2* at the junctions of the repeating-coil windings on each pair of circuits to the battery terminals, and the resistance

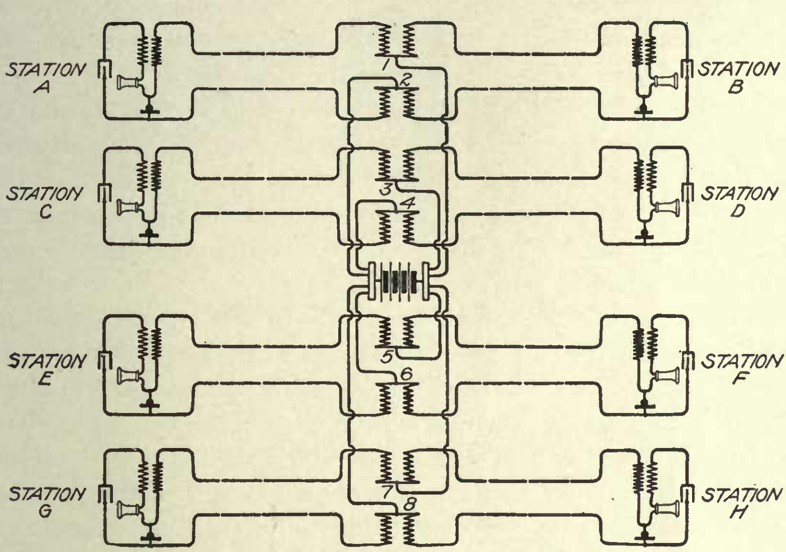


Fig. 138. Common Source for Many Lines

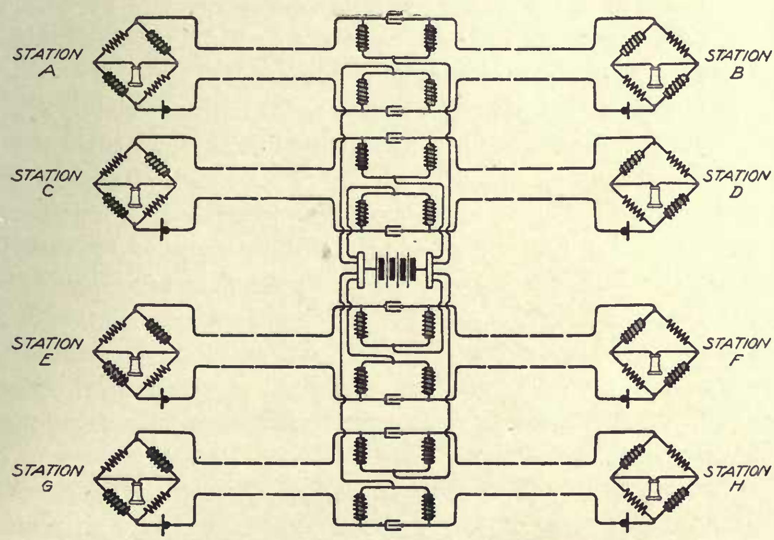


Fig. 139. Common Source for Many Lines

and impedance of the battery itself and of the common leads to it are so small that although the feeble voice currents originating in the pair of lines connecting Station A and Station B pass through the battery, they are not able to alter the potential of the battery in any appreciable degree. As a result, therefore, the supply wires leading from the common-battery terminals to the points *7* and *8*, for instance, cannot be subjected to any variations in potential by virtue of currents flowing through the battery from the points *1* and *2* of the lines joining Station A and Station B.

Retardation Coil—Single Battery:—In Fig. 139 is shown in similar manner the current supply from a single battery to four different pairs of lines, the battery being associated with the lines by the combined impedance coil and condenser method, which was specifically dealt with in connection with Fig. 133. The reasons why there will be no interference between the conversations carried on in the various pairs of connected lines in this case are the same as those just considered in connection with the system shown in Fig. 138. The impedance coils in this case serve to keep the telephone currents confined to their respective pairs of lines in which they originate, and this same consideration applies to the system of Fig. 138, for each of the separate repeating-coil windings of Fig. 138 is in itself an impedance coil with respect to such currents as might leak away from one pair of lines on to another.

Retardation Coil—Double Battery:—The arrangement of feeding a number of pairs of lines according to the Kellogg two-battery system is indicated in Fig. 140, which needs no further explanation in view of the description of the preceding figures. It is interesting to note in this case that the left-hand battery serves only the left-hand lines and the right-hand battery only the right-hand lines. As this is worked out in practice, the left-hand battery is always connected to those lines which originate a call and the right-hand battery always to those lines that are called for. The energy supplied to a calling line is always, therefore, from a different source than that which supplies a called line.

Current Supply from Distant Point. Sometimes it is convenient to supply current to a group of lines centering at a certain point from a source of current located at a distant point. This is often the case in the so-called private branch exchange, where a

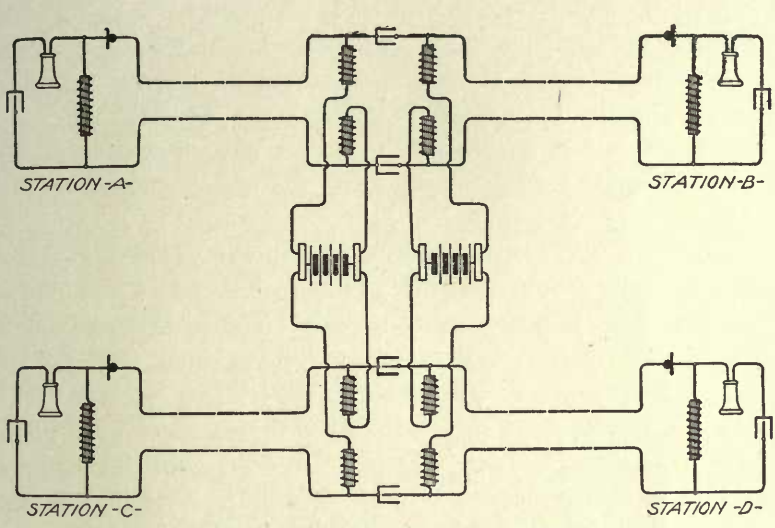


Fig. 140. Two Sources for Many Lines

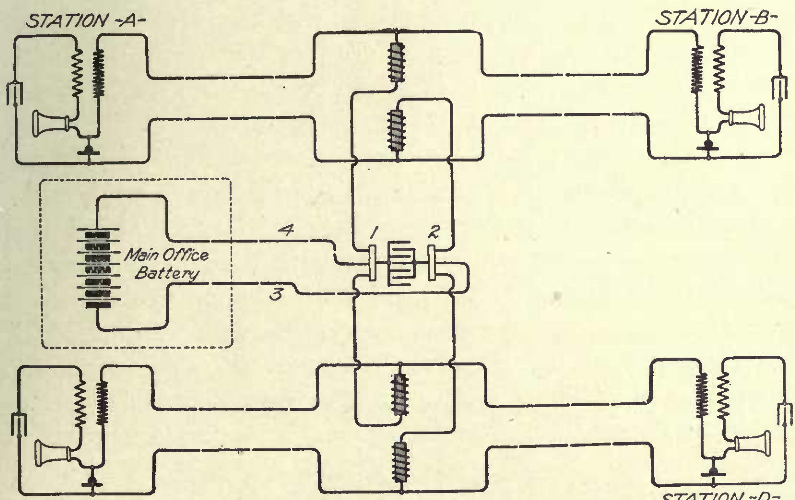


Fig. 141. Current Supply from Distant Point

given business house or other institution is provided with its own switchboard for interconnecting the lines leading to the various telephones of that concern or institution among themselves, and also for connecting them with lines leading to the city exchange. It is not always easy or convenient to maintain at such private switchboards a separate battery for supplying the current needed by the local exchange.

In such cases the arrangement shown in Fig. 141 is sometimes employed. This shows two pairs of lines connected by the impedance-coil system with common terminals *1* and *2*, between which ordinarily the common battery would be connected. Instead of putting a battery between these terminals, however, at the local exchange, a condenser of large capacity is connected between them and from these terminals circuit wires *3* and *4* are led to a battery of suitable voltage at a distant central office. The condenser in this case is used to afford a short-circuit path for the voice currents that leak from one side of one pair of lines to the other, through the impedance coils bridged across the line. In this way the effect of the necessarily high resistance in the common leads *3* and *4*, leading to the storage battery, is overcome and the tendency to cross-talk between the various pairs of connected lines is eliminated. Frequently, instead of employing this arrangement, a storage battery of small capacity will be connected between the terminals *1* and *2*, instead of the condenser, and these will be charged over the wires *3* and *4* from a source of current at a distant point.

A consideration of the various methods of supplying current from a common source to a number of lines will show that it is essential that the resistance of the battery itself be very low. It is also necessary that the resistance and the impedance of the common leads from the battery to the point of distribution to the various pairs of lines be very low, in order that the voice currents which flow through them, by virtue of the conversations going on in the different pairs of lines, shall not produce any appreciable alteration in the difference of potential between the battery terminals.

CHAPTER XIV

THE TELEPHONE SET

We have considered what may be called the elemental parts of a complete telephone; that is, the receiver, transmitter, hook switch, battery, generator, call bell, condenser, and the various kinds of coils which go to make up the apparatus by which one is enabled to transmit and receive speech and signals. We will now consider the grouping of these various elements into a complete working organization known as a telephone.

Before considering the various types it is well to state that the term telephone is often rather loosely used. We sometimes hear the receiver proper called a telephone or a hand telephone. Since this was the original speaking telephone, there is some reason for so calling the receiver. The modern custom more often applies the term telephone to the complete organization of talking and signaling apparatus, together with the associated wiring and cabinet or standard on which it is mounted. The name telephone set is perhaps to be preferred to the word telephone, since it tends to avoid misunderstanding as to exactly what is meant. Frequently, also, the telephone or telephone set is referred to as a subscriber's station equipment, indicating the equipment that is to be found at a subscriber's station. This, as applying to a telephone alone, is not proper, since the subscriber's station equipment includes more than a telephone. It includes the local wiring within the premises of the subscriber and also the lightning arrester and other protective devices, if such exist.

To avoid confusion, therefore, the collection of talking and signaling apparatus with its wiring and containing cabinet or standard will be referred to in this work as a telephone or telephone set. The receiver will, as a rule, be designated as such, rather than as a telephone. The term subscriber's station equipment will refer to the complete equipment at a subscriber's station, and will include the telephone set, the interior wiring, and the protective devices, together with any other apparatus that may be associated with the telephone line and be located within the subscriber's premises.

Classification of Sets. Telephones may be classified under two general headings, magneto telephones and common-battery telephones, according to the character of the systems in which they are adapted to work.

Magneto Telephone. The term magneto telephone, as it was originally employed in telephony, referred to the type of instrument now known as a receiver, particularly when this was used also as a transmitter. As the use of this instrument as a transmitter has practically ceased, the term magneto telephone has lost its significance as applying to the receiver, and, since many telephones are equipped with magneto generators for calling purposes, the term magneto telephone has, by common consent, come to be used to designate any telephone including, as a part of its equipment, a magneto generator. Magneto telephones usually, also, include local batteries for furnishing the transmitter with current, and this has led to these telephones being frequently called local battery telephones. However, a local battery telephone is not necessarily a magneto telephone and *vice versâ,* since sometimes magneto telephones have no local batteries and sometimes local battery telephones have no magnetos. Nearly all of the telephones which are equipped with magneto generators are, however, also equipped with local batteries for talking purposes, and, therefore, the terms magneto telephone and local battery telephone usually refer to the same thing.

Common-Battery Telephone. Common-battery telephones, on the other hand, are those which have no local battery and no magneto generator, all the current for both talking and signaling being furnished from a common source of current at the central office.

Wall and Desk Telephones. Again we may classify telephones or telephone sets in accordance with the manner in which their various parts are associated with each other for use, regardless of what parts are contained in the set. We may refer to all sets adapted to be mounted on a wall or partition as *wall telephones,* and to all in which the receiver, transmitter, and hook are provided with a standard of their own to enable them to rest on any flat surface, such as a desk or table, as *desk telephones.* These latter are also referred to as portable telephones and as portable desk telephones.

In general, magneto or local battery telephones differ from common-battery telephones in their component parts, the difference residing principally in the fact that the magneto telephone always has a magneto generator and usually a local battery, while the common-battery telephone has no local source of current whatever. On the other hand, the differences between wall telephones and desk telephones are principally structural, and obviously either of these types of telephones may be for common-battery or magneto work. The same component parts go to make up a desk telephone as a wall telephone, provided the two instruments are adapted for the same

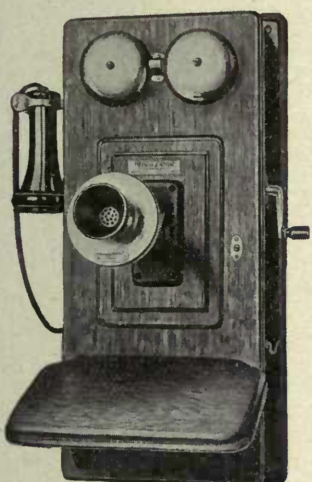


Fig. 142. Magneto Wall Set

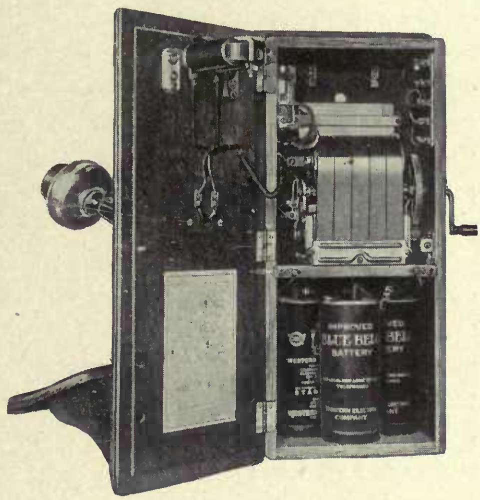


Fig. 143. Magneto Wall Set

class of service, but the difference between the two lies in the structural features by which these same parts are associated with each other and protected from exposure.

Magneto-Telephone Sets. *Wall.* In Fig. 142 is shown a familiar type of wall set. The containing box includes within it all of the working parts of the apparatus except that which is necessarily left outside in order to be within the reach of the user. Fig. 143 shows the same set with the door open. This gives a good idea of the ordinary arrangement of the apparatus within. It is seen that the polarized bell or ringer has its working parts mounted on the inside of the door or cover of the box, the tapper projecting through so as to play between the gongs on the outside. Likewise the transmitter arm, which supports the transmitter and allows its adjustment up and down to accommodate itself to the height of the user, is mounted on the front of the door, and the conductors leading to it may be seen fastened to the rear of the door in Fig. 143.

In some wall sets the wires leading to the bell and transmitter are connected to the wiring of the rest of the set through the hinges of the door, thus allowing the door to be opened and closed repeatedly without breaking off the wires. In order to always insure positive electrical contact between the stationary and movable parts of the hinge a small wire is wound around the hinge pin, one end being soldered to the stationary part and the other end to the movable part of the hinge. In other forms of wall set the wires to the bell and the transmitter lead directly from the stationary portion of the cabinet to the back of the door, the wires being left long enough to have sufficient flexibility to allow the door to be opened and closed without injuring the wires.

At the upper portion of the box there is mounted the hook switch, this being, in this case, of the short lever type. The lever of the hook projects through the side of the box so as to make the hook available as a support for the receiver. Immediately at the right of the hook switch is mounted the induction coil, and immediately below this the generator, its crank handle projecting through the right-hand side of the box so as to be available for use there. The generator is usually mounted on a transverse shelf across the middle of the cabinet, this shelf serving to form a compartment below it in which the dry battery of two or three cells is placed.

The wall telephone-set cabinets have assumed a multitude of forms. When wet cells rather than dry cells were ordinarily employed, as was the case up to about the year 1895, the magneto generator, polarized bell, and hook switch were usually mounted in a rectangular box placed at the top of a long backboard. Immediately below this on the backboard was mounted the transmitter arm, and sometimes the base of this included the induction coil. Below this was the battery box, this being a large affair usually adapted to accommodate two and sometimes three ordinary LeClanché cells side by side.

The dry cell has almost completely replaced the wet cell in this country, and as a result, the general type of wall set as shown in Figs. 142 and 143, has gradually replaced the old wet-cell type, which was more cumbrous and unsightly. It is usual on wall sets to provide some sort of a shelf, as indicated in Fig. 142, for the convenience of the user in making notes and memoranda.

Desk. In the magneto desk-telephone sets, the so-called desk stand, containing the transmitter, the receiver, and the hook switch, with the standard upon which they are mounted, is shown in Fig. 144. This desk stand evidently does not comprise the complete equipment for a magneto desk-telephone set, since the generator, polarized bell, and battery are lacking. The generator and bell are usually mounted together in a box, either on the under side of the desk of the user or on the wall within easy reach of his chair. Connections are made between the apparatus in the desk stand proper and the battery, generator, and bell by means of flexible conducting cords, these carrying a plurality of conductors, as required by the particular circuit of the telephone in question. Such a complete magneto desk-telephone set is shown in Fig. 145, this being one of the types manufactured by the Stromberg-Carlson Manufacturing Company.

Fig. 144. Desk Stand

A great variety of arrangements of the various parts of magneto desk-telephone apparatus is employed in practice. Sometimes, as shown in Fig. 145, the magneto bell box is equipped with binding posts for terminating all of the conductors in the cord, the line wires also running to some of these binding posts.

In the magneto-telephone set illustrated the box is made large enough to accommodate only the generator and call bell, and the batteries are mounted elsewhere, as in a drawer of the desk, while in other cases there is no other equipment but that shown in the cut, the batteries being mounted within the magneto bell box itself. In still other cases, the polarized bell is contained in one box, the generator in another, the batteries in the drawer of the desk, the induction coil being mounted either in the base of the desk stand, in the bell box, or in the generator box. In such cases all of the circuits of the various scattered parts are wired to a terminal strip, located at some convenient point, this strip containing terminals for all the wires leading from the various parts and for the line wires themselves. By combining the various wires on the terminals of this terminal strip, the complete circuits of the telephone are built up. In still other cases the induction coil is mounted on the terminal strip and separate wires or sets of wires are run to the polarized bell and generator, to the desk stand itself, and to the batteries. These various arrangements are subject largely to the desire or personal ideas of the manufacturer or user. All of them work on the same principle so far as the operation of the talking and signaling circuits is concerned.

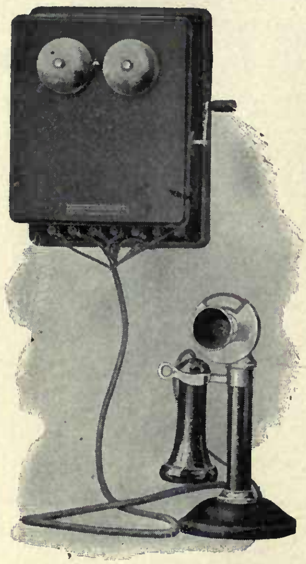


Fig. 145. Magneto Desk Set

Circuits of Magneto-Telephone Sets. Magneto telephones, whether of the wall or desk type, may be divided into two general classes, series and bridging, according to whether the magnet of the bell is included in series or bridge relation with the telephone line when the hook is down.

Series. In the so-called series telephone line, where several telephones are placed in series in a single line circuit, the employment of the series type of telephone results in all of the telephone bells being in series in the line circuit. This means that the voice currents originating in the telephones that are in use at a given time must pass in series through the magnets of the bells of the stations that are not in use. In order that these magnets, through which the voice currents must pass, may interfere to as small a degree as possible with the voice currents, it is common to employ low-resistance magnets in series telephones, these magnets being wound with comparatively few turns and on rather short cores so that the impedance will be as small as possible. Likewise, since the generators are required to ring all of the bells in series, they need not have a large current output, but must have sufficient voltage to ring through all of the bells in series and through the resistance of the line. For this reason the generators are usually of the three-bar type and sometimes have only two bars.

In Fig. 146 are shown, in simplified form, the circuits of an ordinary series telephone. The receiver in this is shown as being removed from the hook and thus the talking apparatus is brought into play. The line wires *1* and *2* connect respectively to the binding posts *3* and *4*, which form the terminals of the instrument. When the hook is up, the circuit between the binding posts *3* and *4* includes the receiver and the secondary winding of the induction coil, together with one of the upper contacts *5* of the switch hook and the hook lever itself. This completes the circuit for receiving speech. The hook switch is provided with another upper contact *6*, between which and the contact *5* is connected the local circuit containing the transmitter, the battery, and the primary of the induction coil in series. The primary and the secondary windings are connected together at one end and connected with the switch contact *5*, as shown. It is thus seen that when the hook is up the circuit through the receiver is automatically closed and also the local circuit containing the primary, the battery, and the transmitter. Thus, all the conditions for transmitting and receiving speech are fulfilled.

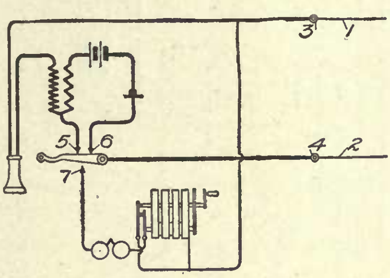


Fig. 146. Circuit of Series Magneto Set

When the hook is down, however, the receiving and transmitting circuits are broken, but another circuit is completed by the engagement of the hook-switch lever with the lower hook contact 7. Between this contact and one side of the line is connected the polarized ringer and the generator. With the hook down, therefore, the circuit may be traced from the line wire *1* to binding post *3*, thence through the generator shunt to the call bell, and thence through the lower switching contact *7* to the binding post *4* and line wire *2*. The generator shunt, as already described in Chapter VIII, normally keeps the generator shunted out of circuit. When, however, the generator is operated the shunt is broken, which allows the armature of the generator to come into the circuit in series with the winding of the polarized bell. The normal shunting of the generator armature from the circuit of the line is advantageous in several ways. In the first place, the impedance of the generator winding is normally cut out of the circuit so that in the case of a line with several stations the talking or voice currents do not have to flow through the generator armatures at the stations which are not in use. Again, the normal shunting of the generator tends to save the generator armature from injury by lightning.

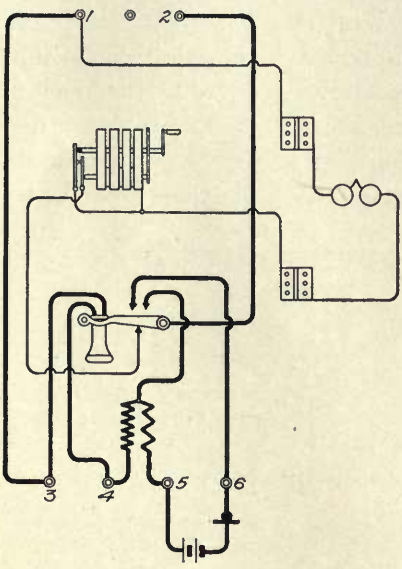


Fig. 147. Circuit of Series Magneto Set

The more complete circuits of a series magneto telephone are shown in Fig. 147. In this the line binding posts are shown as *1* and *2*. At the bottom of the telephone cabinet are four other binding posts marked *3*, *4*, *5*, and *6*. Of these *3* and *4* serve for the receiver terminals and *5* and *6* for the transmitter and battery terminals. The circuits of this diagram will be found to be essentially the same as those of Fig. 146, except that they are shown in greater detail. This particular type of circuit is one commonly employed where the generator, ringer, hook switch, and induction coil are all mounted in a so-called magneto bell box at the top of the instrument, and where the transmitter is mounted on an arm just below this box, and the battery in a separate compartment below the transmitter. The only wiring that has to be done between the bell box and the other parts of the instrument in assembling the complete telephone is to connect the receiver to the binding posts *3* and *4* and to connect the battery and transmitter circuit to the binding posts *5* and *6*.

Bridging. In other cases, where several telephones are placed on a single-line circuit, the bells are arranged in multiple across the line. For this reason their magnets are wound with a very great number of turns and consequently to a high resistance. In order to further increase the impedance, the cores are made long and heavy. Since the generators on these lines must be capable of giving out a sufficient volume of current to divide up between all of the bells in multiple, it follows that these generators must have a large current output, and at the same time a sufficient voltage to ring the bells at the farthest end of the line. Such instruments are commonly called bridging instruments, on account of the method of connecting their bells across the circuit of the line.

The fundamental characteristic of the bridging telephone is that it contains three possible bridge paths across the line wires. The first of these bridge paths is through the talking apparatus, the second through the generator, and the third through the ringer. This is shown in simplified form in Fig. 148. The talking apparatus is associated with the two upper contacts of the hook switch in the usual manner and needs no further description. The generator is the second separate bridge path, normally open, but adapted to be closed when the generator is operated, this automatic closure being performed by the movement of the crank shaft. The third bridge contains the polarized bell, and this, as a rule, is permanently closed. Sometimes, however, the arrangement is such that the bell path is normally closed through the switch which is operated by the generator crank shaft, and this path is automatically broken when the generator is operated, at which time, also, the generator path is automatically closed. This arrangement brings about the result that the generator never can ring its own bell, because its switch always operates to cut out the bell at its own station just before the generator itself is cut into the circuit.

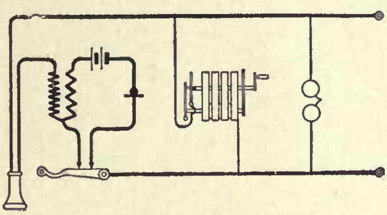


Fig. 148. Circuit of Bridging Magneto Set

In Fig. 149 is shown the complete circuit of a bridging telephone. The circuit given in this figure is for a local-battery wall set similar in type to that shown in Figs. 142 and 143. A simplified diagrammatic arrangement is shown in the lower left-hand corner of this figure, and from a consideration of this it will be seen that the bell circuit across the line is normally completed through the two right-hand normally closed contacts of the switch on the generator. When, however, the generator is operated these two contacts are made to disengage each other while the long spring of the generator switch engages the left-hand spring and thus brings the generator itself into the circuit.

Of the three binding posts, *1*, *2*, and *3*, at the top of Fig. 149, *1* and *2* are for connecting with the line wires, while *3* is for a ground connection, acting in conjunction with the lightning arrester mounted at the top of the telephone and indicated at *4* in Fig. 149. This has no function in talking or ringing, and will be referred to more fully in Chapter XIX. Suffice it to say at this point that these arresters usually consist of two conducting bodies, one connected permanently to each of the line binding posts, and a third conducting body connected to the ground binding post. These three conducting bodies are in close proximity but carefully insulated from each other; the idea being that when the line wires are struck by lightning or subjected otherwise to a dangerous potential, the charge on the line will jump across the space between the conducting bodies and pass harmlessly to ground.

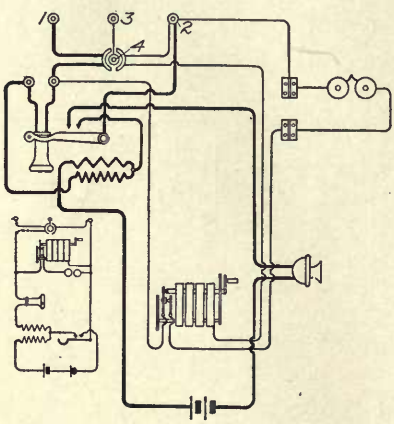


Fig. 149. Circuit of Bridging Magneto Set

If the large detailed circuit of Fig. 149 be compared with the small theoretical circuit in the same figure, the various conducting

NOTE. The student should practice making simplified diagrams from actual wiring diagrams. The difference between the two is that one is laid out for ease in understanding it, while the other is laid out to show the actual course of the wires as installed.

paths will be found to be the same. Such a simplified circuit does more to enable one to grasp the fundamental scheme of a complex circuit than much description, since it shows at a glance the general arrangement. The more detailed circuits are, however, necessary to show the actual paths followed by the wiring.

The circuits of desk stands do not differ from those of wall sets in any material degree, except as may be necessitated by the fact that the various parts of the telephone set are not all mounted in the same cabinet or on the same standard. To provide for the necessary relative movement between the desk stand and the other portions of the set, flexible conductors are run from the desk stand itself to the stationary portions of the equipment, such as the battery and the parts contained in the generator and bell box.

In Fig. 150 is shown the circuit of the Stromberg-Carlson magneto desk-telephone set, illustrated in Fig. 145. This diagram needs no explanation in view of what has already been said. The conductors, leading from the desk-stand group of apparatus to the bell-box group of apparatus, are grouped together in a flexible cord, as shown in Fig. 145, and are connected respectively to the various binding posts or contact points within the desk stand at one end and at the base of the bell box at the other end. These flexible conductors are insulated individually and covered by a common braided covering. They usually are individualized by having a colored thread woven into their insulating braid, so that it is an easy matter to identify the two ends of the same conductor at either end of the flexible cord or cable.

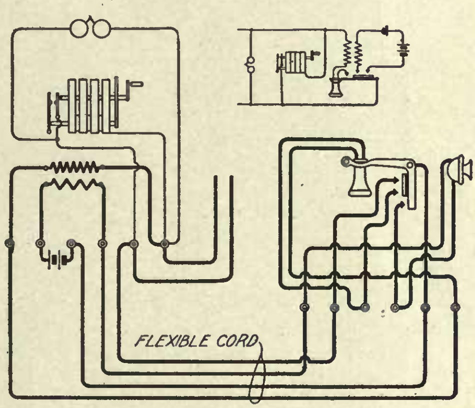


Fig. 150. Circuit of Bridging Magneto Desk Set

Common-Battery Telephone Sets. Owing to the fact that common-battery telephones contain no sources of current, they are usually somewhat simpler than the magneto type. The component parts of a common-battery telephone, whether of the wall or desk type, are the transmitter, receiver, hook switch, polarized bell, condenser, and sometimes an induction coil. The purpose of the condenser is to prevent direct or steady currents from passing through the windings of the ringer while the ringer is connected across the circuit of the line during the time when the telephone is not in use. The requirements of common-battery signaling demand that the ringer shall be connected

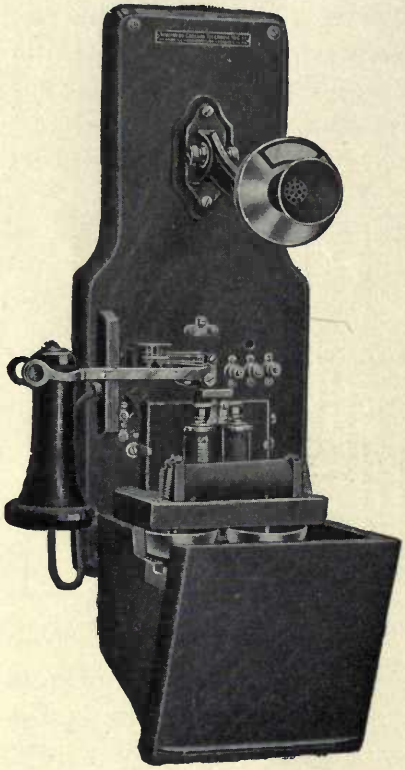


Fig. 151. Common-Battery Wall Set

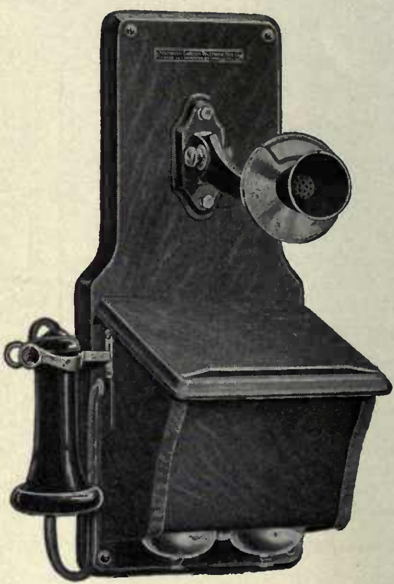


Fig. 152. Common-Battery Wall Set

with the line so as to be receptive of a call at any time while the telephone is not in use. The requirements also demand that no conducting path shall normally exist between the two sides of the line. These two apparently contradictory requirements are met by placing a condenser in series with the ringer so that the ringer will be in a path that will readily transmit the alternating ringing currents sent out from the central-office generator, while at the same time the condenser will afford a complete bar to the passage of steady currents. Sometimes the condenser is also used as a portion of the talking apparatus, as will be pointed out.

Wall. In Figs. 151 and 152 are given two views of a characteristic form of common-battery wall-telephone set, made by the Stromberg-Carlson Manufacturing Company. The common-battery wall set has usually taken this general form. In it the transmitter is mounted on an adjustable arm at the top of the backboard, while the box containing the bell and all working parts of the instrument is placed below the transmitter, the top of the box affording a shelf for writing purposes. In Fig. 151 are shown the hook switch and the receiver; just below these may be seen the magnets of the polarized bell, back of which is shown a rectangular box containing the condenser. Immediately in front of the ringer magnets is the induction coil.

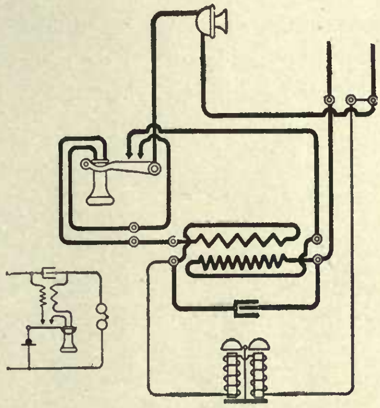


Fig. 153. Stromberg-Carlson Common-Battery Wall Set

In Fig. 153 are shown the details of the circuit of this instrument. This figure also includes a simplified circuit arrangement from which the principles involved may be more readily understood. It is seen that the primary of the induction coil and the transmitter are included in series across the line. The secondary of the induction coil, in series with the receiver, is connected also across the line in series with a condenser and the transmitter.

Hotel. Sometimes, in order to economize space, the shelf of common-battery wall sets is omitted and the entire apparatus mounted in a small rectangular box, the front of which carries the transmitter mounted on the short arm or on no arm at all. Such instruments are commonly termed hotel sets, because of the fact that their use was first confined largely to the rooms in hotels. Later, however, these instruments have become very popular in general use, particularly in residences. Sometimes the boxes or cabinets of these sets are made of wood, but of recent years the tendency has been growing to make them of pressed steel. The steel box is usually finished in black enamel, baked on, the color being sometimes varied to match the color of the surrounding woodwork. In Figs. 154 and 155 are shown two views of a common-battery hotel set manufactured by the Dean Electric Company.

Such sets are extremely neat in appearance and have the advantage of taking up little room on the wall and the commercial advantage of being light and compact for shipping purposes. A possible disadvantage of this type of instrument is the somewhat crowded condition which necessarily follows from the placing of all

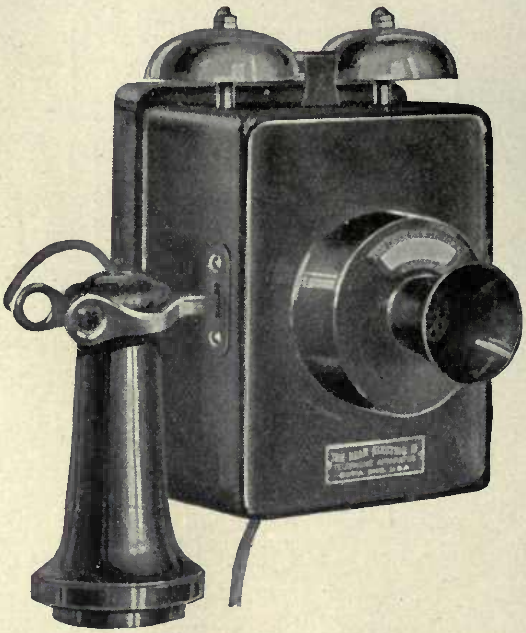


Fig. 154. Steel Box Hotel Set

the parts in so confined a space. This interferes somewhat with the accessibility of the various parts, but great ingenuity has been manifested in making the parts readily get-at-able in case of necessity for repairs or alterations.

Desk. The common-battery desk telephone presents a somewhat simpler problem than the magneto desk telephone for the reason that the generator and local battery, the two most bulky parts of a magneto telephone, do not have to be provided for. Some companies, in manufacturing desk stands for common-battery purposes, mount the condenser and the induction coil or impedance coil, or whatever device is used in connection with the talking cir-

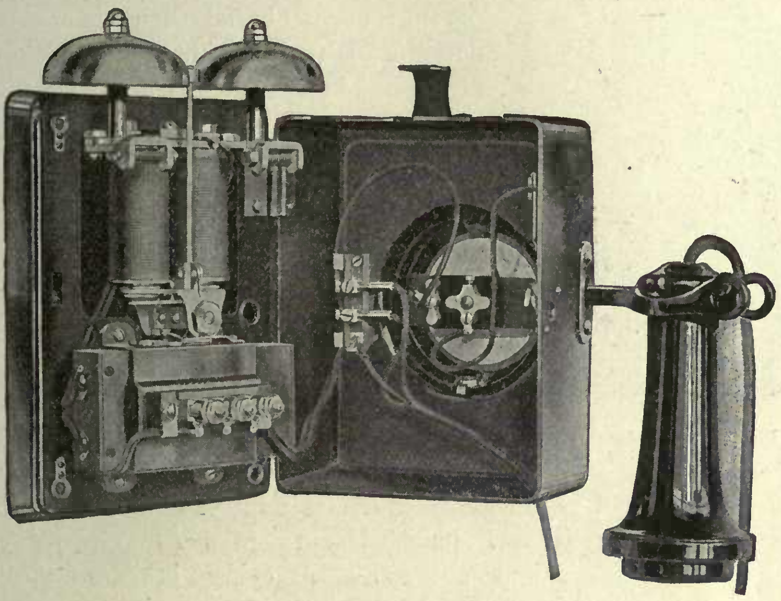


Fig. 155. Steel Box Hotel Set

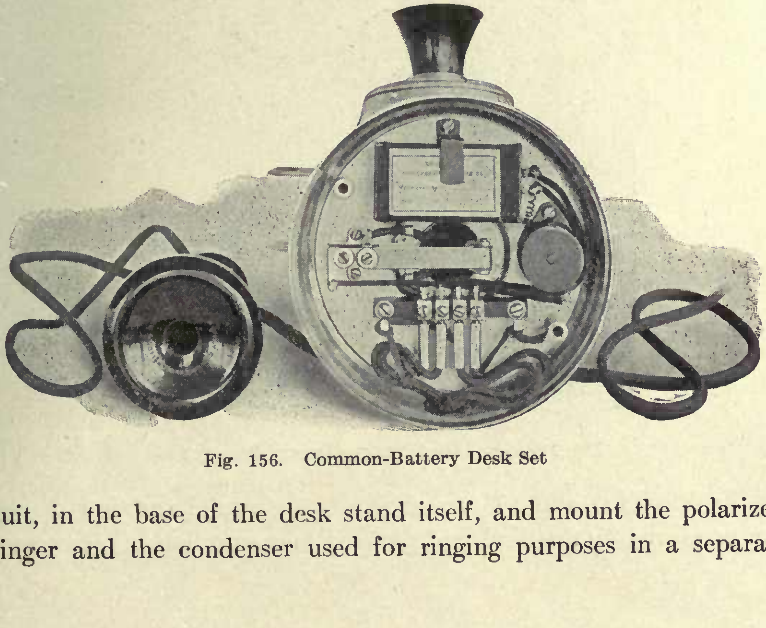


Fig. 156. Common-Battery Desk Set

cuit, in the base of the desk stand itself, and mount the polarized ringer and the condenser used for ringing purposes in a separate bell box adapted to be mounted on thc wall or some portion of the desk. Other companies mount only the transmitter, receiver, and hook switch on the desk stand proper and put the condenser or induction coil, or other device associated with the talking circuit, in the bell box. There is little to choose between the two general practices. The number of conducting strands in the flexible cord is somewhat dependent on the arrangement of the circuit employed.

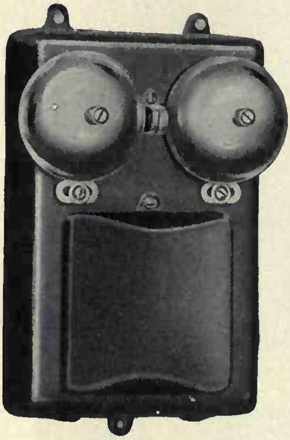


Fig. 157. Bell for Common-Battery Desk Set

The Kellogg Switchboard and Supply Company is one which places all the parts, except the polarized ringer and the associated condenser, in the desk stand itself. In Fig. 156 is shown a bottom view of the desk stand with the bottom plate removed. In the upper portion of the circle of the base is shown a small condenser which is placed in the talking circuit in series with the receiver. In the right-hand portion of the circle of the base is shown a small impedance coil, which is placed in series with the transmitter but in shunt relation with the condenser and the receiver.

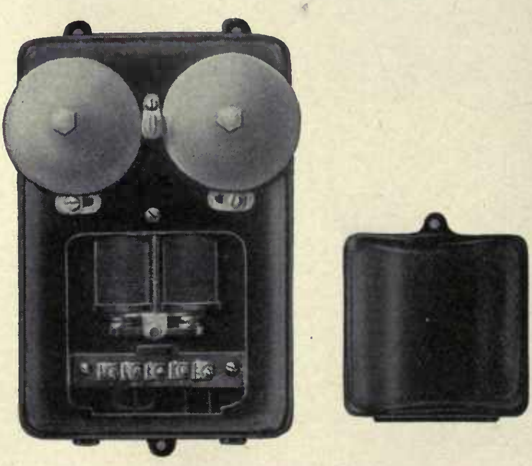


Fig. 158. Bell for Common-Battery Desk Set

In Figs. 157 and 158 are shown two views of the type of bell box employed by the Kellogg Company in connection with the common-battery desk sets, this box being of pressed-steel construction and having a removable lid, as shown in Fig. 158, by which the working parts of the ringer are made readily accessible, as are also the terminals for the cord leading from the desk stand and for the wires of the line circuit. The condenser that is placed in series with the ringer is also mounted in this same box. By employing two condensers, one in the bell box large enough to transmit ringing currents and the other in the base of the desk stand large enough only to trans-

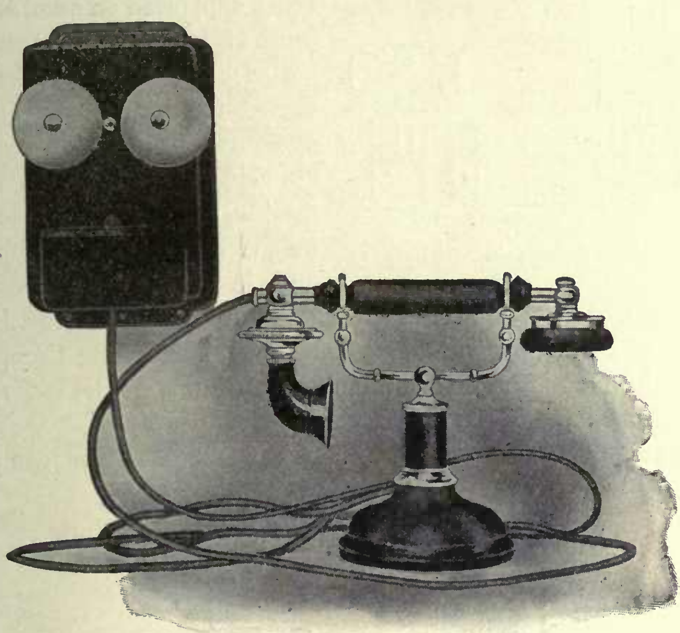


Fig. 159. Microtelephone Set

mit voice currents, a duplication of condensers is involved, but it has the corresponding advantages of requiring only two strands to the flexible cord leading from the bell box to the desk stand proper.

A form of desk-telephone set that is used largely abroad, but that has found very little use in this country, is shown in Fig. 159. In this the transmitter and the receiver are permanently attached together, the receiver being of the watch-case variety and so positioned relatively to the transmitter that when the receiver is held at the ear, the mouthpiece of the transmitter will be just in front of the lips of the user. In order to maintain the transmitter in a vertical position during use, this necessitates the use of a curved mouthpiece as shown. This transmitter and receiver so combined is commonly called, in this country, the *microtelephone set,* although there seems to be no logical reason for this name. The combined transmitter and receiver, instead of being supported on an ordinary form of hook switch, are supported on a forked bracket as shown, this bracket serving to operate the switch springs which are held in one position when the bracket is subjected to the weight of the microtelephone, and in the alternate position when relieved therefrom. This particular microtelephone set is the product of the L. M. Ericsson Telephone Manufacturing Company, of Buffalo, New York. The circuits of such sets do not differ materially from those of the ordinary desk telephone set.

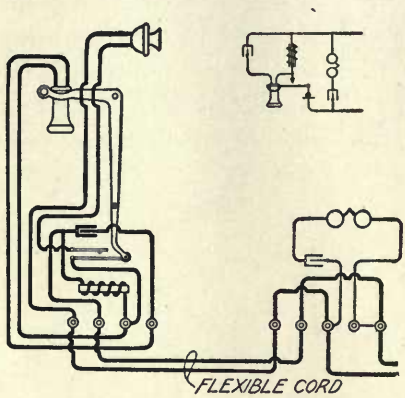


Fig. 160. Kellogg Common-Battery Desk Set

Circuits of Common-Battery Telephone Sets. The complete circuits of the Kellogg desk-stand arrangement are shown in Fig. 160, the desk-stand parts being shown at the left and the bell-box

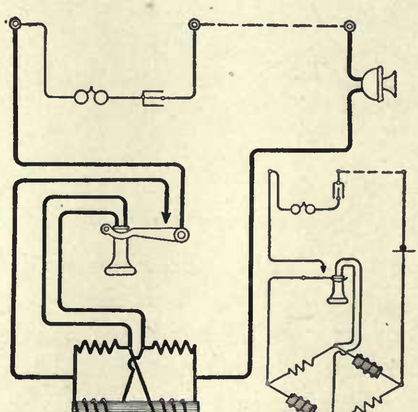


Fig. 161. Dean Common-Battery Set

parts at the right. As is seen, but two conductors extend from the former to the latter. A simplified theoretical sketch is also shown in the upper right-hand corner of this figure.

The details of the common-battery telephone circuits of the Dean Electric Company are shown in Fig. 161. This involves the use of the balanced Wheatstone bridge. The only other thing about this circuit that needs description, in view of what has previously been said about it, is that the polarized bell is placed in series with a condenser so that the two sides of the circuit may be insulated from each other while the telephone is not in use, and yet permit the passage of ringing current through the bell.

The use of the so-called direct-current receiver has brought about a great simplification in the common-battery telephone cir-

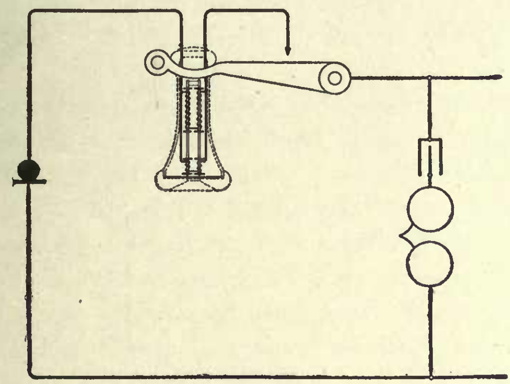


Fig. 162. Monarch Common-Battery Wall Set

cuits of several of the manufacturing companies. By this use the transmitter and the receiver are placed in series across the line, this path being normally opened by the hook-switch contacts. The polarized bell and condenser are placed in another bridge path across the line, this path not being affected by the hook-switch contacts. All that there is to such a complete common-battery telephone set, therefore, is a receiver, transmitter, hook switch, bell, condenser, and cabinet, or other support.

The extreme simplicity of the circuits of such a set is illustrated in Fig. 162, which shows how the Monarch Telephone Manufacturing Company connect up the various parts of their telephone set, using the direct-current receiver already described in connection with Fig. 54.

CHAPTER XV

NON-SELECTIVE PARTY-LINE SYSTEMS

A party line is a line that is for the joint use of several stations. It is, therefore, a line that connects a central office with two or more subscribers' stations, or where no central office is involved, a line that connects three or more isolated stations with each other. The distinguishing feature of a party line, therefore, is that it serves more than two stations, counting the central office, if there is one, as a station.

Strictly speaking, the term *party* line should be used in contradistinction to the term *private* line. Companies operating telephone exchanges, however, frequently lease their wires to individuals for private use, with no central-office switchboard connections, and such lines are, by common usage, referred to as "private lines." Such lines may be used to connect two or more isolated stations. A *private* line, in the parlance of telephone exchange working, may, therefore, be a *party* line, as inconsistent as this may seem.

A telephone line that is connected with an exchange is an exchange line, and it is a party line if it has more than one station on it. It is an individual line or a single party line if it has but a single station on it. A line which has no central-office connection is called an "isolated line," and it is a party line if it has more than two stations on it.

The problem of mere speech transmission on party lines is comparatively easy, being scarcely more complex than that involved in private or single party lines. This is not true, however, of the problem of signaling the various stations. This is because the line is for the common use of all its patrons or subscribers, as they are termed, and the necessity therefore exists that the person sending a signal, whether operator or subscriber, shall be able in some way to inform a person at the desired station that the call is intended for that station. There are two general ways of accomplishing this purpose.

(*1*) The first and simplest of these ways is to make no provision for ringing any one bell on the line to the exclusion of the others, and thus allow all bells to ring at once whenever any station on the line is wanted. Where this is done, in order to prevent all stations from answering, it is necessary, in some way, to convey to the desired station the information that the call is intended for that station, and to all of the other stations the information that the call is not intended for them. This is done on such lines by what is called "code ringing," the code consisting of various combinations of long and short rings.

(*2*) The other and more complex way is to arrange for selective ringing, so that the person sending the call may ring the bell at the station desired, allowing the bells at all the other stations to remain quiet.

These two general classes of party-line systems may, therefore, be termed "non-selective" and "selective" systems. Non-selective

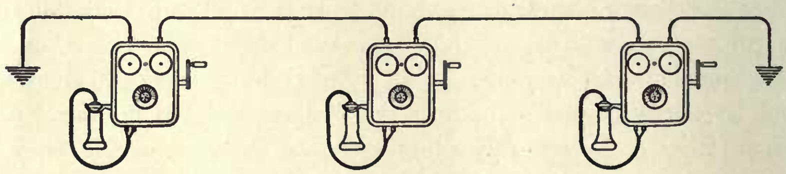


Fig. 163. Grounded-Circuit Series Line

party lines are largely used both on lines having connection with a central office, and through the central office the privilege of connection with other lines, and on isolated lines having no central-office connection. The greatest field of usefulness of non-selective lines is in rural districts and in connection with exchanges in serving rather sparsely settled districts where the cost of individual lines or even lines serving but a few subscribers, is prohibitive.

Non-selective telephone party lines most often employ magneto telephones. The early forms of party lines employed the ordinary series magneto telephone, the bells being of low resistance and comparatively low impedance, while the generators were provided with automatic shunting devices, so that their resistance would normally be removed from the circuit of the line.

Series Systems. The general arrangement of a series party line employing a ground return is shown in Fig. 163. In this three ordinary series instruments are connected together in series, the end stations being grounded, in order to afford a return path for the ringing and voice currents.

In Fig. 164 there is shown a metallic-circuit series line on which

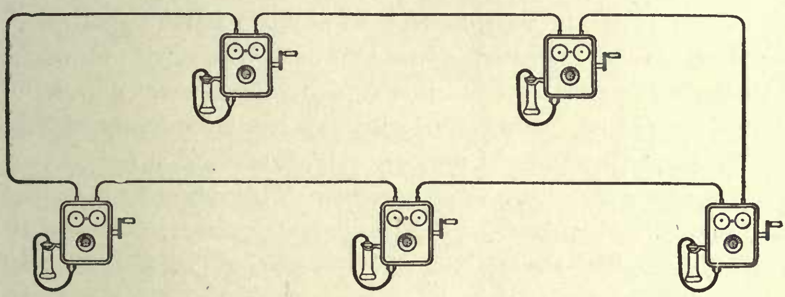


Fig. 164. Metallic-Circuit Series Line

five ordinary series telephones are placed in series. In this no ground is employed, the return being through a line wire, thus making the circuit entirely metallic.

The limitations of the ordinary series party line may be best understood by reference to Fig. 165, in which the circuits of three series telephones are shown connected with a single line. The receiver of Station A is represented as being on its hook, while the receivers of Stations B and C are removed from their hooks, as when the subscribers at those two stations are carrying on a conversation.

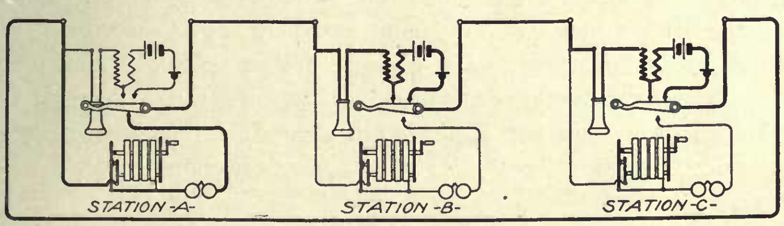


Fig. 165. Series Party Line

The hook switches of Stations B and C being in raised positions, the generators and ringers of those stations are cut out of the circuit, and only the telephone apparatus proper is included, but the hook switch of Station A being depressed by the weight of its receiver, includes the ringer of that station in circuit, and through this ringer, therefore, the voice currents of Stations B and C must pass.

The generator of Station A is not in the circuit of voice currents, however, because of the automatic shunt with which the generator is provided, as described in Chapter VIII.

A slight consideration of the series system as shown in this figure, indicates that the voice currents of any two stations that are in use, must pass (as indicated by the heavy lines) through the ringers of all the stations that are not in use; and when a great number of stations are placed upon a single line, as has been frequently the case, the impedance offered by these ringers becomes a serious barrier to the passage of the voice currents. This defect in the series party line is fundamental, as it is obvious that the ringers must be left in the circuit of the stations which are not in use, in order that those stations may always be in such condition as to be able to receive a call.

This defect may in some measure be reduced by making the ringers of low impedance. This is the general practice with series telephones, the ringers ordinarily having short cores and a comparatively small number of turns, the resistance being as a rule about 80 ohms.

Bridging Systems. Very much better than the series plan of party-line connections, is the arrangement by which the instruments are placed in bridges across the line, such lines being commonly known as bridged or bridging lines. This was first strongly advocated and put into wide practical use by J. J. Carty, now the Chief Engineer of the American Telephone and Telegraph Company.

A simple illustration of a bridging telephone line is shown in Fig. 166, where the three telephones shown are each connected in a bridge path from the line wire to ground, a type known as a "grounded bridging line." Its use is very common in rural districts.

A better arrangement is shown in Fig. 167, which represents a metallic-circuit bridging line, three telephone instruments being shown in parallel or bridge paths across the two line wires.

The actual circuit arrangements of a bridging party line are better shown in Fig. 168. There are three stations and it will be seen that at each station there are three possible bridges, or bridge paths, across the two limbs of the line. The first of these bridges is con-

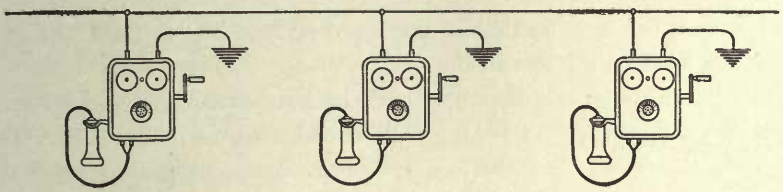


Fig. 166. Grounded Bridging Line

trolled by the hook switch and is normally open. When the hook is raised, however, this path is closed through the receiver and secondary of the induction coil, the primary circuit being also closed so

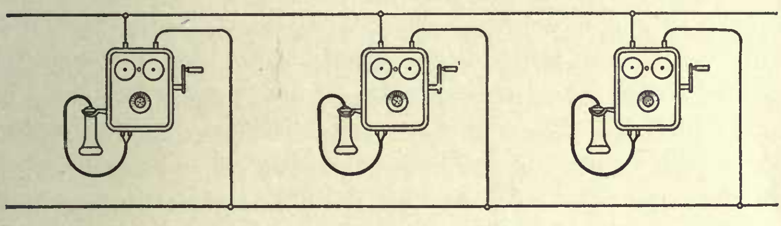


Fig. 167. Metallic Bridging Line

as to include the battery and transmitter. This constitutes an ordinary local-battery talking set.

A second bridge at each station is led through the ringer or call-bell, and this, in most bridging telephones, is permanently closed,

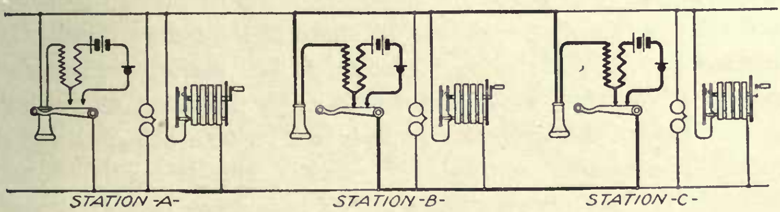


Fig. 168. Metallic Bridging Line

the continuity of this path between the two limbs of the line not being affected either by the hook switch or by the automatic switch in connection with the generator.

A third bridge path at each station is led through the generator. This, as indicated, is normally open, but the automatic cut-in switch of the generator serves, when the generator is operated, to close its path across the line, so that it may send its currents to the line and ring the bells of all the stations.

When any generator is operated, its current divides and passes over the line wires and through all of the ringers in multiple. It is seen, therefore, that the requirements for a bridging generator are that it shall be capable of generating a large current, sufficient when divided up amongst all the bells to ring each of them; and that it shall be capable of producing a sufficient voltage to send the required current not only to the near-by stations, but to the stations at the distant end of the line.

It might seem at first that the bridging system avoided one difficulty only to encounter another. It clearly avoids the difficulty of the series system in that the voice currents, in order to reach distant stations, do not have to pass through all of the bells of the idle stations in series. There is, however, presented at each station a leakage path through the bell bridged across the line, through which it would appear the voice currents might leak uselessly from one side of the line to the other and not pass on in sufficient volume to the distant station. This difficulty is, however, more apparent than real. It is found that, by making the ringers of high impedance, the leakage of voice currents through them from one side of the line to the other is practically negligible.

It is obvious that in a heavily loaded bridged line, the bell at the home station, that is at the station from which the call is being sent, will take slightly more than its share of the current, and it is also obvious that the ringing of the home bell performs no useful function. The plan is frequently adopted, therefore, of having the operation of the generator serve to cut its own bell out of the circuit. The arrangement by which this is done is clearly shown in Fig. 169. The circuit of the bell is normally complete across the line, while the circuit of the generator is normally open. When, however, the generator crank is turned these conditions are reversed, the bell circuit being broken and the generator circuit closed, so as to allow its current all to pass the line. This feature of having the local bell remain silent upon the operation of its own generator is also of advantage because other parties at the same station are not disturbed by the ringing of the bell when a call is being made by that station.

A difficulty encountered on non-selective bridging party lines, which at first seems amusing rather than serious, but which nevertheless is often a vexatious trouble, is that due to the propensity of some people to "listen in" on the line on hearing calls intended for other than their own stations. People whose ethical standards would not permit them to listen at, or peep through, a keyhole, often engage in this telephonic eavesdropping.

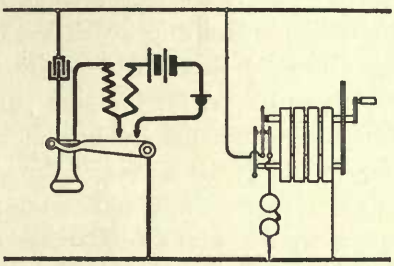


Fig. 169. Circuits of Bridging Station

Frequently, not only one but many subscribers will respond to a call intended for others and will listen to the ensuing conversation. This is disadvantageous in several respects: It destroys the privacy of conversation between any two parties; it subjects the local batteries to an unnecessary and useless drain; and it greatly impairs the ringing efficiency of the line. The reason for this interference with ringing is that the presence of the low-resistance receivers across the line allows the current sent out by any of the generators to pass in large measure through the receivers, thus depriving the ringers, which are of comparatively high resistance and impedance, of the energy necessary to operate them. As a result of this it is frequently impossible for one party to repeat the call for another because, during the interval between the first and second call, a number of parties remove their receivers from their hooks in order to listen. Ring-off or clearing-out signals are likewise interfered with.

A partial remedy for this interference with ringing, due to eavesdropping, is to introduce a low-capacity condenser into the receiver circuit at each station, as shown in Fig. 169. This does not seriously interfere with the speech transmission since the condensers will readily transmit the high-frequency voice currents. Such condensers, however, have not sufficient capacity to enable them readily to transmit the low-frequency ringing currents and hence these are forced, in large measure, to pass through the bells for which they are intended rather than leaking through the low-resistance receiver paths.

The best condenser for this use is of about ½-microfarad capacity, which is ample for voice-transmitting purposes, while it serves to effectively bar the major portion of the generator currents. A higher capacity condenser would carry the generator currents much more readily and thus defeat the purpose for which it was intended.

In order that the requisite impedance may be given to the ringers employed for bridging party lines, it is customary to make the cores rather long and of somewhat larger diameter than in series ringers and at the same time to wind the coils with rather fine wire so as to secure the requisite number of turns. Bridging bells are ordinarily wound to a resistance of 1,000 or 1,600 ohms, these two figures having become standard practice. It is not, however, the high resistance so much as the high impedance that is striven for in bridging bells; it is the number of turns that is of principal importance.

As has already been stated, the generators used for bridging lines are made capable of giving a greater current output than is necessary in series instruments, and for this purpose they are usually provided with at least four, and usually five, bar magnets. The armature is made correspondingly long and is wound, as a rule, with about No. 33 wire.

Sometimes where a bridged party line terminates in a central-office switchboard it is desired to so operate the line that the subscribers shall not be able to call up each other, but shall, instead, be able to signal only the central-office operator, who, in turn, will be enabled to call the party desired, designating his station by a suitable code ring. One common way to do this is to use biased bells instead of the ordinary polarized bells. In order that the bells may not be rung by the subscribers' generators, these generators are made of the direct-current type and these are so associated with the line that the currents which they send out will be in the wrong direction to actuate the bells. On the other hand, the central-office generator is of direct-current type and is associated with the line in the right direction to energize the bells. Thus any subscriber on the line may call the central office by merely turning his generator crank, which action will not ring the bells of the subscribers on the line. The operator will then be able to receive the call and in turn send out currents of the proper direction to ring all the bells and, by code, call the desired party to the telephone.

Signal Code. The code by which stations are designated on non-selective party lines usually consists in combinations of long and short rings similar to the dots and dashes in the Morse code. Thus, one short ring may indicate Station No. 1; two short rings Station No. 2; and so on up to, say, five short rings, indicating Station No. 5. It is not good practice to employ more than five successive short rings because of the confusion which often arises in people's minds as to the number of rings that they hear. When, therefore, the number of stations to be rung by code exceeds five, it is better to employ combinations of long and short rings, and a good way is to adopt a partial decimal system, omitting the numbers higher than five in each ten, and employing long rings to indicate the tens digits and short rings to indicate the units digit, Table X.

TABLE X

Signal Code

Station Number	Ring	Station Number	Ring
1	1 short	12	1 long, 2 short
2	2 short	13	1 long, 3 short
3	3 short	14	1 long, 4 short
4	4 short	15	1 long, 5 short
5	5 short	21	2 long, 1 short
11	1 long, 1 short	22	2 long, 2 short

Other arrangements are often employed and by almost any of them a great variety of readily distinguishable signals may be secured. The patrons of such lines learn to distinguish, with comparatively few errors, between the calls intended for them and those intended for others, but frequently they do not observe the distinction, as has already been pointed out.

Limitations. With good telephones the limit as to the number of stations that it is possible to operate upon a single line is usually due more to limitations in ringing than in talking. As the number of stations is increased indefinitely a condition will be reached at which the generators will not be able to generate sufficient current to ring all of the bells, and this condition is likely to occur before the talking efficiency is seriously impaired by the number of bridges across the line.

Neither of these considerations, however, should determine the maximum number of stations to be placed on a line. The proper limit as to the number of stations is not the number that can be rung by a single generator, or the number with which it is possible to transmit speech properly, but rather the number of stations that may be employed without causing undue interference between the various parties who may desire to use the line. Overloaded party lines cause much annoyance, not only for the reason that the subscribers are often not able to use the line when they want it, but also, in non-selective lines, because of the incessant ringing of the bells, and the liability of confusion in the interpretation of the signaling code, which of course becomes more complex as the number of stations increases.

The amount of business that is done over a telephone line is usually referred to as the "traffic." It will be understood, however, in considering party-line working that the number of calls per day or per hour, or per shorter unit, is not the true measure of the traffic and, therefore, not the true measure of the amount of possible interference between the various subscribers on the line.

An almost equally great factor is the average length of the conversation. In city lines, that is, in lines in city exchanges, the conversation is usually short and averages perhaps two minutes in duration. In country lines, however, serving people in rural districts, who have poor facilities for seeing each other, particularly during the winter time, the conversations will average very much longer. In rural communities the people often do much of their visiting by telephone, and conversations of half an hour in length are not unusual. It is obvious that under such conditions a party line having a great many stations will be subject to very grave interference between the parties, people desiring to use the line for business purposes often being compelled to wait an undue time before they may secure the use of the line.

It is obvious, therefore, that the amount of traffic on the line, whether due to many short conversations or to a comparatively few long ones, is the main factor that should determine the number of stations that, economically, may be placed on a line. The facilities also for building lines enter as a factor in this respect, since it is obvious that in comparatively poor communities the money may not be forthcoming to build as many lines as are needed to properly take care of the traffic. A compromise is, therefore, often necessary, and the only rule that may be safely laid down is to place as few parties on a given line as conditions will admit.

No definite limit may be set to apply to all conditions but it may be safely stated that under ordinary circumstances no more than ten stations should be placed on a non-selective line. Twenty stations are, however, common, and sometimes forty and even fifty have been connected to a single line. In such cases the confusion which results, even if the talking and the ringing efficiency are tolerable, makes the service over such overloaded lines unsatisfactory to all concerned.

CHAPTER XVI

SELECTIVE PARTY-LINE SYSTEMS

The problem which confronts one in the production of a system of selective ringing on party lines is that of causing the bell of any chosen one of the several parties on a circuit to respond to a signal sent out from the central office without sounding any of the other bells. This, of course, must be accomplished without interfering with the regular functions of the telephone line and apparatus. By this is meant that the subscribers must be able to call the central office and to signal for disconnection when desired, and also that the association of the selective-signaling devices with the line shall not interfere with the transmission of speech over the line. A great many ways of accomplishing selective ringing on party lines have been proposed, and a large number of them have been used. All of these ways may be classified under four different classes according to the underlying principle involved.

Classification. (*1*) *Polarity* systems are so called because they depend for their operation on the use of bells or other responsive devices so polarized that they will respond to one direction of current only. These bells or other devices are so arranged in connection with the line that the one to be rung will be traversed by current in the proper direction to actuate it, while all of the others will either not be traversed by any current at all, or by current in the wrong direction to cause their operation.

(*2*) The *harmonic* systems have for their underlying principle the fact that a pendulum or elastic reed, so supported as to be capable of vibrating freely, will have one particular rate of vibration which it may easily be made to assume. This pendulum or reed is placed under the influence of an electromagnet associated with the line, and owing to the fact that it will vibrate easily at one particular rate of vibration and with extreme difficulty at any other rate, it is clear that for current impulses of a frequency corresponding to its natural rate the reed will take up the vibration, while for other frequencies it will fail to respond.

Selection on party lines by means of this system is provided for by tuning all of the reeds on the line at different rates of vibration and is accomplished by sending out on the line ringing currents of proper frequency to ring the desired bell. The current-generating devices for ringing these bells are capable of sending out different frequencies corresponding respectively to the rates of vibration of each of the vibrating reed tongues. To select any one station, therefore, the current frequency corresponding to the rate of vibration of the reed tongue at that station is sent and this, being out of tune with the reed tongues at all of the other stations, operates the tongue of the desired station, but fails to operate those at all of the other stations.

(*3*) In the *step-by-step* system the bells on the line are normally not in operative relation with the line and the bell of the desired party on the line is made responsive by sending over the line a certain number of impulses preliminary to ringing it. These impulses move step-by-step mechanisms at each of the stations in unison, the arrangement being such that the bells at the several stations are each made operative after the sending of a certain number of preliminary impulses, this number being different for all the stations.

(*4*) The *broken-line* systems are new in telephony and for certain fields of work look promising. In these the line circuit is normally broken up into sections, the first section terminating at the first station out from the central office, the second section at the second station, and so on. When the line is in its normal or inactive condition only the bell at the first station is so connected with the line circuit as to enable it to be rung, the line being open beyond. Sending a single preliminary impulse will, however, operate a switching device so as to disconnect the bell at the first station and to connect the line through to the second station. This may be carried out, by sending the proper number of preliminary impulses, so as to build up the line circuit to the desired station, after which the sending of the ringing current will cause the bell to ring at that station only.

Polarity Method. The polarity method of selective signaling on party lines is probably the most extensively used. The standard selective system of the American Telephone and Telegraph Company operates on this principle.

Two-Party Line. It is obvious that selection may be had between two parties on a single metallic-circuit line without the use of biased bells or current of different polarities. Thus, one limb of a metallic circuit may be used as one grounded line to ring the bell at one of the stations, and the other limb of the metallic circuit may be used as another grounded line to ring the bell of the other station; and the two limbs may be used together as a metallic circuit for talking purposes as usual.

This is shown in Fig. 170, where the ringing keys at the central office are diagrammatically shown in the left-hand portion of the figure as K^1 and K^2. The operation of these keys will be more

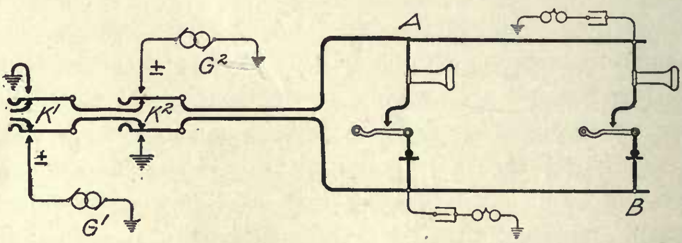


Fig. 170. Simple Two-Party Line Selection

fully pointed out in a subsequent chapter, but a correct understanding will be had if it be remembered that the circuits are normally maintained by these keys in the position shown. When, however, either one of the keys is operated, the two long springs may be considered as pressed apart so as to disengage the normal contacts between the springs and to engage the two outer contacts, with which they are shown in the cut to be disengaged. The two outer contacts are connected respectively to an ordinary alternating-current ringing generator and to ground, but the connection is reversed on the two keys.

At Station A the ordinary talking set is shown in simplified form, consisting merely of a receiver, transmitter, and hook switch in a single bridge circuit across the line. An ordinary polarized bell is shown connected in series with a condenser between the lower limb of the line and ground. At Station B the same talking circuit is shown, but the polarized bell and condenser are bridged between the upper limb of the line and ground.

If the operator desires to call Station A, she will press key K^1 which will ground the upper side of the line and connect the lower side of the line with the generator G^1, and this, obviously, will cause the bell at Station A to ring. The bell at Station B will not ring because it is not in the circuit. If, on the other hand, the operator desires to ring the bell at Station B, she will depress key K^2, which will allow the current from generator G^2 to pass over the upper side of the line through the bell and condenser at Station B and return by the path through the ground. The object of grounding the opposite sides of the keys at the central office is to prevent cross-ringing, that is, ringing the wrong bell. Were the keys not grounded this might occur when a ringing current was being sent out while the receiver at one of the stations was off its hook; the ringing current from, say, generator G^1 then passing not only through the bell at Station A as intended, but also through the bell at Station B by way of the bridge path through the receiver that happened to be connected across the line. With the ringing keys grounded as shown, it is obvious that this will not occur, since the path for the ringing current through the wrong bell will always be shunted by a direct path to ground on the same side of the line.

In such a two-party-line selective system the two generators G^1 and G^2 may be the same generator and may be of the ordinary alternating-current type. The bells likewise may be of the ordinary alternating-current type.

The two-party selective line just described virtually employs two separate circuits for ringing. Now each of these circuits alone may be employed to accomplish selective ringing between two stations by using two biased bells oppositely polarized, and employing pulsating ringing currents of one direction or the other according to which bell it is desired to ring. One side of a circuit so equipped is shown in Fig. 171. In this the two biased bells are at Station A and Station B, these being bridged to ground in each case and adapted to respond only to positive and negative impulses respectively. At the central office the two keys K^1 and K^2 are shown. A single alternating-current generator G is shown, having its brush *1* grounded and brush *2* connected to a commutator disk *3* mounted on the generator shaft so as to revolve therewith. One-half of the periphery of this disk is of insulating material so that the brushes *4* and *5*, which bear against the disk, will be alternately connected with the disk and, therefore, with the brush *2* of the generator. Now the brush *2*, being one terminal of an alternating-current machine, is alternately positive and negative, and the arrangement of the commutator is such that the disk, which is always at the potential of the brush *2*, will be connected to the brush *5* only while it is positively charged and with the brush *4* only while it is negatively charged. As a result, brush *5* has a succession of positive impulses and brush *4* a succession of negative ones. Obviously, therefore, when key

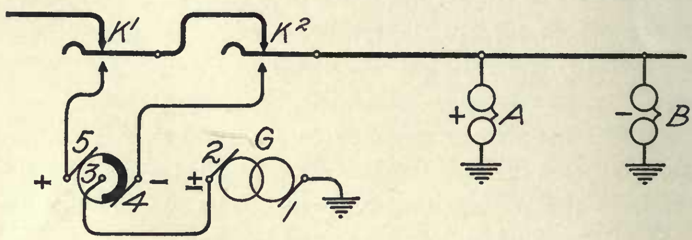


Fig. 171. Principle of Selection by Polarity

K^1 is depressed only the bell at Station A will be rung, and likewise the depression of key K^2 will result only in the ringing of the bell at Station B.

Four-Party Line. From the two foregoing two-party line systems it is evident that a four-party line system may be readily obtained, that is, by employing two oppositely polarized biased bells on each side of the metallic circuit. The selection of any of the four bells may be obtained, choosing between the pairs connected, respectively, with the two limbs of the line, by choosing the limb on which the current is to be sent, and choosing between the two bells of the pair on that side of the line by choosing which polarity of current to send.

Such a four-party line system is shown in Fig. 172. In this the generators are not shown, but the wires leading from the four keys are shown marked plus or minus, according to the terminal of the generator to which they are supposed to be connected. Likewise the two bells connected with the lower side of the line are marked positive and negative, as are the two bells connected with the upper side of the line. From the foregoing description of Figs. 170 and 171, it is clear that if key K^1 is pressed the bell at Station A will be rung, and that bell only, since the bells at Station C and Station *D* are not in the circuit and the positive current sent over the lower side of the line is not of the proper polarity to ring the bell at Station B.

The system shown in Fig. 172 is subject to one rather grave defect. In subsequent chapters it will be pointed out that in common-battery systems the display of the line signal at the central office is affected by any one of the subscribers merely taking his receiver off its hook and thus establishing a connection between the two

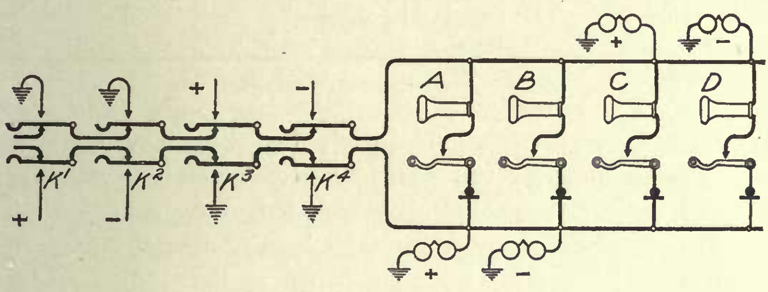


Fig. 172. Four-Party Polarity Selection

limbs of the metallic circuit. Such common-battery systems should have the two limbs of the line, normally, entirely insulated from each other. It is seen that this is not the case in the system just described, since there is a conducting path from one limb of the line through the two bells on that side to ground, and thence through the other pair of bells to the other limb of the line. This means that unless the resistance of the bell windings is made very high, the path of the signaling circuit will be of sufficiently low resistance to actuate the line signal at the central office.

It is not feasible to overcome this objection by the use of condensers in series with the bells, as was done in the system shown in Fig. 170, since the bells are necessarily biased and such bells, as may readily be seen, will not work properly through condensers, since the placing of a condenser in their circuit means that the current which passes through the bell is alternating rather than pulsating, although the original source may have been of pulsating nature only.

The remedy for this difficulty, therefore, has been to place in series with each bell a very high non-inductive resistance of about 15,000 or 20,000 ohms, and also to make the windings of the bells of comparatively high resistance, usually about 2,500 ohms. Even with this precaution there is a considerable leakage of the central-office battery current from one side of the line to the other through the two paths to ground in series. This method of selective signal-

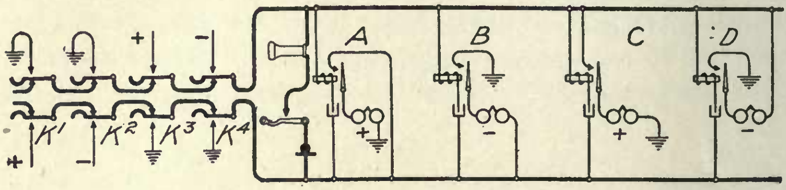


Fig 173. Standard Polarity System

ing has, therefore, been more frequently used with magneto systems. An endeavor to apply this principle to common-battery systems without the objections noted above has led to the adoption of a modification, wherein a relay at each station normally holds the ground connection open. This is shown in Fig. 173 and is the standard four-party line ringing circuit employed by the American Telephone and Telegraph Company and their licensees

In this system the biased bells are normally disconnected from the line, and, therefore, the leakage path through them from one side of the line to the other does not exist. At each station there is a relay winding adapted to be operated by the ringing current bridged across the line in series with a condenser. As a result, when ringing current is sent out on the line all of the relays, *i. e.*, one at each station, are energized and attract their armatures. This establishes the connection of all the bells to line and really brings about temporarily a condition equivalent to that of Fig. 172. As a result, the sending of a positive current on the lower line with a ground return will cause the operation of the bell at Station A. It will not ring the bell at Station B because of the wrong polarity. It will not ring the bells of Station C and Station D because they are in the circuit between the other side of the line and ground. As soon as the ringing current ceases all of the relays release their armatures and disconnect all the bells from the line.

By this very simple device the trouble, due to marginal working of the line signal, is done away with, since normally there is no leakage from one side of the line to the other on account of the presence of the condensers in the bridge at each station.

In Fig. 174, the more complete connections of the central-office ringing keys are shown, by means of which the proper positive or negative ringing currents are sent to line in the proper way to cause the ringing of any one of the four bells on a party line of either of the types shown in Figs. 172 and 173.

In this the generator *G* and its commutator disk *3*, with the various brushes, *1*, *2*, *4*, and *5*, are arranged in the same manner as is shown in Fig. 171. It is evident from what has been said that wire *6* leading from generator brush *2* and commutator disk *3* will carry alternating potential; that wire *7* will carry positive pulsations of potential; and that wire *8* will carry negative pulsations of potential. There are five keys in the set illustrated in Fig. 174, of which four, viz, K^1, K^2, K^3, and K^4, are connected in the same manner as diagrammatically indicated in Figs. 172 and 173, and will, obviously, serve to send the proper current over the proper limb of the line to ring one of the bells. Key K^5, the fifth one in the set, is added so as to enable the operator to ring an ordinary unbiased bell on a single party line when connection is made with such line. As the two outside contacts of this key are connected respectively to the two brushes of the alternating-current dynamo *G*, it is clear that it will impress an alternating current on the line when its contacts are closed.

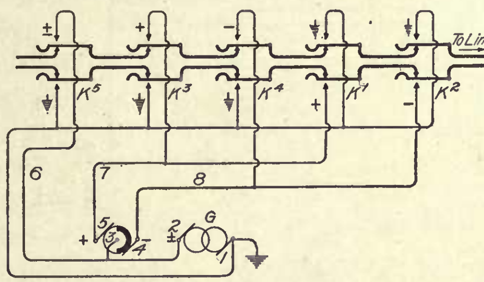


Fig. 174. Ringing-Key Arrangement

Circuits of Two-Party Line Telephones. In Fig. 175 is shown in detail the wiring of the telephone set usually employed in connection with the party-line selective-ringing system illustrated in Fig. 170. In the wiring of this set and the two following, it must be borne in mind that the portion of the circuit used during conversation might be wired in a number of ways without affecting the principle of selective ringing employed; however, the circuits shown are those most commonly employed with the respective selective ringing systems which they are intended to illustrate. In connecting the circuits of this telephone instrument to the line, the two line conductors are connected to binding posts *1* and *2* and a ground connection is made to binding post *3*. In practice, in order to avoid the necessity of changing the permanent wiring of the telephone set in connecting it as an A or B Station (Fig. 170), the line conductors are connected to the binding posts in reverse order at the two stations; that is, for Station A the upper conductor, Fig. 170, is connected to binding post *1* and the lower conductor to binding post *2*, while at Station B the upper conductor is connected to binding post *2* and the lower conductor to binding post *1*. The permanent wiring of this telephone set is the same as that frequently used for a set connected to a line having only one station, the proper ringing circuit being made by the method of connecting up the binding posts. For example, if this telephone set were to be used on a single station line, the binding posts *1* and *2* would be connected to the two conductors of the line as before, while binding post *3* would be connected to post *1* instead of being grounded.

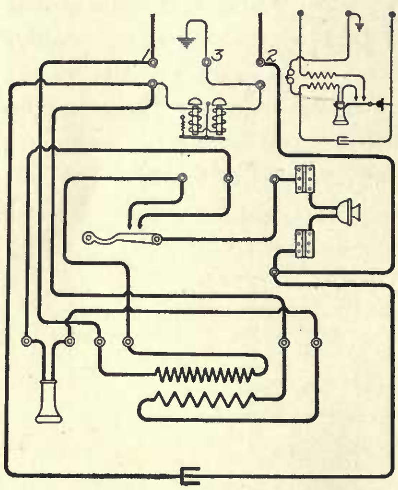


Fig. 175. Circuit of Two-Party Station

Circuits of Four-Party-Line Telephones. The wiring of the telephone set used with the system illustrated in Fig 172 is shown in detail in Fig. 176. The wiring of this set is arranged for local battery or magneto working, as this method of selective ringing is more frequently employed with magneto systems, on account of the objectionable features which arise when applied to common-battery systems. In this figure the line conductors are connected to binding posts *1* and *2*, and a ground connection is made to binding post *3*. In order that all sets may be wired alike and yet permit the instrument to be connected for any one of the various stations, the bell is not permanently wired to any portion of the circuit but has flexible connections which will allow of the set being properly connected for any desired station. The terminals of the bell are connected to binding posts *9* and *10*, to which are connected flexible conductors terminating in terminals *7* and *8*. These terminals may be connected to the binding posts *4*, *5*, and *6* in the proper manner to connect the set as an A, B, C, or D station, as required. For example, in connecting the set for Station A, Fig. 172, terminal *7* is connected to binding post *6* and *8* to *5*. For connecting the set for Station B terminal *7* is connected to binding post *5* and *8* to *6*. For connecting the set for Station C terminal *7* is connected to binding post *6* and *8* to *4*. For connecting the set for Station D terminal *7* is connected to binding post *4* and *8* to *6*.

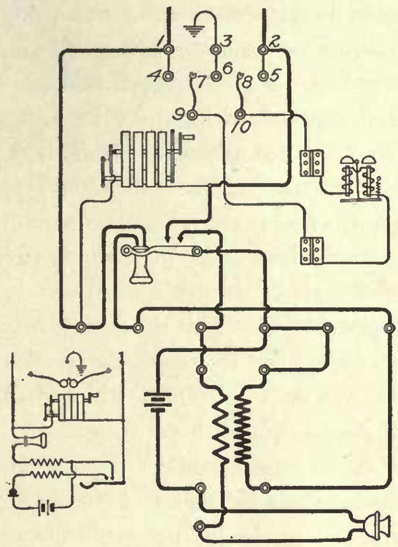


Fig. 176. Circuit of Four-Party Station without Relay

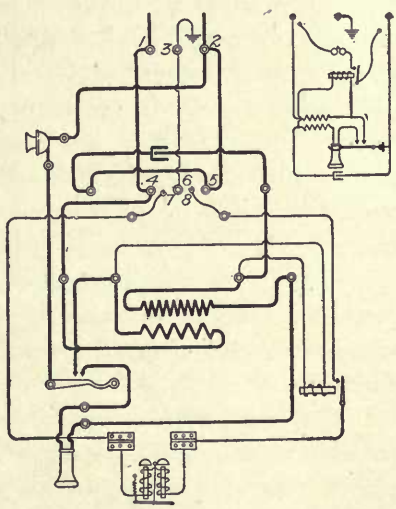


Fig. 177. Circuit of Four-Party Station with Relay

The detailed wiring of the telephone set employed in connection with the system illustrated in Fig 173 is shown in Fig. 177. The wiring of this set is arranged for a common-battery system, inasmuch as this arrangement of signaling circuit is more especially adapted for common-battery working. However, this arrangement is frequently adapted to magneto systems as even with magneto systems a permanent ground connection at a subscriber's station is objectionable inasmuch as it increases the difficulty of determining the existence or location of an accidental ground on one of the line conductors. The wiring of this set is also arranged so that one standard type of wiring may be employed and yet allow any telephone set to be connected as an A, B, C, or D station.

Harmonic Method. *Principles.* To best understand the principle of operation of the harmonic party-line signaling systems, it is to be remembered that a flexible reed, mounted rigidly at one end and having its other end free to vibrate, will, like a violin string, have a certain natural period of vibration; that is, if it be started in vibration, as by snapping it with the fingers, it will take up a certain rate of vibration which will continue at a uniform rate until the vibration ceases altogether. Such a reed will be most easily thrown into vibration by a series of impulses having a frequency corresponding exactly to the natural rate of vibration of the reed itself; it may be thrown into vibration by very slight impulses if they occur at exactly the proper times.

It is familiar to all that a person pushing another in a swing may cause a considerable amplitude of vibration with the exertion of but a small amount of force, if he will so time his pushes as to conform exactly to the natural rate of vibration of the swing. It is of course possible, however, to make the swing take up other rates of vibrations by the application of sufficient force. As another example, consider a clock pendulum beating seconds. By gentle blows furnished by the escapement at exactly the proper times, the heavy pendulum is kept in motion. However, if a person grasps the pendulum weight and shakes it, it may be made to vibrate at almost any desired rate, dependent on the strength and agility of the individual.

The conclusion is, therefore, that a reed or pendulum may be made to start and vibrate easily by the application of impulses at proper intervals, and only with great difficulty by the application of impulses at other than the proper intervals; and these facts form the basis on which harmonic-ringing systems rest.

The father of harmonic ringing in telephony was Jacob B. Currier, an undertaker of Lowell, Mass. His harmonic bells were placed in series in the telephone line, and were considerably used in New England in commercial practice in the early eighties. Somewhat later James A. Lighthipe of San Francisco independently invented a harmonic-ringing system, which was put in successful commercial use at Sacramento and a few other smaller California towns. Lighthipe polarized his bells and bridged them across the line in series with condensers, as in modern practice, and save for some crudities in design, his apparatus closely resembled, both in principle and construction, some of that in successful use today.

Lighthipe's system went out of use and was almost forgotten, when about 1903, Wm. W. Dean again independently redeveloped the harmonic system, and produced a bell astonishingly like that of Lighthipe, but of more refined design, thus starting the development which has resulted in the present wide use of this system.

The signal-receiving device in harmonic-ringing systems takes the form of a ringer, having its armature and striker mounted on a rather stiff spring rather than on trunnions. By this means the moving parts of the bell constitute in effect a reed tongue, which has a natural rate of vibration at which it may easily be made to vibrate with sufficient amplitude to strike the gongs. The harmonic ringer differs from the ordinary polarized bell or ringer, therefore, in that its armature will vibrate most easily at one particular rate, while the armature of the ordinary ringer is almost indifferent, between rather wide limits, as to the rate at which it vibrates.

As a rule harmonic party-line systems are limited to four stations on a line. The frequencies employed are usually $16\frac{2}{3}$, $33\frac{1}{3}$, 50, and $66\frac{2}{3}$ cycles per second, this corresponding to 1,000, 2,000, 3,000, and 4,000 cycles per minute. The reason why this particular set of frequencies was chosen is that they represent approximately the range of desirable frequencies, and that the first ringing-current machines in such systems were made by mounting the armatures of four different generators on a single shaft, these having, respectively, two poles, four poles, six poles, and eight poles each. The two-pole generator gave one cycle per revolution, the four-pole two, the six-pole three, and the eight-pole four, so that by running the shaft of the machine at exactly 1,000 revolutions per minute the frequencies before mentioned were attained. This range of frequencies having proved about right for general practice and the early ringers all having been attuned so as to operate on this basis, the practice of adhering to these numbers of vibrations has been kept up with one exception by all the manufacturers who make this type of ringer.

Tuning. The process of adjusting the armature of a ringer to a certain rate of vibration is called tuning, and it is customary to refer to a ringer as being tuned to a certain rate of vibration, just as it is customary to refer to a violin string as being tuned to a certain pitch or rate of vibration.

The physical difference between the ringers of the various frequencies consists mainly in the size of the weights at the end of the vibrating reed, that is, of the weights which form the tapper for the bell. The low-frequency ringers have the largest weights and the high-frequency the smallest, of course. The ringers are roughly tuned to the desired frequencies by merely placing on the tapper rod the desired weight and then a more refined tuning is given them by slightly altering the positions of the weights on the tapper rod. To make the reed have a slightly lower natural rate of vibration, the weight is moved further from the stationary end of the reed, while to give it a slightly higher natural rate of vibration the weight is moved toward the stationary. In this way very nice adjustments may be made, and the aim of the various factories manufacturing these bells is to make the adjustment permanent so that it will never have to be altered by the operating companies. Several years of experience with these bells has shown that when once properly assembled they maintain the same rate of vibration with great constancy.

There are two general methods of operating harmonic bells. One of these may be called the in-tune system and the other the under-tune system. The under-tune system was the first employed.

Under-Tune System. The early workers in the field of harmonic-selective signaling discovered that when the tapper of the reed struck against gongs the natural rate of vibration of the reed was changed, or more properly, the reed was made to have a different rate of vibration from its natural rate. This was caused by the fact that the elasticity of the gongs proved another factor in the set of conditions causing the reeds to take up a certain rate of vibration, and the effect of this added factor was always to accelerate the rate of vibration which the reed had when it was not striking the gongs. The rebound of the hammer from the gongs tended, in other words, to accelerate the rate of vibration, which, as might be expected, caused a serious difficulty in the practical operation of the bells. To illustrate: If a reed were to have a natural rate of vibration, when not striking the gongs, of 50 per second and a current of 50 cycles per second were impressed on the line, the reed would take up this rate of vibration easily, but when a sufficient amplitude of vibration was attained to cause the tapper to strike the gongs, the reed would be thrown out of tune, on account of the tendency of the gongs to make the reed vibrate at a higher rate. This caused irregular ringing and was frequently sufficient to make the bells cease ringing altogether or to ring in an entirely unsatisfactory manner.

In order to provide for this difficulty the early bells of Currier and Lighthipe were made on what has since been called the "under-tuned" principle. The first bells of the Kellogg Switchboard and Supply Company, developed by Dean, were based on this idea as their cardinal principle. The reeds were all given a natural rate of vibration, when not striking the gongs, somewhat below that of the current frequencies to be employed; and yet not sufficiently below the corresponding current frequency to make the bell so far out of tune that the current frequency would not be able to start it. This was done so that when the tapper began to strike the gongs the tapper would be accelerated and brought practically into tune with the current frequency, and the ringing would continue regularly as long as the current flowed. It will be seen that the under-tuned system was, therefore, one involving some difficulty in starting in order to provide for proper regularity while actually ringing.

Ringers of this kind were always made with but a single gong, it being found difficult to secure uniformity of ringing and uniformity of adjustment when two gongs were employed. Although no ringers of this type are being made at present, yet a large number of them are in use and they will consequently be described. Their action is interesting in throwing better light on the more improved types, if for no other reason.

Figs. 178 and 179 show, respectively, side and front views of the original Kellogg bell. The entire mechanism is self-contained, all parts being mounted on the base plate *1*. The electromagnet is of the two-coil type, and is supported on the brackets *2* and *3*. The bracket *2* is of iron so as to afford a magnetic yoke for the field of the electromagnet, while the bracket *3* is of brass so as not to short-circuit the magnetic lines across the air-gap. The reed tongue—consisting of the steel spring *5*, the soft-iron armature pieces *6*, the auxiliary spring *7*, and the tapper ball *8*, all of which are riveted together, as shown in Fig. 178—constitutes the only moving part of the bell. The steel spring *5* is rigidly mounted in the clamping piece *9* at the upper part of the bracket *3*, and the reed tongue is permitted to vibrate only by the flexibility of this spring. The auxiliary spring *7* is much lighter than the spring *5* and has for its purpose the provision of a certain small amount of flexibility between the tapper ball and the more rigid portion of the armature formed by the iron strips *6-6*. The front ends of the magnet pole pieces extend through the bracket *3* and are there provided with square soft-iron pole pieces *10* set at right angles to the magnet cores so as to form a rather narrow air-gap in which the armature may vibrate.

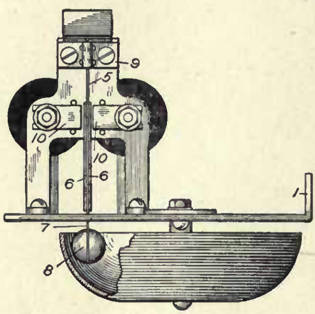


Fig. 178. Under-Tuned Ringer

The cores of the magnet and also the reed tongue are polarized by means of the L-shaped bar magnet *4*, mounted on the iron yoke *2* at one end in such manner that its other end will lie quite close to the end of the spring *5*, which, being of steel, will afford a path for the lines of force to the armature proper. We see, therefore, that the two magnet cores are, by this permanent magnet, given one polarity, while the reed tongue itself is given the other polarity, this being exactly the condition that has already been described in connection with the regular polarized bell or ringer.

The electromagnetic action by which this reed tongue is made to vibrate is, therefore, exactly the same as that of an ordinary polarized ringer, but the difference between the two is that, in this harmonic ringer, the reed tongue will respond only to one particular rate of vibrations, while the regular polarized ringer will respond to almost any.

As shown in Fig. 178, the tapper ball strikes on the inside surface of the single gong. The function of the auxiliary spring 7 between the ball and the main portion of the armature is to allow some resilience between the ball and the balance of the armature so as to counteract in some measure the accelerating influence of the gong on the armature. In these bells, as already stated, the natural rate of vibration of the reed tongue was made somewhat lower than the rate at which the bell was to be operated, so that the reed tongue had to be started by a current slightly out of tune with it, and then, as the tapper struck the gong, the acceleration due to the gong would bring the vibration of the reed tongue, as modified by the gong, into tune with the current that was operating it. In other words, in this system the ringing currents that were applied to the line had frequencies corresponding to what may be called the *operative rates of vibration* of the reed tongues, which operative rates of vibration were in each case the resultant of the natural pitch of the reed as modified by the action of the bell gong when struck.

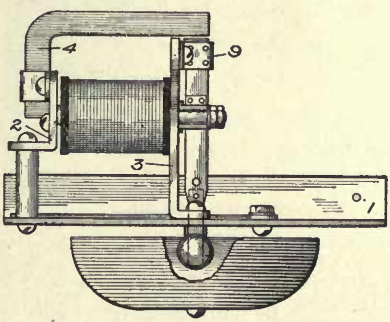


Fig. 179. Under-Tuned Ringer

In-Tune System. The more modern method of tuning is to make the natural rate of vibration of the reed tongue, that is, the rate at which it naturally vibrates when not striking the gongs, such as to accurately correspond to the rate of vibration at which the bells are to be operated—that is, the natural rate of vibration of the reed tongues is made the same as the operative rate. Thus the bells are attuned for easy starting, a great advantage over the under-tuned system. In the under-tuned system, the reeds being out of tune in starting require heavier starting current, and this is obviously conducive to cross-ringing, that is, to the response of bells to other than the intended frequency.

Again, easy starting is desirable because when the armature is at rest, or in very slight vibration, it is at a maximum distance from the poles of the electromagnet, and, therefore, subject to the weakest influence of the poles. A current, therefore, which is strong enough to start the vibration, will be strong enough to keep the bell ringing properly.

When with this "in-tune" mode of operation, the armature is thrown into sufficiently wide vibration to cause the tapper to strike the gong, the gong may tend to accelerate the vibration of the reed tongue, but the current impulses through the electromagnet coils

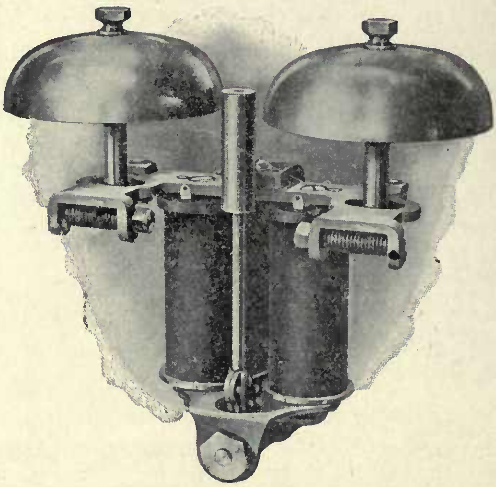


Fig. 180. Dean In-Tune Ringer

continue at precisely the same rates as before. Under this condition of vibration, when the reed tongue has an amplitude of vibration wide enough to cause the tapper to strike the gongs, the ends of the armature come closest to the pole pieces, so that the pole pieces have their maximum magnetic effect on the armature, with the result that even if the accelerating tendency of the gongs were considerable, the comparatively large magnetic attractive impulses occurring at the same rate as the natural rate of vibration of the reed tongue, serve wholly to prevent any actual acceleration of the reed tongue. The magnetic attractions upon the ends of the armature, continuing at the initial rate, serve, therefore, as a check to offset any accelerating tendency which the striking of the gong may have upon the vibrating reed tongue.

It is obvious, therefore, that in the "in-tune" system the electromagnetic effect on the armature should, when the armature is closest to the pole pieces, be of such an overpowering nature as to prevent whatever accelerating tendency the gongs may have from throwing the armature out of its "stride" in step with the current. For this reason it is usual in this type to so adjust the armature that its ends will actually strike against the pole pieces of the electromagnet when thrown into vibration. Sufficient flexibility is given to the tapper rod to allow it to continue slightly beyond the point at which it would be brought to rest by the striking of the armature ends against the pole pieces and thus exert a whipping action so as to allow the ball to continue in its movement far enough to strike against the gongs. The rebound of the gong is then taken up by the elasticity of the tapper rod, which returns to an unflexed position, and at about this time the pole piece releases the armature so that it may swing over in the other direction to cause the tapper to strike the other gong.

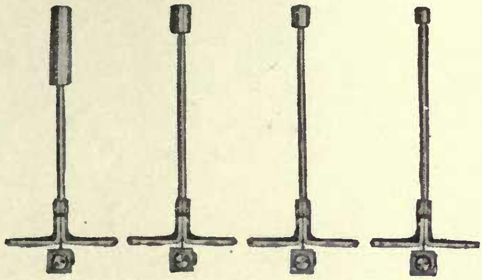


Fig. 181. Tappers for Dean Ringers

The construction of the "in-tune" harmonic ringer employed by the Dean Electric Company, of Elyria, Ohio, is illustrated in Figs. 180, 181, and 182. It will be seen from Fig. 180 that the general arrangement of the magnet and armature is the same as that of the ordinary polarized ringer; the essential difference is that the armature is spring-mounted instead of pivoted. The armature and the tapper rod normally stand in the normal central position with reference to the pole pieces of the magnet and the gongs. Fig. 181 shows the complete vibrating parts of four ringers, adapted, respectively, to the four different frequencies of the system. The assembled armature, tapper rod, and tapper are all riveted together and are non-adjustable. All of the adjustment that is done upon them is done in the factory and is accomplished, first, by choosing the proper size of weight, and second, by forcing this weight into the

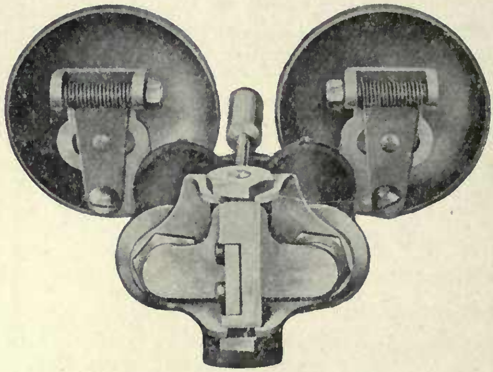


Fig. 182. Dean In-Tune Ringer

proper position on the tapper rod to give exactly the rate of vibration that is desired.

An interesting feature of this Dean harmonic ringer is the gong adjustment. As will be seen, the gongs are mounted on posts which are carried on levers pivoted to the ringer frame. These levers have at their outer end a curved rack provided with gear teeth adapted to engage a worm or screw thread mounted on the ringer frame. Obviously, by turning this worm screw in one direction or the other, the gongs are moved slightly toward or from the armature or tapper. This affords a very delicate means of adjusting the gongs, and at the same time one which has no tendency to work loose or to get out of adjustment.

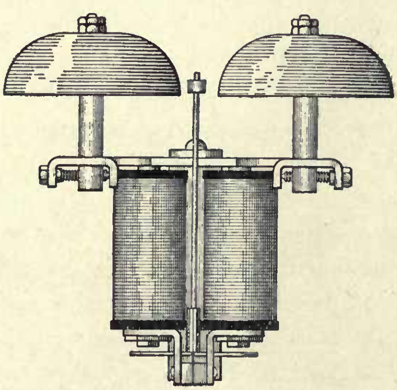


Fig. 183. Kellogg In-Tune Ringer

In Fig. 183 is shown a drawing of the "in-tune" harmonic ringer manufactured by the Kellogg Switchboard and Supply Company. This differs in no essential respect from that of the Dean Company, except in the gong adjustment, this latter being affected by a screw passing through a nut in the gong post, as clearly indicated.

In both the Kellogg and the Dean in-tune ringers, on account of the comparative stiffness of the armature springs and on account of the normal position of the armature with maximum air gaps and consequent minimum magnetic pull, the armature will practically not be affected unless the energizing current is accurately attuned to its own natural rate. When the proper current is thrown on to the line, the ball will be thrown into violent vibration, and the ends of the armature brought into actual contact with the pole pieces, which are of bare iron and shielded in no way. The armature in this position is very strongly attracted and comes to a sudden stop on the pole pieces. The gongs are so adjusted that the tapper ball will have to spring about one thirty-second of an inch in order

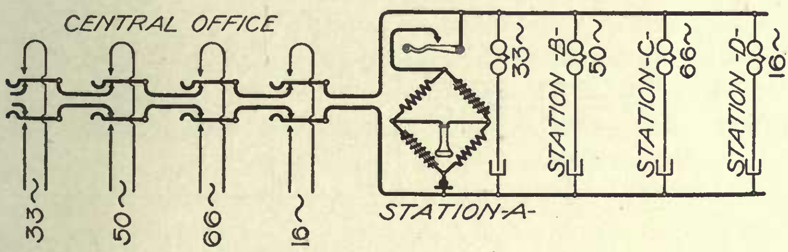


Fig. 184. Circuits of Dean Harmonic System

to hit them. The armature is held against the pole piece while the tapper ball is engaged in striking the gong and in partially returning therefrom, and so strong is the pull of the pole piece on the armature in this position that the accelerating influence of the gong has no effect in accelerating the rate of vibration of the reed.

Circuits. In Fig. 184 are shown in simplified form the circuits of a four-station harmonic party line. It is seen that at the central office there are four ringing keys, adapted, respectively, to impress on the line ringing currents of four different frequencies. At the four stations on the line, lettered A, B, C, and D, there are four harmonic bells tuned accordingly. At Station A there is shown the talking apparatus employing the Wheatstone bridge arrangement. The talking apparatus at all of the other stations is exactly the same, but is omitted for the sake of simplicity. A condenser is placed in series with each of the bells in order that there may be no direct-current path from one side of the line to the other when all of the receivers are on their hooks at the several stations.

In Fig. 185 is shown exactly the same arrangement, with the exception that the talking apparatus illustrated in detail at Station. A is that of the Kellogg Switchboard and Supply Company. Otherwise the circuits of the Dean and the Kellogg Company, and in fact of all the other companies manufacturing harmonic ringing systems, are the same.

Advantages. A great advantage of the harmonic party-line system is the simplicity of the apparatus at the subscriber's station. The harmonic bell is scarcely more complex than the ordinary polarized ringer, and the only difference between the harmonic-ringing telephone and the ordinary telephone is in the ringer itself. The

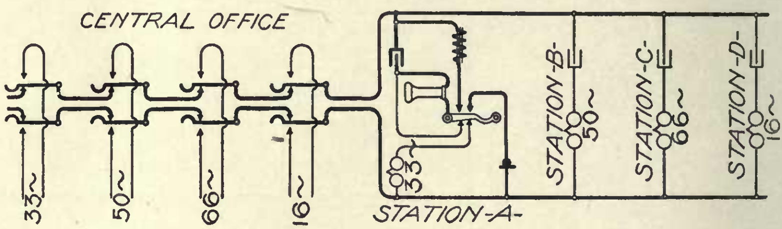


Fig. 185. Circuits of Kellogg Harmonic System

absence of all relays and other mechanism and also the absence of the necessity for ground connections at the telephone are all points in favor of the harmonic system.

Limitations. As already stated, the harmonic systems of the various companies, with one exception, are limited to four frequencies. The exception is in the case of the North Electric Company, which sometimes employs four and sometimes five frequencies and thus gets a selection between five stations. In the four-party North system, the frequencies, unlike those in the Dean and Kellogg systems, wherein the higher frequencies are multiples of the lower, are arranged so as to be proportional to the whole numbers 5, 7, 9, and 11, which, of course, have no common denominator. The frequencies thus employed in the North system are, in cycles per second, 30.3, 42.4, 54.5, and 66.7. In the five-party system, the frequency of 16.7 is arbitrarily added.

While all of the commercial harmonic systems on the market are limited to four or five frequencies, it does not follow that a greater number than four or five stations may not be selectively rung. Double these numbers may be placed on a party line and selectively actuated, if the first set of four or five is bridged across the line and the second set of four or five is connected between one limb of the line and ground. The first set of these is selectively rung, as already described, by sending the ringing currents over the metallic circuit, while the second set may be likewise selectively rung by sending the ringing currents over one limb of the line with a ground return. This method is frequently employed with success on country lines, where it is desired to place a greater number of instruments on a line than four or five.

Step-by-Step Method. A very large number of step-by-step systems have been proposed and reduced to practice, but as yet they have not met with great success in commercial telephone work, and are nowhere near as commonly used as are the polarity and harmonic systems.

Principles. An idea of the general features of the step-by-step systems may be had by conceiving at each station on the line a ratchet wheel, having a pawl adapted to drive it one step at a time, this pawl being associated with the armature of an electromagnet which receives current impulses from the line circuit. There is thus one of these driving magnets at each station, each bridged across the line so that when a single impulse of current is sent out from the central office all of the ratchet wheels will be moved one step. Another impulse will move all of the ratchet wheels another step, and so on throughout any desired number of impulses. The ratchet wheels, therefore, are all stepped in unison.

Let us further conceive that all of these ratchet wheels are provided with a notch or a hole or a projection, alike in all respects at all stations save in the position which this notch or hole or projection occupies on the wheel. The thing to get clear in this part of the conception is that all of these notches, holes, or projections are alike on all of the wheels, but they occupy a different position on the wheel for each one of the stations.

Consider further that the bell circuit at each of the stations is normally open, but that in each case it is adapted to be closed when the notch, hole, or projection is brought to a certain point by the revolution of the wheel.

Let us conceive further that this distinguishing notch, hole, or projection is so arranged on the wheel of the first station as to close the bell circuit when one impulse has been sent, that that on the second station will close the bell circuit after the second impulse has been sent, and so on throughout the entire number of stations. It will, therefore, be apparent that the bell circuits at the various stations will, as the wheels are rotated in unison, be closed one after the other. In order to call a given station, therefore, it is only necessary to rotate all of the wheels in unison, by sending out the proper stepping impulses until they all occupy such a position that the one at the desired station is in such position as to close the bell circuit at that station. Since all of the notches, holes, or projections are arranged to close the bell circuits at their respective stations at different times, it follows that when the bell circuit at the desired station is closed those at all of the other stations will be open. If, therefore, after the proper number of stepping impulses has been sent to the line to close the bell circuit of the desired station, ringing current be applied to the line, it is obvious that the bell of that one station will be rung to the exclusion of all others. It is, of course, necessary that provision be made whereby the magnets which furnish the energy for stepping the wheels will not be energized by the ringing current. This is accomplished in one of several ways, the most common of which is to have the stepping magnets polarized or biased in one direction and the bells at the various stations oppositely biased, so that the ringing current will not affect the stepping magnet and the stepping current will not affect the ringer magnets.

After a conversation is finished, the line may be restored to its normal position in one of several ways. Usually so-called release magnets are employed, for operating on the releasing device at each station. These, when energized, will withdraw the holding pawls from the ratchets and allow them all to return to their normal positions. Sometimes these release magnets are operated by a long impulse of current, being made too sluggish in their action to respond to the quick-stepping impulses; sometimes the release magnets are tapped from one limb of the line to ground, so as not to be affected by the stepping or ringing currents sent over the metallic circuit; and sometimes other expedients are used for obtaining the release of the ratchets at the proper time, a large amount of ingenuity having been spent to this end.

As practically all step-by-step party-line systems in commercial use have also certain other features intended to assure privacy of conversation to the users, and, therefore, come under the general heading of lock-out party-line systems, the discussion of commercial examples of these systems will be left for the next chapter, which is devoted to such lock-out systems.

Broken-Line Method. The broken-line system, like the step-by-step system, is also essentially a lock-out system and for that reason only its general features, by which the selective ringing is accomplished, will be dealt with here.

Principles. In this system there are no tuned bells, no positively and negatively polarized bells bridged to ground on each side of the line, and no step-by-step devices in the ordinary sense, by which selective signaling has ordinarily been accomplished on party lines. Instead of this, each instrument on the line is exclusively brought into operative relation with the line, and then removed from such operative relation until the subscriber wanted is connected, at which time all of the other instruments are locked out and the line is not encumbered by any bridge circuits at any of the instruments that are not engaged in the conversation. Furthermore, in the selecting of a subscriber or the ringing of his bell there is no splitting up of current among the magnets at the various stations as in ordinary practice, but the operating current goes straight to the station desired and to that station alone where its entire strength is available for performing its proper work.

In order to make the system clear it may be stated at the outset that one side of the metallic circuit line is continued as in ordinary practice, passing through all of the stations as a continuous conductor. The other side of the line, however, is divided into sections, its continuity being broken at each of the subscriber's stations. Fig. 186 is intended to show in the simplest possible way how the circuit of the line may be extended from station to station in such manner that only the ringer of one station is in circuit at a time. The two sides of the line are shown in this figure, and it will be seen that limb *L* extends from the central office on the left to the last station on the right without a break. The limb *R*, however, extends to the first station, at which point it is cut off from the ex-

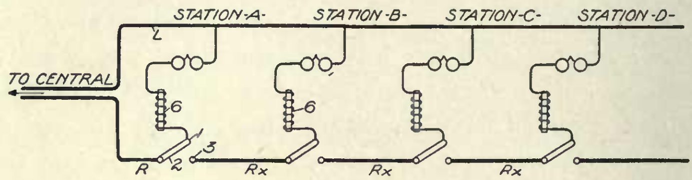


Fig. 186. Principle of Broken-Line System

tension R_x by the open contacts of a switch. For the purpose of simplicity this switch is shown as an ordinary hand switch, but as a matter of fact it is a part of a relay, the operating coil of which is shown at *6*, just above it, in series with the ringer.

Obviously, if a proper ringing current is sent over the metallic circuit from the central office, only the bell at Station A will operate, since the bells at the other stations are not in the circuit. If by any means the switch lever *2* at Station A were moved out of engagement with contact *1* and into engagement with contact *3*, it is obvious that the bell of Station A would no longer be in circuit, but the limb *R* of the line would be continued to the extension

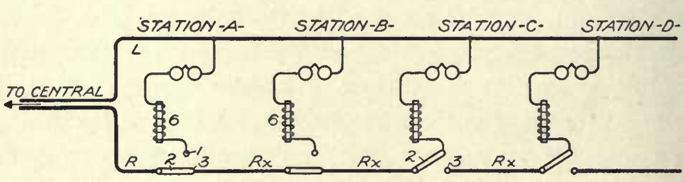


Fig. 187. Principle of Broken-Line System

R_x and the bell of Station B would be in circuit. Any current then sent over the circuit of the line from the central office would ring the bell of this station. In Fig. 187 the switches of both Station A and Station B have been thus operated, and Station C is thus placed in circuit. Inspection of this figure will show that the bells of Station A, Station B, and Station D are all cut out of circuit, and that, therefore, no current from the central office can affect them. This general scheme of selection is a new-comer in the field, and for certain classes of work it is of undoubted promise.

CHAPTER XVII

LOCK-OUT PARTY-LINE SYSTEMS

The party-line problem in rural districts is somewhat different from that within urban limits. In the latter cases, owing to the closer grouping of the subscribers, it is not now generally considered desirable, even from the standpoint of economy, to place more than four subscribers on a single line. For such a line selective ringing is simple, both from the standpoint of apparatus and operation; and moreover owing to the small number of stations on a line, and the small amount of traffic to and from such subscribers as usually take party-line service, the interference between parties on the same line is not a very serious matter.

For rural districts, particularly those tributary to small towns, these conditions do not exist. Owing to the remoteness of the stations from each other it is not feasible from the standpoint of line cost to limit the number of stations to four. A much greater number of stations is employed and the confusion resulting is distressing not only to the subscribers themselves but also to the management of the company. There exists then the need of a party-line system which will give the limited user in rural districts a service, at least approaching that which he would get if served by an individual line.

The principal investment necessary to provide facilities for telephone service is that required to produce the telephone line. In many cases the cost of instruments and apparatus is small in comparison with the cost of the line. By far the greater number of subscribers in rural districts are those who use their instruments a comparatively small number of times a day, and to maintain an expensive telephone line for the exclusive use of one such subscriber who will use it but a few minutes each day is on its face an economic waste. As a result, where individual line service is practiced exclusively one of two things must be true: either the average subscriber pays more for his service than he should, or else the operating company sells the service for less than it costs, or at best for an insufficient profit. Both of these conditions are unnatural and cannot be permanent.

The party-line method of giving service, by which a single line is made to serve a number of subscribers, offers a solution to this difficulty, but the ordinary non-selective or even selective party line has many undesirable features if the attempt is made to place on it such a large number of stations as is considered economically necessary in rural work. These undesirable features work to the detriment of both the user of the telephone and the operating company.

Many attempts have been made to overcome these disadvantages of the party line in sparsely settled communities, by producing what are commonly called lock-out systems. These, as their name implies, employ such an arrangement of parts that when the line is in use by any two parties, all other parties are locked out from the circuit and cannot gain access to it until the parties who are using it are through. System after system for accomplishing this purpose has been announced but for the most part these have involved such a degree of complexity and have introduced so many undesirable features as to seriously affect the smooth operation of the system and the reliability of the service.

We believe, however, in spite of numerous failures, that the lock-out selective-signaling party line has a real field of usefulness and that operating companies as well as manufacturing companies are beginning to appreciate this need, and as a result that the relief of the rural subscriber from the almost intolerable service he has often had to endure is at hand. A few of the most promising lock-out party-line systems now before the public will, therefore, be described in some detail.

Poole System. The Poole system is a lock-out system pure and simple, its devices being in the nature of a lock-out attachment for selective-signaling lines, either of the polarity or of the harmonic type wherein common-battery transmission is employed. It will be here described as employed in connection with an ordinary harmonic-ringing system.

In Fig. 188 there is shown a four-station party line equipped with Poole lock-out devices, it being assumed that the ringers at each station are harmonic and that the keys at the central office are the ordinary keys adapted to impress the proper frequency on the line for ringing any one of the stations. In addition to the ordinary talking and ringing apparatus at each subscriber's station, there is a relay of special form and also a push-button key.

Each of the relays has two windings, one of high resistance and the other of low resistance. Remembering that the system to which this device is applied is always a common-battery system, and that, therefore, the normal condition of the line will be one in which there is a difference of potential between the two limbs, it will be evident that whenever any subscriber on a line that is not in use

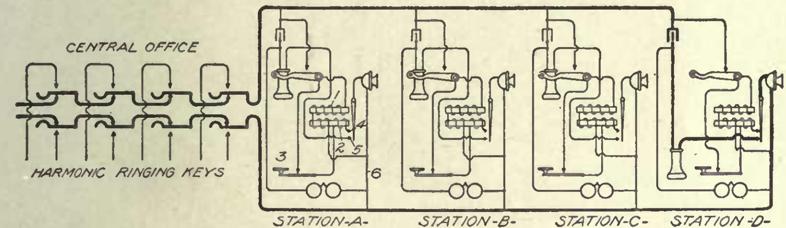


Fig. 188. Poole Lock-Out System

raises his receiver from its hook, a circuit will be established from the upper contact of the hook through the lever of the hook to the high-resistance winding *1* of the relay and thence to the other side of the line by way of wire *6*. This will result in current passing through the high-resistance winding of the relay and the relay will pull up its armature. As soon as it does so it establishes two other circuits by the closure of the relay armature against the contacts *4* and *5*.

The closing of the contact *4* establishes a circuit from the upper side of the line through the upper contact of the switch hook, thence through the contacts of the push button *3*, thence through the low-resistance winding *2* of the relay to the terminal *4*, thence through the relay armature and the transmitter to the lower side of the line. This low-resistance path across the line serves to hold the relay armature attracted and also to furnish current to the transmitter for talking. The establishment of this low-resistance path across the line does another important thing, however; it practically short-circuits the line with respect to all the high-resistance relay windings, and thus prevents any of the other high-resistance relay windings from receiving enough current to actuate them, should the subscriber at any other station remove his receiver from the hook in an attempt to listen in or to make a call while the line is in use. As a subscriber can only establish the proper conditions for talking and listening by the attraction of this relay armature at his station, it is obvious that unless he can cause the pulling up of his relay armature he can not place himself in communication with the line.

The second thing that is accomplished by the pulling up of the relay armature is the closure of the contacts *5*, and that completes the talking circuit through the condenser and receiver across the line in an obvious fashion. The result of this arrangement is that it is the first party who raises his receiver from its hook who is enabled to successfully establish a connection with the line, all subsequent efforts, by other subscribers, failing to do so because of the fact that the line is short-circuited by the path through the low-resistance winding and the transmitter of the station that is already connected with the line.

A little target is moved by the action of the relay so that a visual indication is given to the subscriber in making a call to show whether or not he is successful in getting the use of the line. If the relay operates and he secures control of the line, the target indicates the fact by its movement, while if someone else is using the line and the relay does not operate, the target, by its failure to move, indicates that fact.

When one party desires to converse with another on the same line, he depresses the button *3* at his station until after the called party has been rung and has responded. This holds the circuit of his low-resistance winding open, and thus prevents the lock-out from becoming effective until the called party is connected with the line. The relay armature of the calling party does not fall back with the establishment of the low-resistance path at the called station, because, even though shunted, it still receives sufficient current to hold its armature in its attracted position. After the called party has responded, the button at the calling station is released and both low-resistance holding coils act in multiple.

No induction coil is used in this system and the impedance of the holding coil is such that incoming voice currents flow through the condenser and the receiver, which, by reference to the figure, will be seen to be in shunt with the holding coil. The holding coil is in series with the local transmitter, thus making a circuit similar to that of the Kellogg common-battery talking circuit already discussed.

A possible defect in the use of this system is one that has been common to a great many other lock-out systems, depending for their operation on the same general plan of action. This appears when the instruments are used on a comparatively long line. Since the locking-out of all the instruments that are not in use by the one that is in use depends on the low-resistance shunt that is placed across the line by the instrument that is in use, it is obvious that, in the case of a long line, the resistance of the line wire will enter into the problem in such a way as to tend to defeat the locking-out function in some cases. Thus, where the first instrument to use the line is at the remote end of the line, the shunting effect that this instrument can exert with respect to another instrument near the central office is that due to the resistance of the line plus the resistance of the holding coil at the end instrument. The resistance of the line wire may be so high as to still allow a sufficient current to flow through the high-resistance coil at the nearer station to allow its operation, even though the more remote instrument is already in use.

Coming now to a consideration of the complete selective-signaling lock-out systems, wherein the selection of the party and the locking out of the others are both inherent features, a single example of the step-by-step, and of the broken-line selective lock-out systems will be discussed.

Step-by-Step System. The so-called K. B. system, manufactured by the Dayton Telephone Lock-out Manufacturing Company of Dayton, Ohio, operates on the step-by-step principle. The essential feature of the subscriber's telephone equipment in this system is the step-by-step actuating mechanism which performs also the functions of a relay. This device consists of an electromagnet having two cores, with a permanent polarizing magnet therebetween, the arrangement in this respect being the same as in an ordinary polarized bell. The armature of this magnet works a rocker arm, which, besides stepping the selector segment around, also, under certain conditions, closes the bell circuit and the talking circuit, as will be described.

Referring first to Fig. 189, which shows in simplified form a four-station K. B. lock-out line, the electromagnet is shown at *1* and the rocker arm at *2*. The ratchet *3* in this case is not a complete wheel but rather a segment thereof, and it is provided with a series of notches of different depths. It is obvious that the depth of the notches will determine the degree of movement which the upper end of the rocker arm may have toward the left, this being dependent on the extent to which the pawl *6* is permitted to enter into the segment. The first or normal notch, *i. e.*, the top notch, is always of such a depth that it will allow the rocker-arm lever *2* to engage

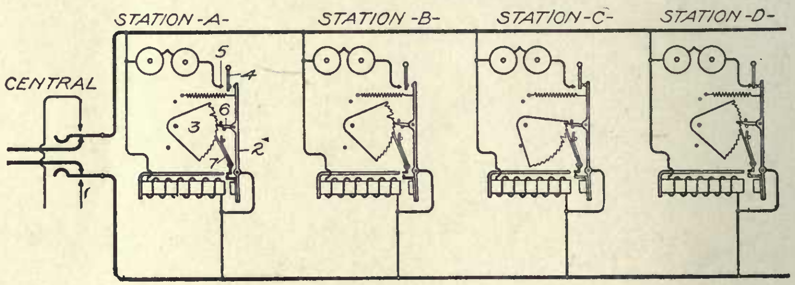


Fig. 189. K. B. Lock-Out System

the contact lever *4*, but will not permit the rocker arm to swing far enough to the left to cause that contact to engage the bell contact *5*. As will be shown later, the condition for the talking circuit to be closed is that the rocker arm *2* shall rest against the contact *4*; and from this we see that the normal notch of each of the segments *3* is of such a depth as to allow the talking circuit at each station to be closed. The next notch, *i. e.*, the second one in each disk, is always shallow, as are all of the other notches except one. A deep notch is placed on each disk anywhere from the third to the next to the last on the segment. This deep notch is called the *selective notch*, and it is the one that allows of contact being made with the ringer circuit of that station when the pawl *6* drops into it. The position of this notch differs on all of the segments on a line, and obviously, therefore, the ringer circuit at any station may be closed to the exclusion of all the others by stepping all of the segments in unison until the deep notch on the segment of the desired station lies opposite to the pawl *6*, which will permit the rocker arm *2* to swing so far to the left as to close not only the circuit between *2* and *4*, but also between *2*, *4*, and *5*. In this position the talking and the ringing circuits are both closed.

The position of the deepest notch, *i. e.*, the selective notch, on the circumference of the segment at any station depends upon the number of that station; thus, the segment of Station 4 will have a deep notch in the sixth position; the segment for Station 9 will have a deep notch in the eleventh position; the segment for any station will have a deep notch in the position corresponding to the number of that station plus two.

From what has been said, therefore, it is evident that the first, or normal, notch on each segment is of such a depth as to allow the moving pawl *6* to fall to such a depth in the segment as to permit the rocker arm *2* to close the talking circuit only. All of the other notches, except one, are comparatively shallow, and while they permit the moving pawl *6* under the influence of the rocker arm *2* to move the segment *3*, yet they do not permit the rocker arm *2* to move so far to the left as to close even the talking circuit. The exception is the deep notch, or selective notch, which is of such depth as to permit the pawl *6* to fall so far into the segment as to allow the rocker arm *2* to close both the talking and the ringing circuits. Besides the moving pawl *6* there is a detent pawl *7*. This always holds the segment *3* in the position to which it has been last moved by the moving pawl *6*.

The actuating magnet *1*, as has been stated, is polarized and when energized by currents in one direction, the rocker arm moves the pawl *6* so as to step the segment one notch. When this relay is energized by current in the opposite direction, the operation is such that both the moving pawl *6* and the detent pawl *7* will be pulled away from the segment, thus allowing the segment to return to its normal position by gravity. This is accomplished by the following mechanism: An armature stop is pivoted upon the face of the rocker arm so as to swing in a plane parallel to the pole faces of the relay, and is adapted, when the relay is actuated by selective impulses of one polarity, to be pulled towards one of the pole faces where it acts, through impact with a plate attached to the pole face of the relay, as a limiting means for the motion of the rocker arm when the rocker arm is actuated by the magnet. When, however, the relay is energized by current in the opposite direction, as on a releasing impulse, the armature stop swings upon its pivot towards the opposite pole face, in which position the lug on the end of the armature stop registers with a hole in the plate on the relay, thus allowing the full motion of the rocker arm when it is attracted by the magnet. This motion of the rocker arm withdraws the detent pawl from engagement with the segment as well as the moving pawl, and thereby permits the segment to return to its normal position. As will be seen from Fig. 189, each of the relay magnets *1* is permanently bridged across the two limbs of the line.

Each station is provided with a push button, not shown, by means of which the subscriber who makes a call may prevent the rocker arm of his instrument from being actuated while selective impulses are being sent over the line. The purpose of this is to enable one party to make a call for another on the same line, depressing his push button while the operator is selecting and ringing the called party. The segment at his own station, therefore, remains in its normal position, in which position, as we have already seen, his talking circuit is closed; all of the other segments are, however, stepped up until the ringing and talking circuits of the desired station are in proper position, at which time ringing current is sent over the line. The segments in Fig. 189, except at Station C, are shown as having been stepped up to the sixth position, which corresponds to the ringing position of the fourth station, or Station D. The condition shown in this figure corresponds to that in which the subscriber at Station C originated the call and pressed his button, thus retaining his own segment in its normal position so that the talking circuits would be established with Station D.

When the line is in normal position any subscriber may call central by his magneto generator, not shown in Fig. 189, which will operate the drop at central, but will not operate any of the subscribers' bells, because all bell circuits are normally open. When a subscriber desires connection with another line, the operator sends an impulse back on the line which steps up and locks out all instruments except that of the calling subscriber.

A complete K. B. lock-out telephone is shown in Fig. 190. This is the type of instrument that is usually furnished when new equipment is ordered. If, however, it is desired to use the K. B. system in connection with telephones of the ordinary bridging type that are already in service, the lock-out and selective mechanism,

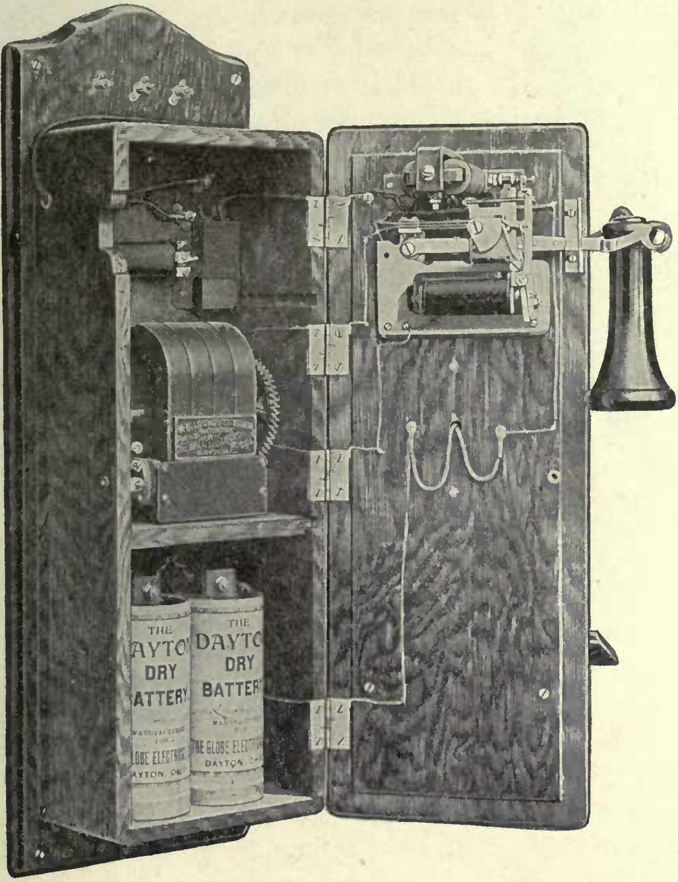


Fig. 190. K. B. Lock-Out Station

which is shown on the upper inner face of the door in Fig. 190, is furnished separately in a box that may be mounted close to the regular telephone and connected thereto by suitable wires, as shown in Fig. 191. It is seen that this instrument employs a local battery for talking and also a magneto generator for calling the central office.

The central-office equipment consists of a dial connected with an impulse wheel, together with suitable keys by which the various circuits may be manipulated. This dial and its associated mechanism may be mounted in the regular switchboard cabinet, or it may be furnished in a separate box and mounted alongside of the cabinet in either of the positions shown at *1* or *2* of Fig. 192.

Fig. 191. K. B. Lock-Out Station

In order to send the proper number of impulses to the line to call a given party, the operator places her finger in the hole in the dial that bears the number corresponding to the station wanted and rotates the dial until the finger is brought into engagement with the fixed stop shown at the bottom of the dial in Fig. 192. The dial is then allowed to return by the action of a spring to its normal position, and in doing so it operates a switch within the box to make and break the battery circuit the proper number of times.

Operation. A complete description of the operation may now be had in connection with Fig. 193, which is similar to Fig. 189, but contains the details of the calling arrangement at the central office and also of the talking circuits at the various subscribers' stations.

Referring to the central-office apparatus the usual ringing key is shown, the inside contacts of which lead to the listening key and to the operator's telephone set as in ordinary switchboard practice. Between the outside contact of this ringing key and the ringing generator there is interposed a pair of contact springs *8-8* and another pair *9-9*. The contact springs *8* are adapted to be moved backward and forward by the impulse wheel which is directly controlled by the dial under the manipulation of the operator. When these springs *8* are in their normal position, the ringing circuit is continued through the release-key springs *9* to the ringing generator. These springs *8* occupy their normal position only when the dial is in its normal position, this being due to the notch *10* in the contact wheel. At all other times, *i. e.*, while the impulse wheel is out of its normal position, the springs *8-8* are either depressed so as to engage the lower battery contacts, or else held in an intermediate position so as to engage neither the battery contacts nor the generator contacts.

When it is desired to call a given station, the operator pulls the subscriber's number on the dial and holds the ringing key closed,

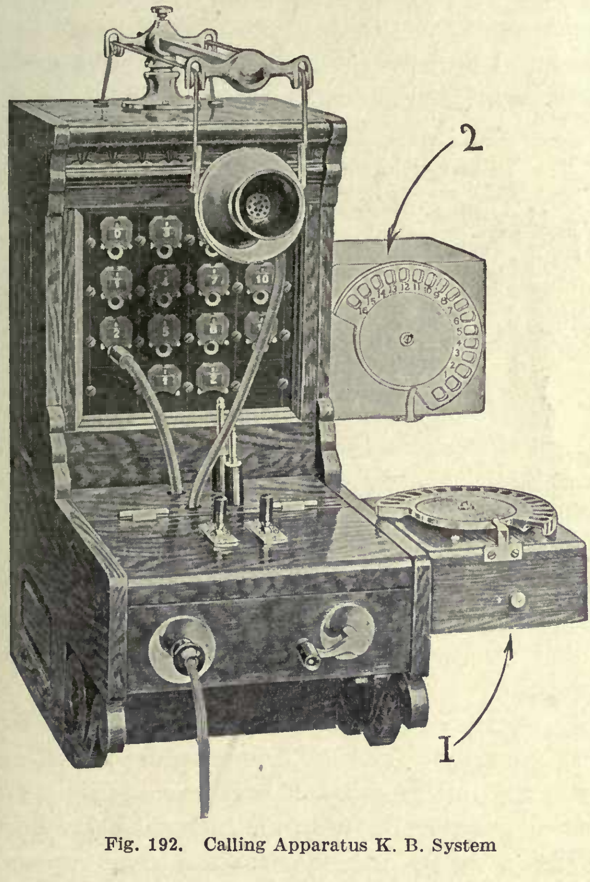


Fig. 192. Calling Apparatus K. B. System

allowing the dial to return to normal. This connects the impulse battery to the subscriber's line as many times as is required to move the subscriber's sectors to the proper position, and in such direction as to cause the stepping movement of the various relays. As the impulse wheel comes to its normal position, the springs *8*, associated with it, again engage their upper contacts, by virtue of the notch *10* in the impulse wheel, and this establishes the connection between the ringing generator and the subscriber's line, the ringing key being still held closed. The pulling of the transmitter dial and holding the ringing key closed, therefore, not only sends the stepping impulses to line, but also follows it by the ringing current. The sending of five impulses to line moves all of the sectors to the sixth notch, and this corresponds to the position necessary to make the fourth station operative. Such a condition is shown in Fig. 193, it being assumed that the subscriber at Station C originated the call and pressed his own button so as to prevent his sector from be-

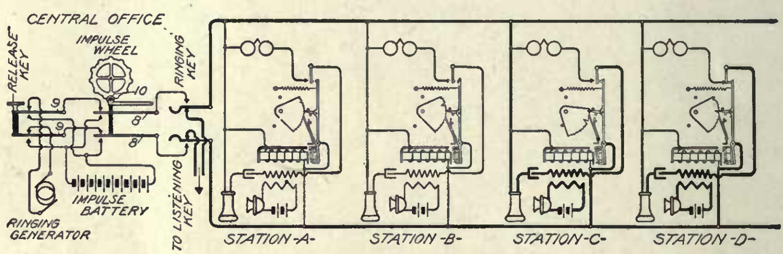


Fig. 193. Circuit K. B. System

ing moved out of its normal position. As a result of this, the talking circuit at Station C is left closed, and the talking and the ringing circuit of Station D, the called station, are closed, while both the talking and the ringing circuits of all the other stations are left open. Station D may, therefore, be rung and may communicate with Station C, while all of the other stations on the line are locked out, because of the fact that both their talking and ringing circuits are left open.

When conversation is ended, the operator is notified by the usual clearing-out signal, and she then depresses the release button, which brings the springs *9* out of engagement with the generator contact but into engagement with the battery contact in such relation as to send a battery current on the line in the reverse direction from that sent out by the impulse wheel. This sends current through all of the relays in such direction as to withdraw both the moving and the holding pawls from the segments and thus allow all of the segments to return to their normal positions. Of course, in thus establishing the release current, it is necessary for the operator to depress the ringing key as well as the release key.

A one-half microfarad condenser is placed in the receiver circuit at each station so that the line will not be tied up should some subscriber inadvertently leave his receiver off its hook. This permits the passage of voice currents, but not of the direct currents used in stepping the relays or in releasing them.

The circuit of Fig. 193 is somewhat simplified from that in actual practice, and it should be remembered that the hook switch, which is not shown in this figure, controls in the usual way the continuity of the receiver and the transmitter circuits as well as of the generator circuits, the generator being attached to the line as in an ordinary telephone.

Broken-Line System. The broken-line method of accomplishing selective signaling and locking-out on telephone party lines is due to Homer Roberts and his associates.

To understand just how the principles illustrated in Figs. 186 and 187 are put into effect, it will be necessary to understand the latching relay shown diagrammatically in its two possible positions in Fig. 194, and in perspective in Fig. 195. Referring to Fig. 194, the left-hand cut of which shows the line relay in its normal position, it is seen that the framework of the device resembles that of an ordinary polarized ringer. Under the influence of current in one direction flowing through the left-hand coil, the armature of this device depresses the hard rubber stud *4*, and the springs *1*, *2*, and *3* are forced downwardly until the spring *2* has passed under the latch carried on the spring *5*. When the operating current through the coil *6* ceases, the pressure of the armature on the spring *1* is relieved, allowing this spring to resume its normal position and spring *3* to engage with spring *2*. The spring *2* cannot rise, since it is held by the latch *5*, and the condition shown in the right-hand cut of Fig. 194 exists. It will be seen that the spring *2* has in this operation carried out just the same function as the switch lever performed

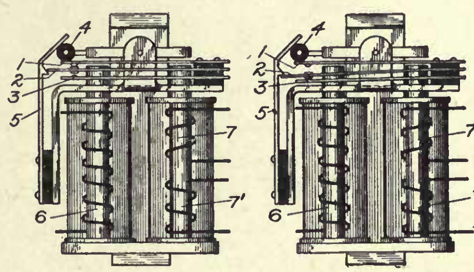


Fig. 194. Roberts Latching Relay

as described in connection with Figs. 186 and 187. An analysis of this action will show that the normal contact between the springs *1* and *2*, which contact controls the circuit through the relay coil and the bell, is not broken until the coil *6* is de-energized, which means that the magnet is effective until it has accomplished its work. It is impossible, therefore, for this relay to cut itself out of circuit before it has caused the spring *2* to engage under the latch *5*. If

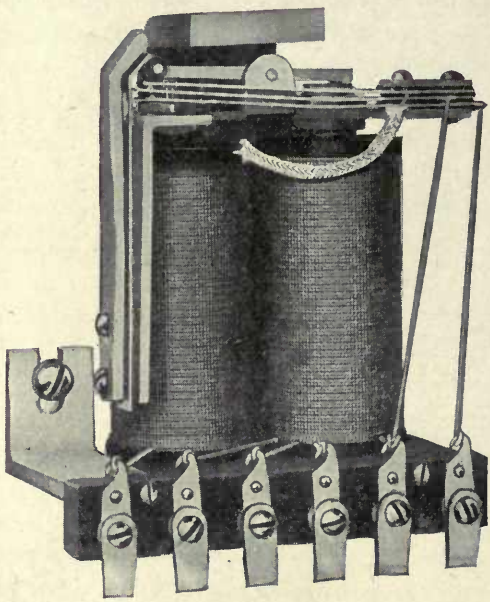


Fig. 195. Roberts Latching Relay

current of the proper direction were sent through the coil *7* of the relay, the opposite end of the armature would be pulled down and the hard rubber stud at the left-hand end of the armature would bear against the bent portion of the spring *5* in such manner as to cause the latch of this spring to release the spring *2* and thus allow the relay to assume its normal, or unlatched, position.

A good idea of the mechanical construction of this relay may be obtained from Fig. 195. The entire selecting function of the Roberts system is performed by this simple piece of apparatus at each station.

The diagram of Fig. 196 shows, in simplified form, a four-station line, the circuits being given more in detail than in the diagrams of Chapter XVI.

It will be noticed that the ringer and the relay coil *6* at the first station are bridged across the sides of the line leading to the central office. In like manner the bell and the relay magnets are bridged across the two limbs of the line leading into each succeeding station, but this bridge at each of the stations beyond Station A is ineffective because the line extension R_x is open at the next station nearest the central office.

In order to ring Station A it is only necessary to send out ringing current from the central office. This current is in such direction as not to cause the operation of the relay, although it passes through the coil *6*. If, on the other hand, it is desired to ring Station B, a preliminary impulse would be sent over the metallic circuit from the central office, which impulse would be of such direction as to operate the relay at Station A, but not to operate the bell at that

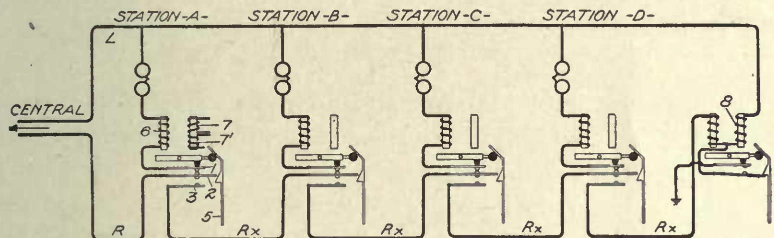


Fig. 196. Simplified Circuits of Roberts System

station. The operation of the relay at Station A causes the spring *2* of this relay to engage the spring *3*, thus extending the line on to the second station. After the spring *2* at Station A has been forced into contact with the spring *3*, it is caught by the latch of the spring *5* and held mechanically. When the impulse from the central office ceases, the spring *1* resumes its normal position, thus breaking the bridge circuit through the bell at that station. It is apparent now that the action of coil *6* at Station A has made the relay powerless to perform any further action, and at the same time the line has been extended on to the second station. A second similar impulse from the central office will cause the relay at Station B to extend the line on to Station C, and at the same time break the circuit through the operating coil and the bell at Station B. In this way any station may be picked out by sending the proper number of impulses to operate the line relays of all the stations between the station desired and the central office, and having picked out a station it is only necessary to send out ringing current, which current is in such direction as to ring the bell but not to operate the relay magnet at that station.

In Fig. 197, a four-station line, such as is shown in Fig. 196, is illustrated, but the condition shown in this is that existing when two preliminary impulses have been sent over the line, which caused

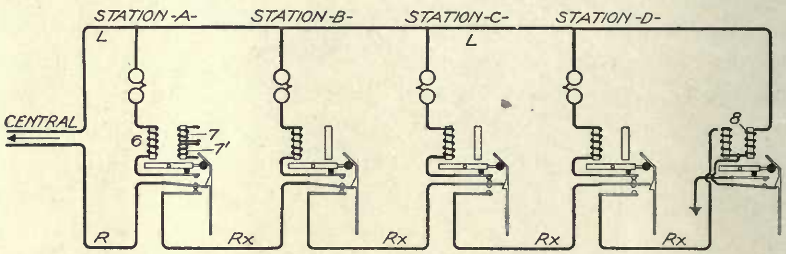


Fig. 197. Simplified Circuits of Roberts System

the line relays at Station A and Station B to be operated. The bell at Station C is, therefore, the only one susceptible to ringing current from the central office.

Since only one bell and one relay are in circuit at any one time, it is obvious that all of the current that passes over the line is effective in operating a single bell or relay only. There is no splitting up of the current among a large number of bells as in the bridging system of operating step-by-step devices, which method sometimes so greatly reduces the effective current for each bell that it is with great difficulty made to respond. All the energy available is applied directly to the piece of apparatus at the time it is being operated. This has a tendency toward greater surety of action, and the adjustment of the various pieces of apparatus may be made with less delicacy than is required where many pieces of apparatus, each having considerable work to do, must necessarily be operated in multiple.

The method of unlatching the relays has been briefly referred to. After a connection has been established with a station in the manner already described, the operator may clear the line when it is proper to do so by sending impulses of such a nature as to cause the line relays of the stations beyond the one chosen to operate, thus continuing the circuit to the end of the line. The operation of the line relay at the last station brings into circuit the coil *8*, Figs. 196 and 197, of a grounding device. This is similar to the line relay, but it holds its operating spring in a normally latched position so as to maintain the two limbs of the line disconnected from the ground. The next impulse following over the metallic circuit passes through the coil *8* and causes the operation of this grounding device which, by becoming unlatched, grounds the limb *L* of the line through the coil *8*. This temporary ground at the end of the line makes it possible to send an unlocking or restoring current from the central office over the limb *L*, which current passes through all of the unlocking coils *7*, shown in Figs. 194, 196, and 197, thus causing the simultaneous unlocking of all of the line relays and the restoration of the line to its normal condition, as shown in Fig. 196.

As has been stated, the windings *7* on the line relays are the unlatching windings. In Figs. 196 and 197, for the purpose of simplicity, these windings are not shown connected, but as a matter of fact each of them is included in series in the continuous limb *L* of the line. This would introduce a highly objectionable feature from the standpoint of talking over the line were it not for the balancing coils 7^1, each wound on the same core as the corresponding winding *7*, and each included in series in the limb *R* of the line, and in such direction as to be differential thereto with respect to currents passing in series over the two limbs of the line.

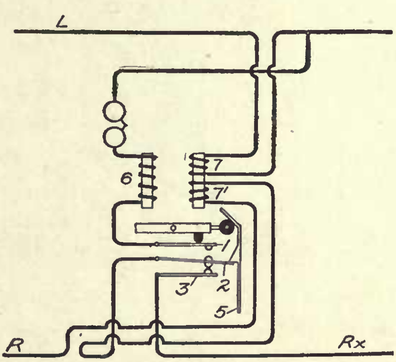


Fig. 198. Details of Latching Relay Connections

The windings *7* are the true unlocking windings, while the windings 7^1 have no other function than to neutralize the inductive effects of these unlocking windings necessarily placed in series in the talking circuit. All of these windings are of low ohmic resistance, a construction which, as has previously been noted, brings about the desired effect without introducing any self-induction in the line, and without producing any appreciable effect upon the transmission. A study of Fig. 198 will make clear the connections of these unlocking and balancing windings at each station.

The statement of operation so far given discloses the general method of building up the line in sections in order to choose any party and of again breaking it up into sections when the conversation is finished. It has been stated that the same operation which selects the party wanted also serves to give that party the use of the line and to lock the others off. That this is true will be understood when it is stated that the ringer is of such construction that when operated to ring the subscriber wanted, it also operates to unlatch a set of springs similar to those shown in Fig. 194, this unlatching causing the proper connection of the subscriber's talking circuit across the limbs of the line, and also closing the local circuit through his transmitter. The very first motion of the bell armature performs this unlatching operation after which the bell behaves exactly as an ordinary polarized biased ringer.

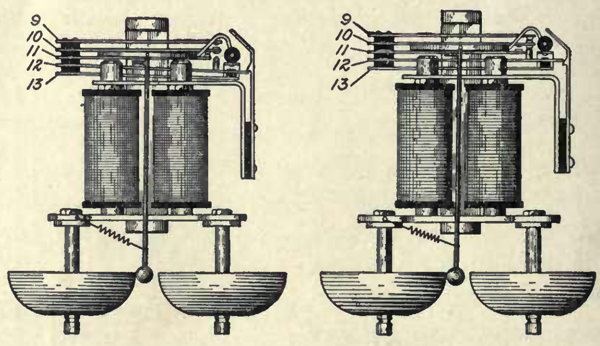


Fig. 199. Broken-Back Ringer

The construction of this ringer is interesting and is shown in its two possible positions in Fig. 199. The group of springs carried on its frame is entirely independent of the movement of the armature during the ringing operation. With reversed currents, however, the armature is moved in the opposite direction from that necessary to ring the bells, and this causes the latching of the springs into their normal position. In order that this device may perform the double function of ringer and relay the tapper rod of the bell is hinged on the armature so as to partake of the movements of the armature in one direction only. This has been called by the inventor and engineers of the Roberts system a *broken-back ringer*, a name suggestive of the movable relation between the armature and the tapper rod. The construction of the ringer is of the same nature as that of the standard polarized ringer universally employed, but a hinge action between the armature and the tapper rod, of such nature as to make the tapper partake positively of the movements of the armature in one direction, but to remain perfectly quiescent when the armature moves in the other direction, is provided.

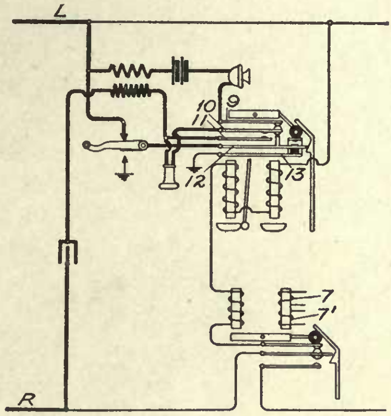


Fig. 200 Details of Ringer Connection

How this broken-back ringer controls the talking and the locking-out conditions may best be understood in connection with Fig. 200. The ringer springs are normally latched at all stations. Under these conditions the receiver is short-circuited by the engagement of springs *10* and *11*, the receiver circuit is open between springs *10* and *12*, and the local-battery circuit is open between springs *9* and *12*. The subscribers whose ringers are latched are, therefore, locked out in more ways than one.

When the bell is rung, the first stroke it makes unlatches the springs, which assume the position shown in the right-hand cut of Fig. 199, and this, it will be seen from Fig. 200, establishes proper conditions for enabling the subscriber to transmit and to receive speech.

The hook switch breaks both transmitter and receiver circuits when down and in raising it establishes a momentary circuit between the ground and the limb *L* of the line, both upper and lower hook contacts engaging the hook lever simultaneously during the rising of the hook.

The mechanism at the central office by which selection of the proper station is made in a rapid manner is shown in Fig. 201. It has already been stated that the selection of the proper subscriber is brought about by the sending of a predetermined number of impulses from the central office, these impulses passing in one direction only and over the metallic circuit. After the proper party has been reached, the ringing current is put on in the reverse direction.

The operator establishes the number of impulses to be sent by placing the pointer opposite the number on the dial corresponding

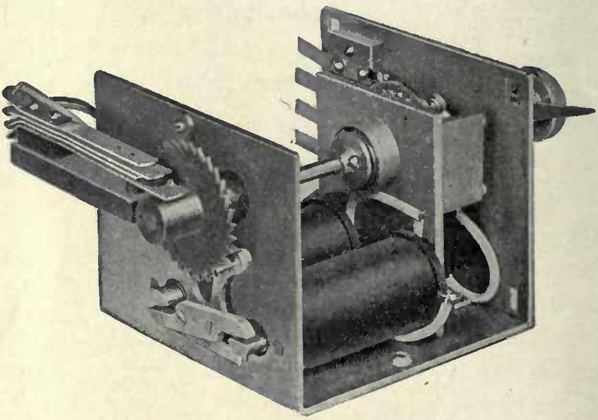


Fig. 201. Central-Office Impulse Transmitter

to the station wanted. The ratchet wheel is stepped around automatically by each impulse of current from an ordinary pole changer such as is employed in ringing biased bells. When the required number of impulses has been sent, a projection, carried on a group of springs, drops into a notch on the drum of the selector shaft, which operation instantly stops the selecting current impulses and at the same time throws on the ringing current which consists of impulses in the reverse direction. So rapidly does this device operate that it will readily follow the impulses of an ordinary pole changer, even when this is adjusted to its maximum rate of vibration.

Operation. Space will not permit a full discussion of the details of the central-office selective apparatus, but a general resumé of the operation of the system may now be given, with the aid of Fig. 202, which shows a four-station line with the circuits of three of the stations somewhat simplified. In this figure Station

A, Station B, and Station D are shown in their locked-out positions, A and B having been passed by the selection and ringing of Station C, while Station D is inoperative because it was not reached in the selection and the line is still broken at Station C. Station C, therefore, has possession of the line.

When the subscriber at Station C raised his receiver in order to call central, a "flash" contact was made as the hook moved up, which momentarily grounded the limb L of the line. (See Fig. 200.) This "flash" contact is produced by the arrangement of the hook which assures that the lower contact shall, by virtue of its flexibility, follow up the hook lever until the hook lever engages the upper contact, after which the lower contact breaks. This results in the momentary connection of both the upper and the lower contacts of the hook with the lever, and, therefore, the momentary grounding of the limb L of the line. This limb always being continuous serves, when this "flash" contact is made, to actuate the line signal at the central office.

Since, however, all parties on the line are normally locked out of talking circuits, some means must be provided whereby the operator may place the signaling party in talking connection and leave all the other instruments on the line in their normally locked-out position. In fact, the operator must be able automatically to pick out the station that signaled in, and operate the ringer to unlatch

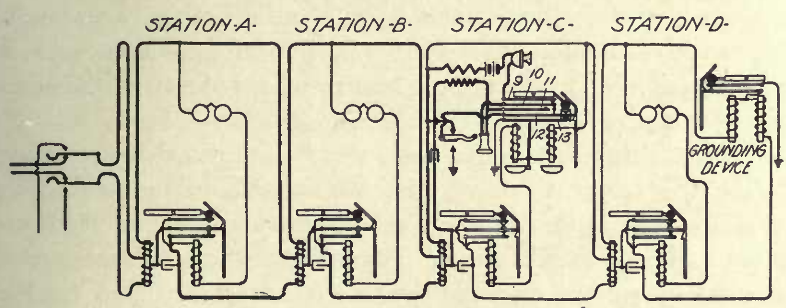


Fig. 202. Circuits of Roberts Line

the springs controlling the talking circuit of that station. Accordingly the operator sends impulses on the line, from a grounded battery, which are in the direction to operate the line relays and to continue the line circuit to the station calling. When, after a sufficient number of impulses, this current reaches that station it finds a path to ground from the limb *L*. This path is made possible by the fact that the subscriber's receiver is off its hook at that station. In order to understand just how this ground connection is made, it must be remembered that each of the ringer magnets is energized with each selecting impulse, but in such a direction as not to ring the bells, it being understood that all of the ringer mechanisms are normally latched. When the selecting impulse for Station C arrives, it passes through the ringer and the selecting relay coils at that station and starts to operate the remainder of the ringers sufficiently to cause the spring *12* to engage the spring *13*. This establishes the ground connection from the limb *L* of the line, the circuit being traced through limb *L* through the upper contact of the switch, thence through springs *12* and *13* to ground, and this, before the line relay has time to latch, operates the quick-acting relay at the central office, which acts to cut off further impulses, and thus automatically stops at the calling station. Ringing current in the opposite direction is then sent to line; this unlatches the ringer springs and places the calling subscriber in talking circuit. When the operator has communicated with the calling subscriber, and found, for example, that another party on another similar line is desired, she turns the dial pointer on the selector to the number corresponding to the called-for party's number on that line, and presses the signal key. Pressing this key causes impulses to "run down the line," selecting the proper party and ringing his bell in the manner already described. The connection between the two parties is then established, and no one else can in any possible way, except by permission of the operator, obtain access to the line.

It is obvious that some means must be provided for restoring the selecting relays to normal after a conversation is finished. By referring to Fig. 194 it will be seen that the upper end of the latch spring *5* is bent over in such a manner that when the armature is attracted by current flowing through the coil *7*, the knob on the left-hand end of the armature on rising engages with the bent cam surface and forces back the latch, permitting spring *2* to return to its normal position.

To restore the line the operator sends out sufficient additional selective impulses to extend the circuit to the end of the line, and thus brings the grounder into circuit. The winding of the grounder is connected in such a manner that the next passing impulse throws off its latch, permitting the long spring to contact with the ground spring. The operator now sends a grounded impulse over the continuous limb L of the line which passes through the restoring coils 7 at all the stations and through the right-hand coil of the grounding device to ground. The selecting relays are, therefore, simultaneously restored to normal. The grounder is also energized and restored to its normal position by the same current.

If a party in calling finds that his own line is busy and he cannot get central, he may leave his receiver off its hook. When the party who is using the line hangs up his receiver the fact that another party desires a connection is automatically indicated to the operator, who then locks out the instrument of the party who has just finished conversation and passes his station by. When the operator again throws the key, the waiting subscriber is automatically selected in the same manner as was the first party. If there are no subscribers waiting for service, the stop relay at central will not operate until the grounder end of the line is unlatched, the selecting relays being then restored automatically to normal.

The circuits are so organized that at all times whether the line is busy or not, the movement up and down of the switch hook, at any sub-station, operates a signal before the operator. Such a movement, when made slowly and repeatedly, indicates to the operator that the subscriber has an emergency call and she may use her judgment as to taking the line away from the parties who are using it, and finding out what the emergency call is for. If the operator finds that the subscriber has misused this privilege of making the emergency call, she may restore the connection to the parties previously engaged in conversation.

One of the salient points of this Roberts system is that the operator always has control of the line. A subscriber is not able even to use his own battery till permitted to do so. A subscriber who leaves his receiver off its hook in order that he may be signaled by the operator when the line is free, causes no deterioration of the local battery because the battery circuit is held open by the switch contacts carried on the ringer. It cannot be denied, however, that this system is complicated, and that it has other faults. For instance, as described herein, both sides of the line must be looped into each subscriber's station, thus requiring four drop, or service, wires instead of two. It is possible to overcome this objection by placing the line relays on the pole in a suitably protected casing, in which case it is sufficient to run but two drop wires from the nearer line to station. There are undoubtedly other objections to this system, and yet with all its faults it is of great interest, and although radical in many respects, it teaches lessons of undoubted value.

CHAPTER XVIII

ELECTRICAL HAZARDS

All telephone systems are exposed to certain electrical hazards. When these hazards become actively operative as causes, harmful results ensue. The harmful results are of two kinds: those causing damage to property and those causing damage to persons. The damage to persons may be so serious as to result in death. Damage to property may destroy the usefulness of a piece of apparatus or of some portion of the wire plant. Or the property damage may initiate itself as a harm to apparatus or wiring and may result in greater and extending damage by starting a fire.

Electrical currents which endanger life and property may be furnished by natural or artificial causes. Natural electricity which does such damage usually displays itself as lightning. In rare cases, currents tending to flow over grounded lines because of extraordinary differences of potential between sections of the earth's surface have damaged apparatus in such lines, or only have been prevented from causing such damage by the operation of protective devices.

Telegraph and telephone systems have been threatened by natural electrical hazards since the beginning of the arts and by artificial electrical hazards since the development of electric light and power systems. At the present time, contrary to the general supposition, it is in the artificial, and not in the natural electrical hazards that the greater variety and degree of danger lies.

Of the ways in which artificial electricity may injure a telephone system, the entrance of current from an external electrical power system is a greater menace than an abnormal flow of current from a source belonging to the telephone system itself. Yet modern practice provides opportunities for a telephone system to inflict damage upon itself in that way. Telephone engineering designs need to provide means for protecting *all* parts of a system against damage, from external ("foreign") as well as internal ("domestic") hazards, and to cause this protection to be inclusive enough to protect persons against injury and property from damage by any form of overheating or electrolytic action.

A part of a telephone system for which there is even a remote possibility of contact with an external source of electrical power, whether natural or artificial, is said to be *exposed* to electrical hazard. The degree or character of possible contact or other interference often is referred to in relative terms of *exposure*. The same terms are used concerning inductive relations between circuits. The whole tendency of design, particularly of wire plants, is to arrange the circuits in such a way as to limit the exposure as greatly as possible, the intent being to produce a condition in which all parts of the system will be *unexposed* to hazards.

Methods of design are not yet sufficiently advanced for any plant to be formed of circuits wholly unexposed, so that protective means are required to safeguard apparatus and circuits in case the hazard, however remote, becomes operative.

Lightning discharges between the clouds and earth frequently charge open wires to potentials sufficiently high to damage apparatus; and less frequently, to destroy the wires of the lines themselves. Lightning discharges between clouds frequently induce charges in lines sufficient to damage apparatus connected with the lines. Heavy rushes of current in lines, from lightning causes, occasionally induce damaging currents in adjacent lines not sufficiently exposed to the original cause to have been injured without this induction. The lightning hazard is least where the most lines are exposed. In a small city with all of the lines formed of exposed wires and all of them used as grounded circuits, a single lightning discharge may damage many switchboard signals and telephone ringers if there be but 100 or 200 lines, while the damage might have been nothing had there been 800 to 1,000 lines in the same area.

Means of protecting lines and apparatus against damage by lightning are little more elaborate than in the earliest days of telegraph working. They are adequate for the almost entire protection of life and of apparatus.

Power circuits are classified by the rules of various governing bodies as high-potential and low-potential circuits. The classification of the National Board of Fire Underwriters in the United States defines low-potential circuits as having pressures below 550 volts; high-potential circuits as having pressures from 550 to 3,500 volts, and extra high-potential circuits as having pressures above 3,500 volts. Pressures of 100,000 volts are becoming more common. Where power is valuable and the distance over which it is to be transmitted is great, such high voltages are justified by the economics of the power problem. They are a great hazard to telephone systems, however. An unprotected telephone system meeting such a hazard by contact will endanger life and property with great certainty. A very common form of distribution for lighting and power purposes is the three-wire system having a grounded neutral wire, the maximum potential above the earth being about 115 volts.

Telephone lines and apparatus are subject to damage by any power circuit whether of high or low potential. The cause of property damage in all cases is the flow of current. Personal damage, if it be death from shock, ordinarily is the result of a high potential between two parts of the body. The best knowledge indicates that death uniformly results from shock to the heart. It is believed that death has occurred from shock due to pressure as low as 100 volts. The critical minimum voltage which can not cause death is not known. A good rule is never willingly to subject another person to personal contact with any electrical pressure whatever.

Electricity can produce actions of four principal kinds: physiological, thermal, chemical, and magnetic. Viewing electricity as establishing hazards, the physiological action may injure or kill living things; the thermal action may produce heat enough to melt metals, to char things which can be burned, or to cause them actually to burn, perhaps with a fire which can spread; the chemical action may destroy property values by changing the state of metals, as by dissolving them from a solid state where they are needed into a state of solution where they are not needed; the magnetic action introduces no direct hazard. The greatest hazard to which property values are exposed is the electro-thermal action; that is, the same useful properties by which electric lighting and electric heating thrive may produce heat where it is not wanted and in an amount greater than can safely be borne.

The tendency of design is to make all apparatus capable of carrying without overheating any current to which voltage within the telephone system may subject it, and to provide the system so designed with specific devices adapted to isolate it from currents originating without. Apparatus which is designed in this way, adapted not only to carry its own normal working currents but to carry the current which would result if a given piece of apparatus were connected directly across the maximum pressure within the telephone system itself, is said to be self-protecting. Apparatus amply able to carry its maximum working current but likely to be overheated, to be injured, or perhaps to destroy itself and set fire to other things if subjected to the maximum pressure within the system, is not self-protecting apparatus.

To make all electrical devices self-protecting by surrounding them with special arrangements for warding off abnormal currents from external sources, is not as simple as might appear. A lamp, for example, which can bear the entire pressure of a central-office battery, is not suitable for direct use in a line several miles long because it would not give a practical signal in series with that line and with the telephone set, as it is required to do. A lamp suitable for use in series with such a line and a telephone set would burn out by current from its own normal source if the line should become short-circuited in or near the central office. The ballast referred to in the chapter on "Signals" was designed for the very purpose of providing rapidly-rising resistance to offset the tendency toward rapidly-rising current which could burn out the lamp.

As another example, a very small direct-current electric motor can be turned on at a snap switch and will gain speed quickly enough so that its armature winding will not be overheated. A larger motor of that kind can not be started safely without introducing resistance into the armature circuit on starting, and cutting it out gradually as the armature gains speed. Such a motor could be made self-protecting by having the armature winding of much larger wire than really is required for mere running, choosing its size great enough to carry the large starting current without overheating itself and its insulation. It is better, and for long has been standard practice, to use starting boxes, frankly admitting that such motors are not self-protecting until started, though they are self-protecting while running at normal speeds. Such a motor, once started, may be overloaded so as to be slowed down. So much more current now can pass through the armature that its winding is again in danger. Overload circuit-breakers are provided for the very purpose of taking motors out of circuit in cases where, once up to speed, they are mechanically brought down again and into danger. Such a circuit-breaker is a device for protecting against an *internal* hazard; that is, internal to the power system of which the motor is a part.

Another example: In certain situations, apparatus intended to operate under impulses of large current may be capable of carrying its normal impulses successfully but incapable of carrying currents from the same pressure continuously. Protective means may be provided for detaching such apparatus from the circuit whenever the period in which the current acts is not short enough to insure safety. This is cited as a case wherein a current, normal in amount but abnormal in duration, becomes a hazard.

The last mentioned example of damage from internal hazards brings us to the law of the electrical generation of heat. *The greater the current or the greater the resistance of the conductor heated or the longer the time, the greater will be the heat generated in that conductor.* But this generated heat varies directly as the resistance and as the time and as the square of the current, that is, the law is

$$\text{Heat generated} = C^2Rt$$

in which C = the current; R = the resistance of the conductor; and t = the time.

It is obvious that a protective device, such as an overload circuit-breaker for a motor, or a protector for telephone apparatus, needs to operate more quickly for a large current than for a small one, and this is just what all well-designed protective devices are intended to do. The general problem which these heating hazards present with relation to telephone apparatus and circuits is: *To cause all parts of the telephone system to be made so as to carry successfully all currents which may flow in them because of any internal or external pressure, or to supplement them by devices which will stop or divert currents which could overheat them.*

Electrolytic hazards depend not on the heating effects of currents but on their chemical effects. The same natural law which enables primary and secondary batteries to be useful provides a hazard which menaces telephone-cable sheaths and other conductors.

When a current leaves a metal in contact with an electrolyte, the metal tends to dissolve into the electrolyte. In the processes of electroplating and electrotyping, current enters the bath at the anode, passes from the anode through the solution to the cathode, removing metal from the former and depositing it upon the latter. In a primary battery using zinc as the positive element and the negative terminal, current is caused to pass, within the cell, from the zinc to the negative element and zinc is dissolved. Following the same law, any pipe buried in the earth may serve to carry current from one region to another. As single-trolley traction systems with positive trolley wires constantly are sending large currents through the earth toward their power stations, such a pipe may be of positive potential with relation to moist earth at some point in its length. Current leaving it at such a point may cause its metal to dissolve enough to destroy the usefulness of the pipe for its intended purpose.

Lead-sheathed telephone cables in the earth are particularly exposed to such damage by electrolysis. The reasons are that such cables often are long, have a good conductor as the sheath-metal, and that metal dissolves readily in the presence of most aqueous solutions when electrolytic differences of potential exist. The length of the cables enables them to connect between points of considerable difference of potential. It is lack of this length which prevents electrolytic damage to masses of structural metal in the earth.

Electrical power is supplied to single-trolley railroads principally in the form of direct current. Usually all the trolley wires of a city are so connected to the generating units as to be positive to the rails. This causes current to flow from the cars toward the power stations, the return path being made up jointly of the rails, the earth itself, actual return wires which may supplement the rails, and also all other conducting things in the earth, these being principally lead-covered cables and other pipes. These conditions establish definite areas in which the currents tend to leave the cables and pipes, *i. e.*, in which the latter are positive to other things. These positive areas usually are much smaller than the negative areas, that is, the regions in which currents tend *to enter* the cables form a larger total than the regions in which the currents tend *to leave* the cables.

These facts simplify the ways in which the cables may be protected against damage by direct currents leaving them and also they reduce the amount, complication, and cost of applying the corrective and preventive measures.

All electric roads do not use direct current. Certain simplifications in the use of single-phase alternating currents in traction motors have increased the number of roads using a system of alternating-current power supply. Where alternating current is used, the electrolytic conditions are different and a new problem is set, for, as the current flows in recurrently different directions, an area which at one instant is positive to others, is changed the next instant into a negative area. The protective means, therefore, must be adapted to the changed requirements.

CHAPTER XIX

PROTECTIVE MEANS

Any of the heating hazards described in the foregoing chapter may cause currents which will damage apparatus. All devices for the protection of apparatus from such damage, operate either to stop the flow of the dangerous current, or to send that flow over some other path.

Protection Against High Potentials. Lightning is the most nearly universal hazard. All open wires are exposed to it in some degree. Damaging currents from lightning are caused by extraordinarily high potentials. Furthermore, a lightning discharge is oscillatory; that is, alternating, and of very high frequency. Drops, ringers, receivers, and other devices subject to lightning damage suffer by having their windings burned by the discharge. The impedance these windings offer to the high frequency of lightning oscillations is great. The impedance of a few turns of heavy wire may be negligible to alternating currents of ordinary frequencies because the resistance of the wire is low, its inductance small, and the frequency finite. On the other hand, the impedance of such a coil to a lightning discharge is much higher, due to the very high frequency of the discharge.

Were it not for the extremely high pressure of lightning discharges, their high frequency of oscillation would enable ordinary coils to be self-protecting against them. But a discharge of electricity can take place through the air or other insulating medium if its pressure be high enough. A pressure of 70,000 volts can strike across a gap in air of one inch, and lower pressures can strike across smaller distances. When lightning encounters an impedance, the discharge seldom takes place through the entire winding, as an ordinary current would flow, usually striking across whatever short paths may exist. Very often these paths are across the insulation between the outer turns of a coil. It is not unusual for a lightning discharge to plow its way across the outer layer of a wound spool, melting the copper of the turns as it goes. Often the discharge will take place from inner turns directly to the core of the magnet. This is more likely when the core is grounded.

Air-Gap Arrester. The tendency of a winding to oppose lightning discharges and the ease with which such discharge may strike across insulating gaps, points the way to protection against them. Such devices consist of two conductors separated by an air space or other insulator and are variously known as lightning arresters, spark gaps, open-space cutouts, or air-gap arresters. The conductors between which the gap exists may be both of metal, may be one of metal and one of carbon, or both of carbon. One combination consists of carbon and mercury, a liquid metal. The space between the conductors may be filled with either air or solid matter, or it may be a vacuum. Speaking generally, the conductors are separated by some insulator. Two conductors separated by an insulator form a condenser. The insulator of an open-space arrester often is called the dielectric.

Discharge Across Gaps:—Electrical discharges across a given distance occur at lower potentials if the discharge be between points than if between smooth surfaces. Arresters, therefore, are provided with points. Fig. 203 shows a device known as a "saw-tooth" arrester because of its metal plates being provided with teeth. Such an arrester brings a ground connection close to plates connected with the line and is adapted to protect apparatus either connected across a metallic circuit or in series with a single wire circuit.

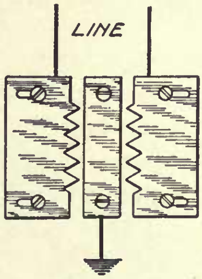


Fig. 203. Saw-Tooth Arrester

Fig. 204 shows another form of metal plate air-gap arrester having the further possibility of a discharge taking place from one line wire to the other. Inserting a plug in the hole between the two line plates connects the line wires directly together at the arrester. This practice was designed for use with series lines, the plug short-circuiting the telephone set when in place.

A defect of most ordinary types of metal air-gap lightning arresters is that heavy discharges tend to melt the teeth or edges of the plates and often to weld them together, requiring special attention to re-establish the necessary gap.

Advantages of Carbon:—Solid carbon is found to be a much better material than metal for the reasons that a discharge will not melt it and that its surface is composed of multitudes of points from which discharges take place more readily than from metals.

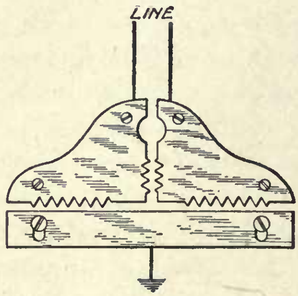


Fig. 204. Saw-Tooth Arrester

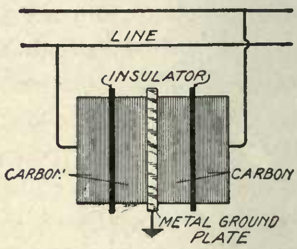


Fig. 205. Carbon Block Arrester

Carbon arresters now are widely used in the general form shown in Fig. 205. A carbon block connected with a wire of the line is separated from a carbon block connected to ground by some form of insulating separator. Mica is widely used as such a separator, and holes of some form in a mica slip enable the discharge to strike freely from block to block, while preventing the blocks from touching each other. Celluloid with many holes is used as a separator between carbon blocks. Silk and various special compositions also have their uses.

Dust Between Carbons:—Discharges between the carbon blocks tend to throw off particles of carbon from them. The separation between the blocks being small—from .005 to .015 inch—the carbon particles may lodge in the air-gap, on the edges of the separator, or otherwise, so as to leave a conducting path between the two blocks. Slight moisture on the separator may help to collect this dust, thus placing a ground on that wire of the line. This ground may be of very high resistance, but is probably one of many such—one at each arrester connected to the line. In special forms of carbon arresters an attempt has been made to limit

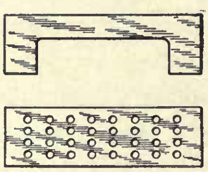


Fig. 206. Arrester Separators

this danger of grounding by the deposit of carbon dust. The object of the U-shaped separator of Fig. 206 is to enable the arrester to be mounted so that this opening in the separator is downward, in the hope that loosened carbon particles may fall out of the space between the blocks. The deposit of carbon on the inside edges of the U-shaped separator often is so fine and clings so tightly as not to fall out. The separator projects beyond the blocks so as to avoid the collection of carbon on the outer edges.

Commercial Types:—Fig. 207 is a commercial form of the arrangement shown in Fig. 205 and is one of the many forms made by the American Electric Fuse Company. Line wires are attached to outside binding posts shown in the figure and the ground wire to the metal binding post at the front. The carbon blocks with their separator slide between clips and a ground plate. The air-gap is determined by the thickness of the separator between the carbon blocks.

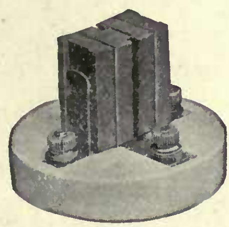


Fig. 207. Carbon Block Arrester

The Roberts carbon arrester is designed with particular reference to the disposal of carbon dust and is termed self-cleaning for that reason. The arrangement of carbons and dielectric in this device is shown in Fig. 208; mica is cemented to the line carbon and is large enough to provide a projecting margin all around. The spark gap is not uniform over the entire surface of the block but is made wedge-shaped by grinding away the line carbon as shown. It is claimed that a continuous arcing fills the wedge-shaped chamber with heated air or gas, converting the whole of the space into a field of low resistance to ground, and that this gas in expanding drives out every particle of carbon that may be thrown off. It seems obvious that the wedge-shaped space offers greater freedom for carbon dust to fall out than in the case of the parallel arrangement of the block faces.

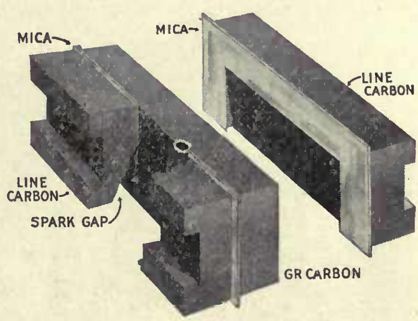


Fig. 208. Roberts "Self-Cleaning" Arrester

An outdoor arrester for metallic circuits, designed by F. B. Cook, is shown in Fig. 209. The device is adapted to mount on a pole or elsewhere and to be covered by a protecting cap. The carbons are large and are separated by a special compound intended to

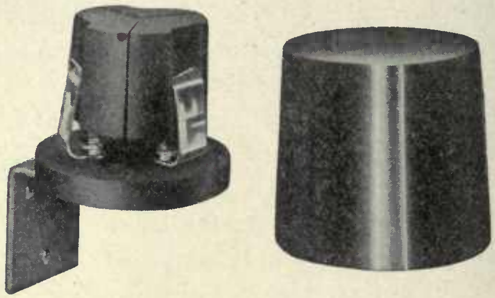


Fig. 209. Cook Air-Gap Arrester

assist the self-cleaning feature. The three carbons being grouped together as a unit, the device has the ability to care for discharges from one terminal to either of the others direct, without having to pass through two gaps. In this particular, the arrangement is the same as that of Fig. 204.

A form of Western Electric arrester particularly adapted for outside use on railway lines is shown with its cover in Fig. 210.

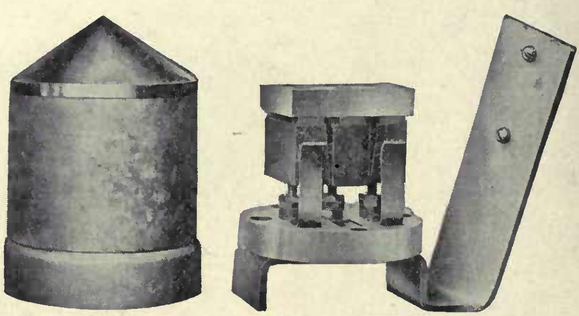


Fig. 210. Western Electric Air-Gap Arrester

The Kellogg Company regularly equips its magneto telephones with air-gap arresters of the type shown in Fig. 211. The two line plates are semicircular and of metal. The ground plate is of carbon, circular in form, covering both line plates with a mica separator. This is mounted on the back board of the telephone and permanently wired to the line and ground binding posts.

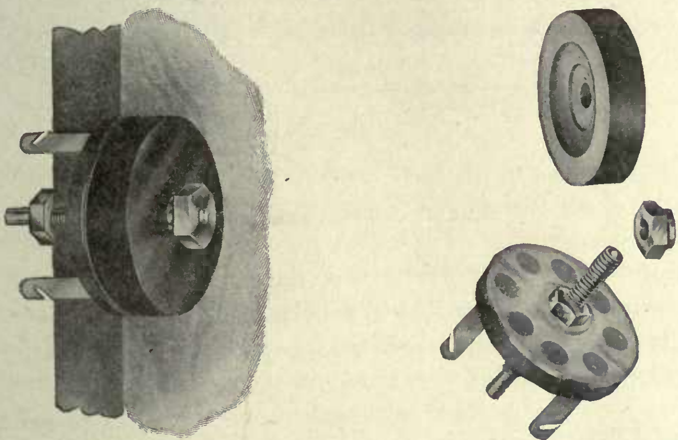


Fig. 211. Kellogg Air-Gap Arrester

Vacuum Arresters:—All of the carbon arresters so far mentioned depend on the discharge taking place through air. A given pressure will discharge further in a fairly good vacuum than in air. The National Electric Specialty Company mounts three conductors in a vacuum of the incandescent lamp type, Fig. 212. A greater separation and less likelihood of short-circuiting can be provided in this way. Either carbon or metal plates are adapted for use in such vacuum devices. The plates may be further apart for a given discharge pressure if the surfaces are of carbon.

Fig. 212. Vacuum Arrester

Introduction of Impedance:—It has been noted that the existence of impedance tends to choke back the passage of lightning discharge through a coil Fig. 213 suggests the relation between such an impedance and air-gap arrester. If the coil shown therein be considered an arrangement of conductors having inductance, it will be seen that a favorable place for an air-gap arrester is between that impedance and the line. This fact is made known in practice by frequent damage to aërial cables by electricity brought into them over long open wires, the discharge taking place at the first turn or bend in the aërial cable; this discharge often damages both core and sheath. It is well to

Fig. 213. Impedance and Air-Gap

have such bends as near the end of the cable as possible, and turns or goosenecks at entrances to terminals have that advantage.

This same principle is utilized in some forms of arresters, such as the one shown in Fig. 214, which provides an impedance of its own directly in the arrester element. In this device an insulating base carries a grounded carbon rod and two impedance coils. The impedance coils are wound on insulating rods, which hold them near, but not touching, the ground carbon. The coils are arranged so that they may be turned when discharges roughen the surfaces of the wires.

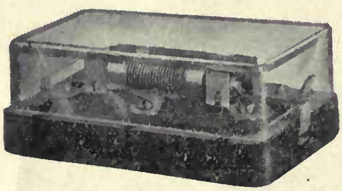


Fig. 214. Holtzer-Cabot Arrester

Metallic Electrodes:—Copper or other metal blocks with roughened surfaces separated by an insulating slip may be substituted for the carbon blocks of most of the arresters previously described. Metal blocks lack the advantage of carbon in that the latter allows discharges at lower potentials for a given separation, but they have the advantage that a conducting dust is not thrown off from them.

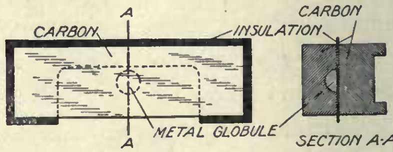


Fig. 215. Carbon Air-Gap Arrester

Provision Against Continuous Arc:—For the purpose of short-circuiting an arc, a globule of low-melting alloy may be placed in one carbon block of an arrester. This feature is not essential in an arrester intended solely to divert lightning discharges. Its purpose is to provide an immediate path to ground if an arc arising from artificial electricity has been maintained between the blocks long enough to melt the globule. Fig. 215 is a plan and section of the Western Electric Company's arrester used as the high potential element in conjunction with others for abnormal currents and sneak currents; the latter are currents too small to operate air-gap arresters or substantial fuses.

Protection Against Strong Currents. *Fuses.* A fuse is a metal conductor of lower carrying capacity than the circuit with which it is in series at the time it is required to operate. Fuses in use in electrical circuits generally are composed of some alloy of lead, which melts at a reasonably low temperature. Alloys of lead have lower conductivity than copper. A small copper wire, however, may fuse at the same volume of current as a larger lead alloy wire.

Proper Functions:—A fuse is not a good lightning arrester. As lightning damage is caused by current and as it is current which destroys a fuse, a lightning discharge *can* open a circuit over which it passes by melting the fuse metal. But lightning may destroy a fuse and at the same discharge destroy apparatus in series with the fuse. There are two reasons for this: One is that lightning discharges act very quickly and may have destroyed apparatus before heating the fuse enough to melt it; the other reason is that when a fuse is operated with enough current even to vaporize it, the vapor serves as a conducting path for an instant after being formed. This conducting path may be of high resistance and still allow currents to flow through it, because of the extremely high pressure of the lightning discharge. A comprehensive protective system may include fuses, but it is not to be expected that they always will arrest lightning or even assist other things in arresting lightning. They should be considered as of no value for that purpose. Furthermore, fuses are best adapted to be a part of a general protective system when they do all that they must do in stopping abnormal currents and yet withstand lightning discharges which may pass through them. Other things being equal, that system of protection is best in which all lightning discharges are arrested by gap arresters and in which no fuses ever are operated by lightning discharges.

Mica Fuse:—A convenient and widely used form of fuse is that shown in Fig. 216. A mica slip has metal terminals at its ends and a fuse wire joins these terminals. The fuse is inserted in the circuit by clamping the terminals under screws or sliding them

Fig. 216. Mica Slip Fuse

between clips as in Figs. 217 and 218. Advantages of this method of fuse mounting for protecting circuits needing small currents are that the fuse wire can be seen, the fuses are readily replaced when blown, and their mountings may be made compact. As elements of a comprehensive protective system, however, the ordinary types of mica-slip fuses are objectionable because too short, and because they have no means of their own for extinguishing an arc which may

Fig. 217. Postal Type Mica Fuse

Fig. 218. Western Union Type Mica Fuse

follow the blowing of the fuses. As protectors for use in distributing low potential currents from central-office power plants they are admirable. By simple means, they may be made to announce audibly or visibly that they have operated.

Enclosed Fuses:—If a fuse wire within an insulating tube be made to connect metal caps on that tube and the space around the tube be filled with a non-conducting powder, the gases of the vaporized fuse metal will be absorbed more quickly than when formed

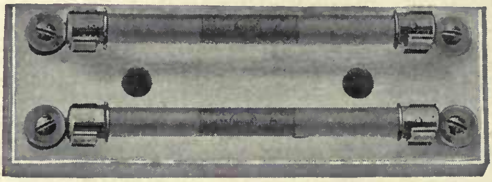


Fig. 219. Pair of Enclosed Fuses

without such imbedding in a powder. The filling of such a tubular fuse also muffles the explosion which occurs when the fuse is vaporized.

Fuses of the enclosed type, with or without filling, are widely used in power circuits generally and are recommended by fire insurance bodies. Fig. 219 illustrates an arrester having a fuse of the enclosed type, this example being that of the H. W. Johns-Manville Company.

In telephony it is frequently necessary to mount a large number of fuses or other protective devices together in a restricted space. In Fig. 220 a group of Western Electric tubular fuses, so mounted, is shown. These fuses have ordinarily a carrying capacity of 6 or 7 amperes. It is not expected that this arrester will blow because 6 or 7 amperes of abnormal currents are flowing through it and the apparatus to be protected. What is intended is that the fuse shall withstand lightning discharges and when a foreign current passes through it, other apparatus will increase that current enough to blow the fuse. It will be noticed that the fuses of Fig. 220 are open at the upper end, which is the end connected to the exposed wire of the line The fuses are closed at the lower end, which is the end connected to the apparatus. When the fuse blows, its discharge is somewhat muffled by the lining of the tube, but enough explosion remains so that the heated gases, in driving outward, tend to break the arc which is established through the vaporized metal.

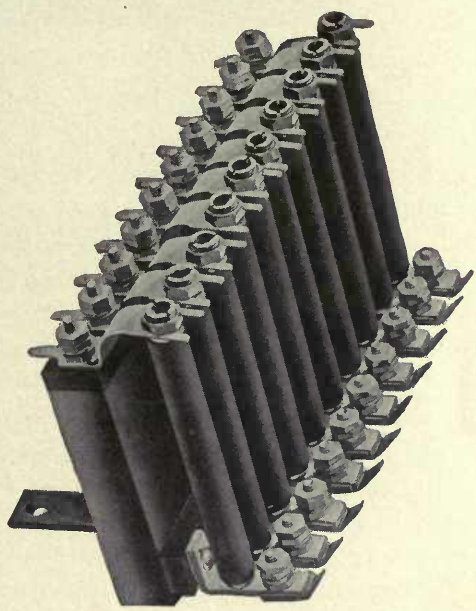


Fig. 220. Bank of Enclosed Fuses

A pair of Cook tubular fuses in an individual mounting is shown in Fig. 221 Fuses of this type are not open at one end like a gun, but opportunity for the heated gases to escape exists at the caps. The tubes are made of wood, of lava, or of porcelain.

Fig. 222 is another tubular fuse, the section showing the arrangement of asbestos lining which serves the two purposes of muffling the sound of the discharge and absorbing and cooling the resulting gases.

Air-Gap vs. Fuse Arresters. It is hoped that the student grasps clearly the distinction between the purposes of air-gap and fuse

Fig. 221. Pair of Wooden Tube Fuses

arresters. The air-gap arrester acts in response to high voltages, either of lightning or of high-tension power circuits. The fuse acts in response to a certain current value flowing through it and this minimum current in well-designed protectors for telephone lines is not very small. Usually it is several times larger than the maximum current apparatus in the line can safely carry. Fuses *can* be made so delicate as to operate on the very smallest current which could injure apparatus and the earlier protective systems depended on such an arrangement. The difficulty with such delicate fuses is that they are not robust enough to be reliable, and, worse still, they change their carrying capacity with age and are not uniform in operation in different surroundings and at different temperatures. They are also sensitive to lightning discharges, which they have no power to stop or to divert.

Protection Against Sneak Currents. For these reasons, a system containing fuses and air-gap arresters only, does not protect against abnormal currents which are continuous and small, though large enough to injure apparatus *because* continuous. These currents have come to be known as sneak currents, a term more descriptive than elegant. Sneak currents though small, may, when allowed to flow for a long time through the winding of an electromagnet for instance, develop enough heat to char or injure the insulation. They are the more dangerous because insidious.

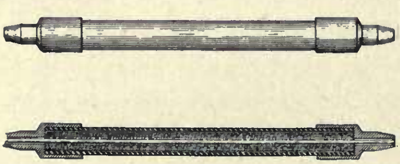


Fig. 222. Tubular Fuse with Asbestos Filling

Sneak-Current Arresters. As typical of sneak-current arresters, Fig. 223 shows the principle, though not the exact form, of an arrester once widely used in telephone and signal lines. The normal path from the line to the apparatus is through a small coil of fine wire imbedded in sealing wax. A spring forms a branch path from the line and has a tension which would cause it to bear against the ground contact if it were allowed to do so. It is prevented from touching that contact normally by a string between itself and a rigid support. The string is cut at its middle and the knotted ends as thus cut are imbedded in the sealing wax which contains the coil.

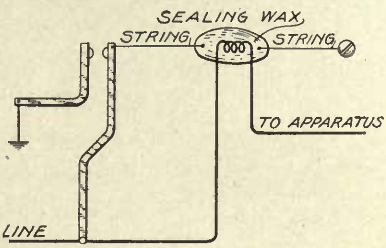


Fig. 223. Principle of Sneak-Current Arrester

A small current through the little coil will warm the wax enough to allow the string to part. The spring then will ground the line. Even so simple an apparatus as this operates with considerable accuracy. All currents below a certain critical amount may flow through the heating coil indefinitely, the heat being radiated rapidly enough to keep the wax from softening and the string from parting. All currents above this critical amount will operate the arrester; the larger the current, the shorter the time of operating. It will be remembered that the law of these heating effects is that the heat generated = C^2Rt, so that if a certain current operates the arrester in, say 40 seconds, twice as great a current should operate the arrester in 10 seconds. In other words, the time of operation varies inversely as the square of the current and inversely as the resistance. To make the arrester more sensitive for a given current—*i. e.*, to operate in a shorter time—one would increase the resistance of the coil in the wax either by using more turns or finer wire, or by making the wire of a metal having higher specific resistance.

The present standard sneak-current arrester embodies the two elements of the devices of Fig. 223: a *resistance* material to transform the dangerous sneak current into localized heat; and a *fusible* material softened by this heat to release some switching mechanism.

The resistance material is either a resistance wire or a bit of carbon, the latter being the better material, although both are good. The fusible material is some alloy melting at a low temperature. Lead, tin, bismuth, and cadmium can be combined in such proportions as will enable the alloy to melt at temperatures from 140° to 180° F. Such an alloy is a solder which, at ordinary temperatures, is firm enough to resist the force of powerful springs; yet it will melt so as to be entirely fluid at a temperature much less than that of boiling water.

Heat Coil. Fig. 224 shows a practical way of bringing the heating and to-be-heated elements together. A copper spool is wound with resistance wire. A metal pin is soldered in the bore of the spool by an easily melting alloy. When current heats the spool enough, the pin may slide or turn in the spool. It may slide or turn in many ways and this happily enables many types of arresters to result. For example, the pin may pull out, or push in, or push through, or rotate like a shaft in a bearing, or the spool may turn on it like a hub on an axle. Messrs. Hayes, Rolfe, Cook, McBerty, Kaisling, and many other inventors have utilized these combinations and motions in the production of sneak-current arresters. All of them depend on one action: the softening of a low-melting alloy by heat generated in a resistance.

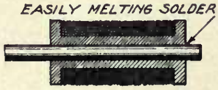


Fig. 224. Heat Coil

When a heat coil is associated with the proper switching springs, it becomes a sneak-current arrester. The switching springs always are arranged to ground the line wire. In some arresters, the line wire is cut off from the wire leading toward the apparatus by the same movement which grounds it. In others, the line is not broken at all, but merely grounded. Each method has its advantages.

Complete Line Protection. Fig. 225 shows the entire scheme of protectors in an exposed line and their relation to apparatus in the central-office equipment and at the subscriber's telephone. The central-office equipment contains heat coils, springs, and carbon arresters. At some point between the central office and the subscriber's premises, each wire contains a fuse. At the subscriber's premises each wire contains other fuses and these are associated with carbon arresters. The figure shows a central battery equipment, in which the ringer of the telephone is in series with a condenser. A sneak-current arrester is not required at the subscriber's station with such equipment.

Assume the line to meet an electrical hazard at the point X. If this be lightning, it will discharge to ground at the central office or at the subscriber's instrument or at both through the carbon arresters connected to that side of the line. If it be a high potential from a power circuit and of more than 350 volts, it will strike an arc at the carbon arrester connected to that wire of the line in the central office or at the subscriber's telephone or at both, if the separation of the carbons in those arresters is .005 inch or less. If the carbon arresters are separated by celluloid, it will burn away and allow the carbons to come together, extinguishing the arc. If they are separated by mica and one of the carbons is equipped with a globule of low-melting alloy, the heat of the arc will melt this, short-circuiting

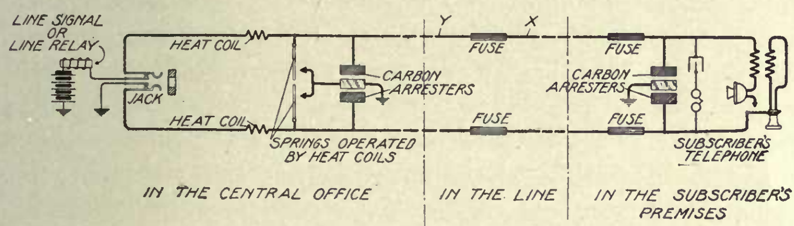


Fig. 225. Complete Line Protection

the gap and extinguishing the arc. The passage of current to ground at the arrester, however, will be over a path containing nothing but wire and the arrester. The resulting current, therefore, may be very large. The voltage at the arrester having been 350 volts or more, in order to establish the arc, short-circuiting the gap will make the current 7 amperes or more, unless the applied voltage miraculously falls to 50 volts or less. The current through the fuse being more than 7 amperes, it will blow promptly, opening the line and isolating the apparatus. It will be noted that this explanation applies to equipment at either end of the line, as the fuse lies between the point of contact and the carbon arrester.

Assume, on the other hand, that the contact is made at the point Y. The central-office carbon arrester will operate, grounding the line and increasing the amount of current flowing. There being no fuse to blow, a worse thing will befall, in the overheating of the line wire and the probable starting of a fire in the central office. It is obvious, therefore, that a fuse must be located between the carbon arrester and any part of the line which is subject to contact with a potential which can give an abnormal current when the carbon arrester acts.

Assume, as a third case, that the contact at the point X either is with a low foreign potential or is so poor a contact that the difference of potential across the gap of the carbon arrester is lower than its arcing point. Current will tend to flow by the carbon arrester without operating it, but such a current must pass through the winding of the heat coil if it is to enter the apparatus. The sneak current may be large enough to overheat the apparatus if allowed to flow long enough, but before it has flowed long enough it will have warmed the heat-coil winding enough to soften its fusible alloy and to release springs which ground the line, just as did the carbon arrester in the case last assumed. Again the current will become large and will blow the fuse which lies between the sneak-current arrester and the point of contact with the source of foreign current. In this case, also, contact at the point Y would have operated mechanism to ground the line at the central office, and, no fuse interposing, the wiring would have been overheated.

Exposed and Unexposed Wiring. Underground cables, cables formed of rubber insulated wires, and interior wiring which is properly done, all may be considered to be wiring which is unexposed, that is, not exposed to foreign high potentials, discharges, sneak, or abnormal currents. *All other wiring,* such as bare wires, aërial cables, etc., should be considered as *exposed* to such hazards and a fuse should exist in each wire between its exposed portion and the central office or subscriber's instrument. The rule of action, therefore, becomes:

The proper position of the fuse is between exposed and unexposed wiring.

It may appear to the student that wires in an aërial cable with a lead sheath—that sheath being either grounded or ungrounded—are not exposed to electrical hazards; in the case of the grounded sheath, this would presume that a contact between the cable and a high potential wire would result merely in the foreign currents going to ground through the cable sheath, the arc burning off the high-potential wire and allowing the contact to clear itself by the falling of the wire. If the assumption be that the sheath is not grounded, then the student may say that no current at all would flow from the high-potential wire.

Both assumptions are wrong. In the case of the grounded sheath, the current flows to it at the contact with the high-potential wire; the lead sheath is melted, arcs strike to the wires within, and currents are led directly to the central office and to subscribers' premises. In the case of the ungrounded sheath, the latter charges at once through all its length to the voltage of the high-potential wire; at some point, a wire within the cable is close enough to the sheath for an arc to strike across, and the trouble begins. All the wires in the cable are endangered if the cross be with a wire of the primary circuit of a high-tension transmission line. Any series arc-light circuit is a high-potential menace. Even a 450-volt trolley wire or feeder can burn a lead-covered cable entirely in two in a few seconds. The authors have seen this done by the wayward trolley pole of a street car, one side of the pole touching the trolley wire and the extreme end just touching the telephone cable.

The answer lies in the foregoing rule. Place the fuse between the wires which *can* and the wires which *can not* get into contact with high potentials. In application, the rule has some flexibility. In the case of a cable which is aërial as soon as it leaves the central office, place the fuses in the central office; in a cable wholly underground, from central office to subscriber—as, for example, the feed for an office building—use no fuses at all; in a cable which leaves the central office underground and becomes aërial, fuse the wires just where they change from underground to aërial. The several branches of an underground cable into aërial ones should be fused as they branch.

Wires properly installed in subscribers' premises are considered unexposed. The position of the fuse thus is at or near the point of entrance of the wires into that building if the wires of the subscriber's line outside the premises are exposed, as determined by the definitions given. If the line is unexposed, by those definitions, no protector is required. If one is indicated, it should be used, as compliance with the best-known practice is a clear duty. Less than what is known to be best is not honest practice in a matter which involves life, limb, and indefinite degrees of property values.

Protectors in central-battery subscribers' equipments need no sneak-current arresters, as the condenser reduces that hazard to a negligible amount. Magneto subscribers' equipments usually lack condensers in ringer circuits, though they may have them in talking circuits on party lines. The ringer circuit is the only path through the telephone set for about 98 per cent of the time. Sneak-current arresters, therefore, should be a part of subscribers' station protectors in magneto equipment, except in such rural districts as may have no lighting or power wires. When sneak-current arresters are so used the arrangement of the parts then is the same as in the central-office portion of Fig. 225.

Types of Central-Office Protectors. A form of combined heat coil and air-gap arrester, widely used by Bell companies for central-office protection, is shown in Fig. 226. The two inner springs form the terminals for the two limbs of the metallic-circuit line, while the two outside springs are terminals for the continuation of the line leading to the switchboard. The heat coils, one on each side, are supported between the inner and outer springs. High-tension currents jump to ground through the air-gap arrester, while sneak currents permit the pin of the heat coil to slide within the sleeve, thus grounding the outside line and the line to the switchboard.

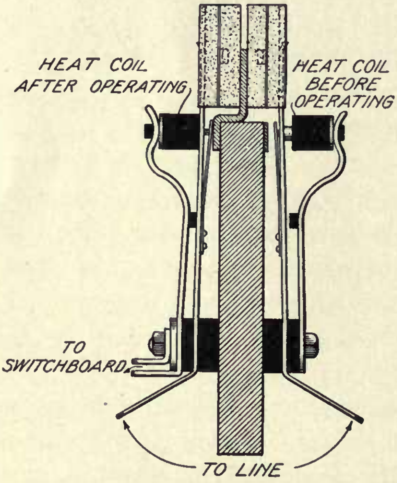


Fig. 226. Sneak-Current and Air-Gap Arrester

Self-Soldering Heat Coils. Another form designed by Kaisling and manufactured by the American Electric Fuse Company is shown in Fig. 227. In this the pin in the heat coil projects unequally from the ends of the coil, and under the action of a sneak current the melting of the solder which holds it allows the outer spring to push the pin through the coil until it presses the line spring against the ground plate and at the same time opens the path to the switchboard. When the heat-coil pin assumes this new position it cools off, due to the cessation of the current, and *resolders* itself, and need only be turned end for end by the attendant to be reset. Many are the variations that have been made on this self-soldering idea, and there has been much controversy as to its desirability. It is certainly a feature of convenience.

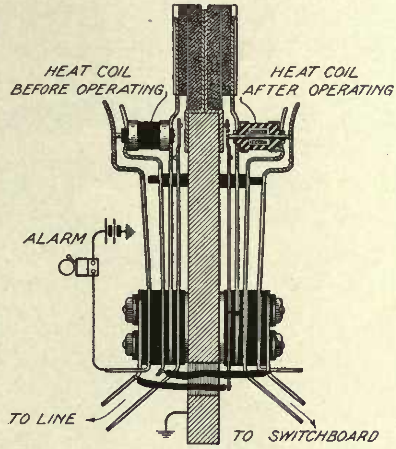


Fig. 227. Self-Soldering Heat-Coil Arrester

Instead of using a wire-wound resistance element in heat-coil construction some manufacturers employ a mass of high-resistance material, interposed in the path of the current. The Kellogg Company has long employed for its sneak-current arrester a short graphite rod, which forms the resistance element. The ends of this rod are electroplated with copper to which the brass terminal heads are soldered. These heads afford means for making the connection with the proper retaining springs.

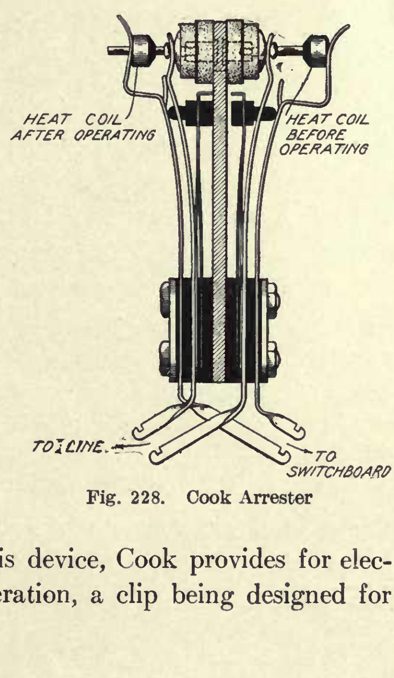


Fig. 228. Cook Arrester

Another central-office protector, which uses a mass of special metal composition for its heat producing element is that designed by Frank B. Cook and shown in Fig. 228. In this the carbon blocks are cylindrical in form and specially treated to make them "self-cleaning." Instead of employing a self-soldering feature in the sneak-current arrester of this device, Cook provides for electrically resoldering them after operation, a clip being designed for holding the elements in proper position and passing a battery current through them to remelt the solder.

In small magneto exchanges it is not uncommon to employ combined fuse and air-gap arresters for central-office line protection, the fuses being of the mica-mounted type already referred to. A group of such arresters, as manufactured by the Dean Electric Company, is shown in Fig. 229.

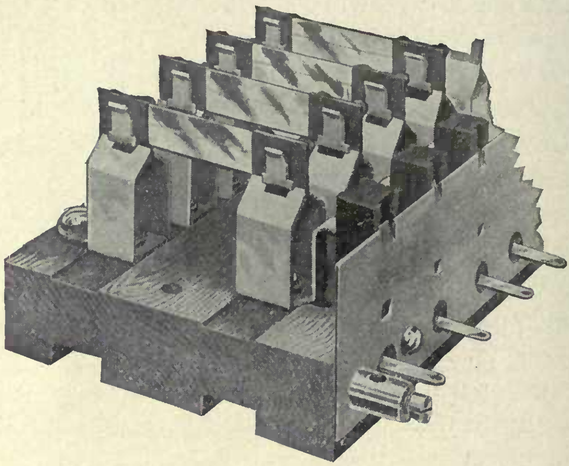


Fig. 229. Mica Fuse and Air-Gap Arresters

Types of Subscribers' Station Protectors. Figs. 230 and 231 show types of subscribers' station protectors adapted to the requirements of central-battery and magneto systems. These, as has been said, should be mounted at or near the point of entrance of the subscriber's line into the premises, if the line is exposed outside of the premises. It is possible to arrange the fuses so that they will be safe and suitable for their purposes if they are mounted out-of-doors near the point of entrance to the premises. The sneak-current arrester, if one exists, and the carbon arrester also, must be mounted inside of the premises or in a protecting case, if outside, on account of the necessity of shielding both of these devices from the weather. Speaking generally, the wider practice is to put all the elements of the subscriber's station protector inside of the house. It is nearer to the ideal arrangement of conditions if the protector be placed immediately at the point of entrance of the outside wires into the building.

Ribbon Fuses. A point of interest with relation to tubular fuses is that in some of the best types of such fuses, the resistance material is not in the form of a round wire but in the form of a flat

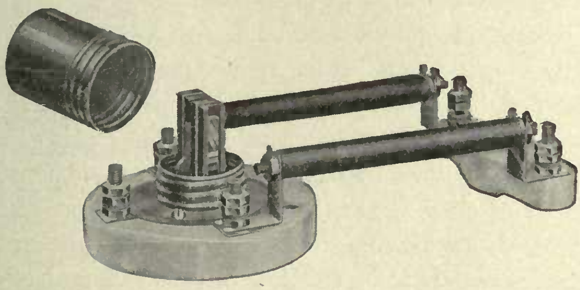


Fig. 230. Western Electric Station Arrester

ribbon. This arrangement disposes the necessary amount of fusible metal in a form to give the greatest amount of surface, while a round wire offers the least surface for a given weight of metal—a circle encloses its area with less periphery than any other figure. The reason for giving the fuse the largest possible surface area is to decrease the likelihood of the fuse being ruptured by lightning. The fact that such fuses do withstand lightning discharges much more thoroughly than round fuses of the same rating is an interesting proof of the oscillating nature of lightning discharges, for the density of the current of those discharges is greater on and near the surface of the conductor than within the metal and, therefore, flattening

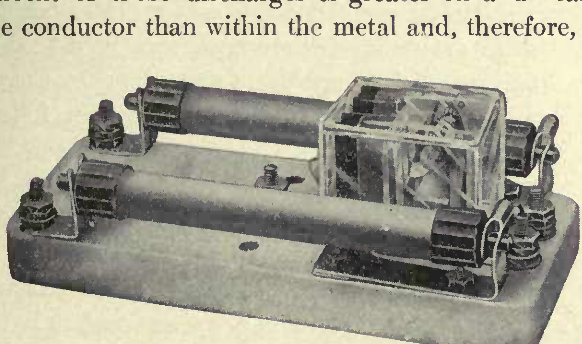


Fig. 231. Cook Arrester for Magneto Stations

the fuse increases its carrying capacity for high-frequency currents, without appreciably changing its carrying capacity for direct currents. The reason its capacity for direct currents is increased at all by flattening it, is that the surface for the radiation of heat is increased. However, when enclosed in a tube, radiation of heat is limited, so that for direct currents the carrying capacity of fuses varies closely with the area of cross-section.

City-Exchange Requirements. The foregoing has set down the requirements of good practice in an average city-exchange system. Nothing short of the general arrangement shown in Fig. 225 meets the usual assortment of hazards of such an exchange. It is good modern practice to distribute lines by means of cables, supplemented in part by short insulated drop wires twisted in pairs. Absence of bare wires reduces electrical hazards enormously. Nevertheless, hazards remain.

Though no less than the spirit of this plan of protection should be followed, additional hazards may exist, which may require additional elements of protection. At the end of a cable, either aërial or underground, long open wires may extend into the open country as rural or long-distance circuits. If these be longer than a mile or two, in most regions they will be subjected to lightning discharges. These may be subjected to high-potential contacts as well.

If a specific case of such exposure indicates that the cables may be in danger, the long open lines then are equipped with additional air-gap arresters at the point of junction of those open lines with the cable. Practice varies as to the type. Maintenance charges are increased if carbon arresters separated .005 inch are used, because of the cost of sending to the end of the long cable to clear the blocks from carbon dust after each slight discharge. Roughened metal blocks do not become grounded as readily as do carbon blocks. The occasions of visit to the arresters, therefore, usually follow actual heavy discharges through them.

The recommendations and the practice of the American Telephone and Telegraph Company differ on this point, while the practice of other companies varies with the temperaments of the engineers. The American Company specifies copper-block arresters where long country lines enter cables, if those lines are exposed to lightning discharges only. The exposed line is called *long* if more than one-half mile in length. If it is exposed to high-potential hazards, carbon blocks are specified instead of copper. Other specifications of that company have called for the use of copper-block arresters on lines exposed to hazards above 2,500 volts.

The freedom of metal-block arresters from dust troubles gives them a large economical advantage over carbon. For similar separations, the ratio of striking voltages between carbon blocks and metal blocks respectively is as 7 to 16. In certain regions of the Pacific Coast where the lightning hazard is negligible and the high tension hazard is great, metal-block arresters at the outer ends of cables give acceptable protection.

High winds which drive snow or dust against bare wires of a long line, create upon or place upon those wires a charge of static electricity which makes its way from the line in such ways as it can. Usually it discharges across arresters and when this discharge takes place, the line is disturbed in its balance and loud noises are heard in the telephones upon it.

A telephone line which for a long distance is near a high-tension transmission line may have electrostatic or electromagnetic poten-

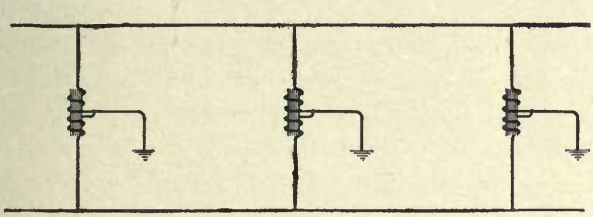


Fig. 232. Drainage Coils

tials, or both, induced upon it. If the line be balanced in its properties, including balance by transposition of its wires, the electrostatic induction may neutralize itself. The electromagnetic induction still may disturb it.

Drainage Coils. The device shown in Fig. 232, which amounts merely to an inductive leak to earth, is intended to cure both the snowstorm and electromagnetic induction difficulties. It is required that its impedance be high enough to keep voice-current losses low, while being low enough to drain the line effectively of the disturbing charges. Such devices are termed "drainage coils."

Electrolysis. The means of protection against the danger due to chemical action, set forth in the preceding chapter, form such a distinct phase of the subject of guarding property against electrical hazards as to warrant treatment in a separate chapter devoted to the subject of electrolysis.

CHAPTER XX

GENERAL FEATURES OF THE TELEPHONE EXCHANGE

Up to this point only those classes of telephone service which could be given between two or more stations on a single line have been considered. Very soon after the practical conception of the telephone, came the conception of the telephone exchange; that is, the conception of centering a number of lines at a common point and there terminating them in apparatus to facilitate their interconnection, so that any subscriber on any line could talk with any subscriber on any other line.

The complete equipment of lines, telephone instruments, and switching facilities by which the telephone stations of the community are given telephone service is called a telephone exchange.

The building where a group of telephone lines center for interconnection is called a central office, and its telephonic equipment the central-office equipment. The terms telephone office and telephone exchange are frequently confused. Although a telephone office building may be properly referred to as a telephone exchange building, it is hardly proper to refer to the telephone office as a telephone exchange, as is frequently done. In modern parlance the telephone exchange refers not only to the central office and its equipment but to the lines and instruments connected therewith as well; furthermore, a telephone exchange may embrace a number of telephone offices that are interconnected by means of so-called trunk lines for permitting the communication of subscribers whose lines terminate in one office with those subscribers whose lines terminate in any other office.

Since a given telephone exchange may contain one or more central offices, it is proper to distinguish between them by referring to an exchange which contains but a single central office as a single office exchange, and to an exchange which contains a plurality of central offices as a multi-office exchange.

In telephone exchange working, three classes of lines are dealt with—subscribers' lines, trunk lines, and toll lines.

Subscribers' Lines. The term subscriber is commonly applied to the patron of the telephone service. His station is, therefore, referred to as a subscriber's station, and the telephone equipment at any subscriber's station is referred to as a subscriber's station equipment. Likewise, a line leading from a central office to one or more subscribers' stations is called a subscriber's line. A subscriber's line may, as has been shown in a previous chapter, be an individual line if it serves but one station, or a party line if it serves to connect more than one station with the central office.

Trunk Lines. A trunk line is a line which is not devoted to the service of any particular subscriber, but which may form a connecting link between any one of a group of subscribers' lines which terminate in one place and any one of a group of subscribers' lines which terminate in another place. If the two groups of subscribers' lines terminate in the same building or in the same switchboard, so that the trunk line forming the connecting link between them is entirely within the central-office building, it is called a local trunk line, or a local trunk. If, on the other hand, the trunk line is for connecting groups of subscribers' lines which terminate in different central offices, it is called an inter-office trunk.

Toll Lines. A toll line is a telephone line for the use of which a special fee or toll is charged; that is, a fee that is not included in the charges made to the subscriber for his regular local exchange service. Toll lines extend from one exchange district to another, more or less remote, and they are commonly termed *local* toll and *long-distance* toll lines according to the degree of remoteness. A toll line, whether local or long-distance, may be looked upon in the nature of an inter-exchange trunk.

Districts. The district in a given community which is served by a single central office is called an office district. Likewise, the district which is served by a complete exchange is called an exchange district. An exchange district may, therefore, consist of a number of central-office districts, just as an exchange may comprise a number of central offices. To illustrate, the entire area served by the exchange of the Chicago Telephone Company in Chicago, embracing the entire city and some of its suburbs, is the Chicago exchange district. The area served by one of the central offices, such as the Hyde Park office, the Oakland office, the Harrison office, or any of the others, is an office district.

Switchboards. The apparatus at the central office by which the telephone lines are connected for conversation and afterwards disconnected, and by which the various other functions necessary to the giving of complete telephone service are performed, is called a switchboard. This may be simple in the case of small exchanges, or of vast complexity in the case of the larger exchanges.

Sometimes the switchboards are of such nature as to require the presence of operators, usually girls, to connect and disconnect the line and perform the other necessary functions, and such switchboards, whether large or small, are termed *manual*.

Sometimes the switchboards are of such a nature as not to require the presence of operators, the various functions of connection, disconnection, and signaling being performed by the aid of special forms of apparatus which are under the control of the subscriber who makes the call. Such switchboards are termed *automatic*.

Of recent years there has appeared another class of switchboards, employing in some measure the features of the automatic and in some measure those of the manual switchboard. These boards are commonly referred to as *semi-automatic* switchboards, presumably because they are supposed to be half automatic and half manual.

Manual. Manual switchboards may be subdivided into two classes according to the method of distributing energy for talking purposes. Thus we may have *magneto* switchboards, which are those capable of serving lines equipped with magneto telephones, local batteries being used for talking purposes. On the other hand, we may have *common-battery* switchboards, adapted to connect lines employing common-battery telephones in which all the current for both talking and signaling is furnished from the central office. In still another way we may classify manual switchboards if the method of distributing the energy for talking and signaling purposes is ignored. Thus, entirely irrespective of whether the switchboards are adapted to serve common-battery or local-battery lines, we may have non-multiple switchboards and multiple switchboards.

The term *multiple* switchboard is applied to that class of switchboards in which the connection terminals or jacks for all the lines are repeated at intervals along the face of the switchboard, so that each operator may have within her reach a terminal for each line and may thus be able to complete by herself any connection between two lines terminating in the switchboard.

The term *non-multiple* switchboard is applied to that class of boards where the provision for repeating the line terminals at intervals along the face of the board is not employed, but where, as a consequence, each line has but a single terminal on the face of the board. Non-multiple switchboards have their main use in small exchanges where not more than a few hundred lines terminate. Where such is the case, it is an easy matter to handle all the traffic by one, two, or three operators, and as all of these operators may reach all over the face of the switchboard, there is no need for giving any line any more than one connection terminal. Such boards may be called *simple* switchboards.

There is another type of non-multiple switchboard adaptable for use in larger exchanges than the simple switchboard. A correct idea of the fundamental principle involved in these may be had by imagining a row of simple switchboards each containing terminals or jacks for its own group of lines. In order to provide for the connection of a line in one of these simple switchboards with a line in another one, out of reach of the operator at the first, short connecting lines extending between the two switchboards are provided, these being called *transfer* or *trunk* lines. In order that connections may be made between any two of the simple boards, a group of transfer lines is run from each board to every other one.

In such switchboards an operator at one of the boards or positions may complete the connection herself between any two lines terminating at her own board. If, however, the line called for terminates at another one of the boards, the operator makes use of the transfer or trunk line extending to that board, and the operator at this latter board completes the connection, so that the two subscribers' lines are connected through the trunk or transfer line. A distinguishing feature, therefore, in the operation of so-called transfer switchboards, is that an operator can not always complete a connection herself, the connection frequently requiring the attention of two operators.

Transfer systems are not now largely used, the multiple switchboard having almost entirely supplanted them in manual exchanges of such size as to be beyond the limitation of the simple switchboard. At multi-office manual exchanges, however, where there are a number of multiple switchboards employed at various central offices, the same sort of a requirement exists as that which was met by the provision of trunk lines between the various simple switchboards in a transfer system. Obviously, the lines in one central office must be connected to those of another in order to give universal service in the community in which the exchange operates. For this purpose inter-office trunk lines are used, the arrangement being such that when an operator at one office receives a call for a subscriber in another office, she will proceed to connect the calling subscriber's line, not directly with the line of the called subscriber because that particular line is not within her reach, but rather with a trunk line leading to the office in which the called-for subscriber's line terminates; having done this she will then inform an operator at that second office of the connection desired, usually by means of a so-called order-wire circuit. The connection between the trunk line so used and the line of the called-for subscriber will then be completed by the connecting link or trunk line extending between the two offices.

In such cases the multiple switchboard at each office is divided into two portions, termed respectively the *A* board and the *B* board. Each of these boards, with the exception that will be pointed out in a subsequent chapter, is provided with a full complement of multiple jacks for all of the lines entering that office. At the *A* board are located operators, called *A* operators, who answer all the calls from the subscribers whose lines terminate in that office. In the case of calls for lines in that same office, they complete the connection themselves without the assistance of the other operators. On the other hand, the calls for lines in another office are handled through trunk lines leading to that other office, as before described, and these trunk lines always terminate in the *B* board at that office. The *B* operators are, therefore, those operators who receive the calls over trunk lines and complete the connection with the line of the subscriber desired.

To define these terms more specifically, an *A* board is a multiple switchboard in which the subscriber's lines of a given office district terminate. For this reason the *A* board is frequently referred to as a subscribers' board, and the operators who work at these boards and who answer the calls of the subscribers are called *A* operators or subscribers' operators. *B* boards are switchboards in which terminate the incoming ends of the trunk lines leading from other offices in the same exchange. These boards are frequently called incoming trunk boards, or merely trunk boards, and the operators who work at them and who receive the directions from the *A* operators at the other boards are called *B* operators, or incoming trunk operators.

The circuits which are confined wholly to the use of operators and over which the instructions from one operator to another are sent, as in the case of the *A* operator giving an order for a connection to a *B* operator at another switchboard, are designated *call circuits* or *order wire circuits.*

Sometimes trunk lines are so arranged that connections may be originated at either of their ends. In other cases they are so arranged that one group of trunk lines connecting two offices is for the traffic in one direction only, while another group leading between the same two offices is for handling only the traffic in the other direction. Trunk lines are called *one-way* or *two-way* trunks, according to whether they handle the traffic in one direction or in two. A trunking system, where the same trunks handle traffic both ways, is called a *single-track system;* and, on the other hand, a system in which there are two groups of trunks, one handling traffic in one direction and the other in the other, is called a *double-track system.* This nomenclature is obviously borrowed from railroad practice.

There is still another class of manual switchboards called the *toll board* of which it will be necessary to treat. Telephone calls made by one person for another within the limits of the same exchange district are usually charged for either by a flat rate per month, or by a certain charge for each call. This is usually regardless of the duration of the conversation following the call. On the other hand, where a call is made by one party for another outside of the limits of the exchange district and, therefore, in some other exchange district, a charge is usually made, based on the time that the connecting long-distance line is employed. Such calls and their ensuing conversations are charged for at a very much higher rate than the purely local calls, this rate depending on the distance between the stations involved. The making up of connections between a long-distance and a local line is usually done by means of operators other than those employed in handling the local calls, who work either by means of special equipment located on the local board, or by means of a separate board. Such equipments for handling long-distance or toll traffic are commonly termed toll switchboards.

They differ from local boards (*a*) in that they are arranged for a very much smaller number of lines; (*b*) in that they have facilities by which the toll operator may make up the connections with a minimum amount of labor on the part of the assisting local operators; and (*c*) in that they have facilities for recording the identification of the parties and timing the conversations taking place over the toll lines, so that the proper charge may be made to the proper subscriber.

CHAPTER XXI

THE SIMPLE MAGNETO SWITCHBOARD

Definitions. As already stated those switchboards which are adapted to work in conjunction with magneto telephones are called magneto switchboards. The signals on such switchboards are electromagnetic devices capable of responding to the currents of the magneto generators at the subscribers' stations. Since, as a rule, magneto telephones are equipped with local batteries, it follows that the magneto switchboard does not need to be arranged for supplying the subscribers' stations with talking current. This fact is accountable for magneto switchboards often being referred to as local-battery switchboards, in contradistinction to common-battery switchboards which are equipped so as to supply the connected subscribers' stations with talking current.

The term *simple* as applied in the headings of this and the next chapter, is employed to designate switchboards adapted for so small a number of lines that they may be served by a single or a very small group of operators; each line is provided with but a single connection terminal and all of them, without special provision, are placed directly within the reach of the operator, or operators if there are more than one. This distinction will be more apparent under the discussion of transfer and multiple switchboards.

Mode of Operation. The cycle of operation of any simple manual switchboard may be briefly outlined as follows: The subscriber desiring a connection transmits a signal to the central office, the operator seeing the signal makes connection with the calling line and places herself in telephonic communication with the calling subscriber to receive his orders; the operator then completes the connection with the line of the called subscriber and sends ringing current out on that line so as to ring the bell of that subscriber; the two subscribers then converse over the connected lines and when the conversation is finished either one or both of them may send a signal to the central office for disconnection, this signal being called a clearing-out signal; upon receipt of the clearing-out signal, the operator disconnects the two lines and restores all of the central-office apparatus involved in the connection to its normal position.

Component Parts. Before considering further the operation of manual switchboards it will be well to refer briefly to the component pieces of apparatus which go to make up a switchboard.

Line Signal. The line signal in magneto switchboards is practically always in the form of an electromagnetic annunciator or drop. It consists in an electromagnet adapted to be included in the line circuit, its armature controlling a latch, which serves to hold the drop or shutter or target in its raised position when the magnet is not energized, and to release the drop or shutter or target so as to permit the display of the signal when the magnet is energized. The symbolic representation of such an electromagnetic drop is shown in Fig. 233.

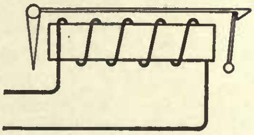


Fig. 233. Drop Symbol

Jacks and Plugs. Each line is also provided with a connection terminal in the form of a switch socket. This assumes many forms, but always consists in a cylindrical opening behind which are arranged one or more spring contacts. The opening forms a receptacle for plugs which have one or more metallic terminals for the conductors in the flexible cord in which the plug terminates. The arrangement is such that when a plug is inserted into a jack the contacts on the plug will register with certain of the contacts in the jack and thus continue the line conductors, which terminate in the jack contacts, to the cord conductors, which terminate in the plug contacts. Usually also when a plug is inserted certain of the spring contacts in the jack are made to engage with or disengage other contacts in the jack so as to make or break auxiliary circuits.

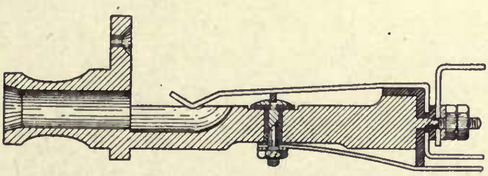


Fig. 234. Spring Jack

A simple form of spring jack is shown in section in Fig. 234. In Fig. 235 is shown a sectional view of a plug adapted to co-operate with the jack of Fig. 234. In Fig. 236 the plug is shown inserted into the jack. The cylindrical portion of the jack is commonly

Fig. 235. Plug

called the *sleeve* or *thimble* and it usually forms one of the main terminals of the jack; the spring, forming the other principal terminal,

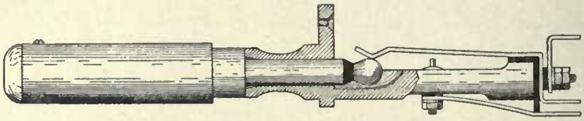


Fig. 236. Plug and Jack

is called the *tip spring*, since it engages the tip of the plug. The tip spring usually rests on another contact which may be termed the *anvil*. When the plug is inserted into the jack as shown in Fig. 236, the tip spring is raised from contact with this anvil and thus breaks the circuit leading through it. It will be understood that spring jacks are not limited to three contacts such as shown in these figures nor are plugs limited to two contacts. Sometimes the plugs have three, and even more, contacts, and frequently the jacks corresponding to such plugs have not only a contact spring adapted to register with each of the contacts of the plug, but several other auxiliary contacts also, which will be made or broken according to whether the plug is inserted or withdrawn from the jack. Symbolic representations of plugs and jacks are shown in Fig. 237. These are employed in diagrammatic representations of circuits and are supposd to represent the essential elements of the plugs and jacks in such a way as to be suggestive of their operation. It will be understood that such symbols may be greatly modified to express the various peculiarities of the plugs and jacks which they represent.

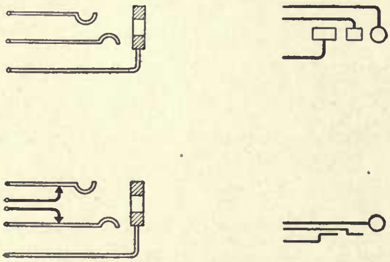


Fig. 237. Jack and Plug Symbols

Keys. Other important elements of manual switchboards are ringing and listening keys. These are the devices by means of which the operator may switch the central-office generator or her telephone set into or out of the circuit of the connected lines. The details of a simple ringing and listening key are shown in Fig. 238. This con-

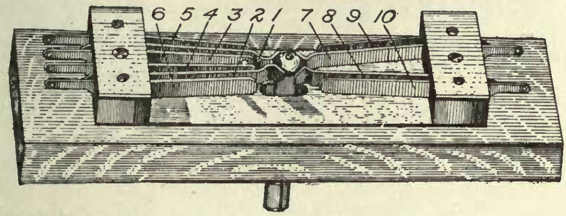


Fig. 238. Ringing and Listening Key

sists of two groups of springs, one of four and one of six, the springs in each group being insulated from each other at their points of mounting. Two of these springs *1* and *2* in one group—the ringing group—are longer than the others, and act as movable levers engaging the inner pair of springs *3* and *4* when in their normal positions, and the outer pair *5* and *6* when forced into their alternate positions. Movement is imparted to these springs by the action of a cam which is mounted on a lever, manipulated by the operator. When this lever is moved in one direction the cam presses the two springs *1* and *2* apart, thus causing them to disengage the springs *3* and *4* and to engage the springs *5* and *6*.

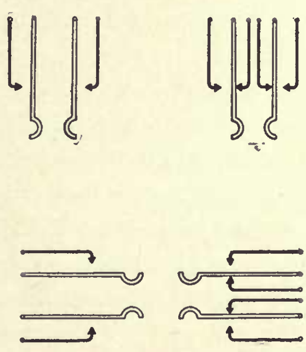


Fig. 239. Ringing- and Listening-Key Symbols

The springs of the other group constitute the switching element of the listening key and are very similar in their action to those of the ringing key, differing in the fact that they have no inner pair of springs such as *3* and *4*. The two long springs *7* and *8*, therefore, normally do not rest against anything, but when the key lever is pressed, so as to force the cam between them, they are made to engage the two outer springs *9* and *10*.

The design and construction of ringing and listening keys assume many different forms. In general, however, they are adapted to do exactly the same sort of switching operations as that of which the device of Fig. 238 is capable. Easily understood symbols of ringing and listening keys are shown in Fig. 239; the cam member which operates on the two long springs is usually omitted for ease of illustration. It will be understood in considering these symbols, therefore, that the two long curved springs usually rest against a pair of inner contacts in case of the ringing key or against nothing at all in case of the listening key, and that when the key is operated the two springs are assumed to be spread apart so as to engage the outer pair of contacts with which they are respectively normally disconnected.

Line and Cord Equipments. The parts of the switchboard that are individual to the subscriber's line are termed the *line equipment;* this, in the case of a magneto switchboard, consists of the line drop and the jack together with the associated wiring necessary to connect them properly in the line circuit. The parts of the switchboard that are associated with a connecting link—consisting of a pair of plugs and associated cords with their ringing and listening keys and clearing-out drop—are referred to as a *cord equipment.* The circuit of a complete pair of cords and plugs with their associated apparatus is called a *cord circuit.* In order that there may be a number of simultaneous connections between different pairs of lines terminating in a switchboard, a number of cord circuits are provided, this number depending on the amount of traffic at the busiest time of the day.

Operator's Equipment. A part of the equipment that is not individual to the lines or to the cord circuits, but which may, as occasion requires, be associated with any of them is called the *operator's equipment.* This consists of the operator's transmitter and receiver, induction coil, and battery connections together with the wiring and other associated parts necessary to co-ordinate them with the rest of the apparatus. Still another part of the equipment that is not individual to the lines nor to the cord circuits is the calling-current generator. This may be common to the entire office or a separate one may be provided for each operator's position.

Operation in Detail. With these general statements in mind we may take up in some detail the various operations of a telephone system wherein the lines center in a magneto switchboard. This may best be done by considering the circuits involved, without special regard to the details of the apparatus.

The series of figures showing the cycle of operations of the magneto switchboard about to be discussed are typical of this type of switchboard almost regardless of make. The apparatus is in each case represented symbolically, the representations indicating type rather than any particular kind of apparatus within the general class to which it belongs.

Normal Condition of Line. In Fig. 240 is shown the circuit of an ordinary magneto line. The subscriber's sub-station apparatus, shown at the left, consists of the ordinary bridging telephone but might with equal propriety be indicated as a series telephone. The subscriber's station is shown connected with the central office by the two limbs of a metallic-circuit line. One limb of the line terminates

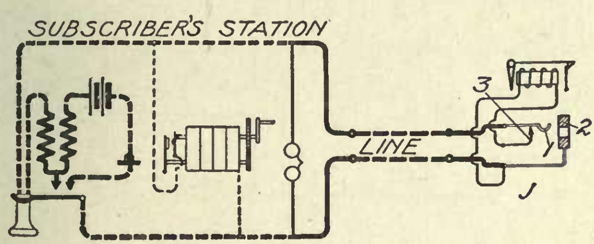


Fig. 240. Normal Condition of Line

in the spring *1* of the jack, and the other limb in the sleeve or thimble *2* of the jack. The spring *1* normally rests on the third contact or anvil *3* in the jack, its construction being such that when a plug is inserted this spring will be raised by the plug so as to break contact with the anvil *3*. It is understood, of course, that the plug associated with this jack has two contacts, referred to respectively as the tip and the sleeve; the tip makes contact with the tip spring *1* and the sleeve with the sleeve or thimble *2*.

The drop or line signal is permanently connected between the jack sleeve and the anvil *3*. As a result, the drop is normally bridged across the circuit of the line so as to be in a receptive condition to signaling current sent out by the subscriber. It is evident, however, that when the plug is inserted into the jack this connection between the line and the drop will be broken.

In this normal condition of the line, therefore, the drop stands ready at the central office to receive the signal from the subscriber and the generator at the sub-station stands ready to be bridged across the circuit of the line as soon as the subscriber turns its handle. Similarly the ringer—the call-receiving device at the sub-station—is permanently bridged across the line so as to be responsive to any signal that may be sent out from the central office in order to call the subscriber. The subscriber's talking apparatus is, in this normal condition of the line, cut out of the circuit by the switch hook.

Subscriber Calling. Fig. 241 shows the condition of the line when the subscriber at the sub-station is making a call. In turning his generator the two springs which control the connection of the generator with the line are brought into engagement with each other

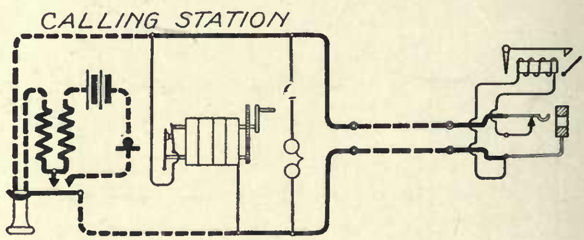


Fig. 241 Subscriber Calling

so that the generator currents may pass out over the line. The condition at the central office is the same as that of Fig. 240 except that the drop is shown with its shutter fallen so as to indicate a call.

Operator Answering. The next step is for the operator to answer the call and this is shown in Fig. 242. The subscriber has released the handle of his generator and the generator has, therefore, been automatically cut out of the circuit. He also has removed his receiver from its hook, thus bringing his talking apparatus into the line circuit. The operator on the other hand has inserted one of the plugs P_a into the jack. This action has resulted in the breaking of the circuit through the drop by the raising of the spring *1* from the anvil *3*, and also in the continuance of the line circuit through the conductors of the cord circuits. Thus, the upper limb of the line is continued by means of the engagement of the tip spring *1* with the tip *4* of the plug to the conducting strand *6* of the cord circuit; likewise the lower limb of the line is continued by the engagement of the thimble *2* of the jack with the sleeve contact *5* of the plug P_a to the strand *7* of the cord circuit. The operator has also closed her listening key *L.K.* In doing so she has brought the springs *8* and *9* into engagement with the anvils *10* and *11* and has thus bridged her head telephone receiver with the secondary of her induction coil across the two strands *6* and *7* of the cord. Associated with the secondary winding of her receiver is a primary circuit containing a transmitter, battery, and the primary of the induction coil. It will be seen that the conditions are now such as to permit the subscriber at the calling station to converse with the operator and this conversation consists in the familiar "Number Please" on the part of the operator and the response of the subscriber giving the number of the line that is desired.

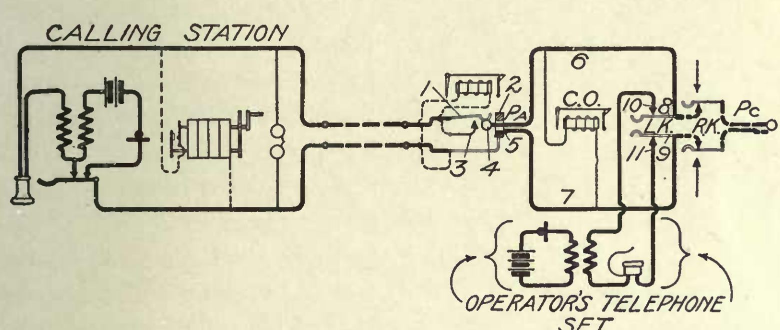


Fig. 242. Operator Answering

Neither the plug P_c, nor the ringing key *R.K.*, shown in Fig. 242, is used in this operation. The clearing-out drop *C.O.* is bridged permanently across the strands *6-7* of the cord, but is without function at this time; the fact that it is wound to a high resistance and impedance prevents its having a harmful effect on the transmission.

It may be stated at this point that the two plugs of an associated pair are commonly referred to as the answering and calling plugs. The answering plug is the one which the operator always uses in answering a call as just described in connection with Fig. 242. The calling plug is the one which she next uses in connecting with the line of the called subscriber. It lies idle during the answering of a call and is only brought into play after the order of the calling subscriber has been given, in which case it is used in establishing connection with the called subscriber.

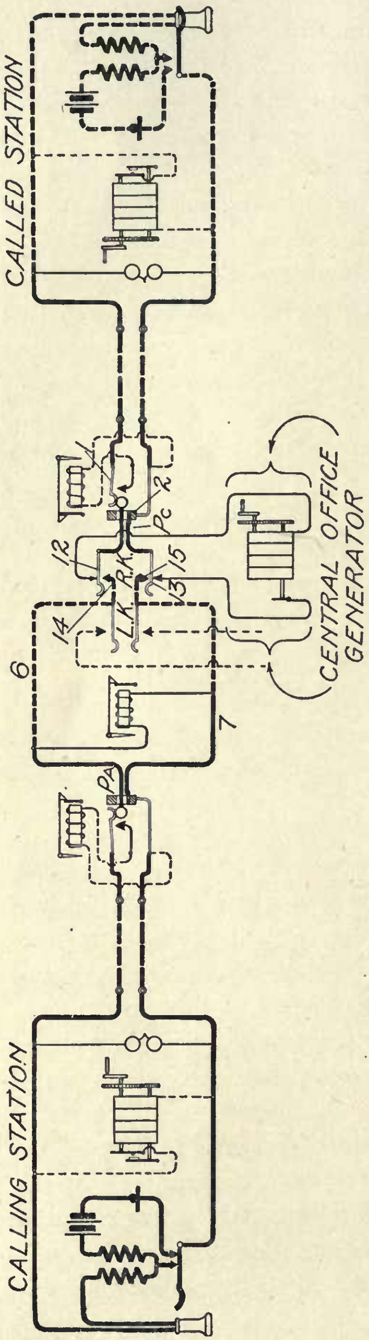


Fig. 243. Operator Calling

Operator Calling. We may now consider how the operator calls the called subscriber. The condition existing for this operation is shown in Fig. 243. The operator after receiving the order from the calling subscriber inserts the calling plug P_c into the jack of the line of the called station. This act at once connects the limbs of the line with the strands *6* and *7* of the cord circuit, and also cuts out the line drop of the called station, as already explained. The operator is shown in this figure as having opened her listening key *L.K.* and closed her ringing key *R.K.* As a result, ringing current from the central-office generator will flow out over the two ringing key springs *12* and *13* to the tip and sleeve contacts of the calling plug P_c, then to the tip spring *1* and the sleeve or thimble *2* of the jack, and then to the two sides of the metallic-circuit line to the sub-station and through the bell there. This causes the ringing of the called subscriber's bell, after which the operator releases the ringing key and thereby allows the two springs *12* and *13* of that key to again engage their normal contacts *14* and *15,* thus making the two strands *6* and *7* of the cord circuit continuous from the contacts of the answering plug P_a to the contacts of the calling plug P_c. This establishes the condition at the central office for conversation between the two subscribers.

Subscribers Conversing. The only other thing necessary to establish a complete set of talking conditions between the two subscribers is for the called subscriber to remove his receiver from its hook, which he does as soon as he responds to the call. The conditions for conversation between the two subscribers are shown in Fig. 244. It is seen that the two limbs of the calling line are connected respectively to the two limbs of the called line by the two strands of the cord circuit, both the operator's receiver and the central-office generator being cut out by the listening and ringing keys, respectively. Likewise the two line drops are cut out of circuit and the only thing left associated with the circuit at the central office is the clearing-out drop *C. O.*, which remains bridged across the cord circuit. This, like the two ringers at the respective connected stations, which also remain bridged across the circuit when bridging instruments are used, is of such high resistance and impedance that it offers practically no path to the rapidly fluctuating voice currents to leak from one side of the line circuit to the other. Fluctuating currents generated by the transmitter at the calling station, for instance, are converted by means of the induction coil into alternating currents flowing in the secondary of the induction coil at that station. Considering a momentary current as passing up through the secondary winding of the induc-

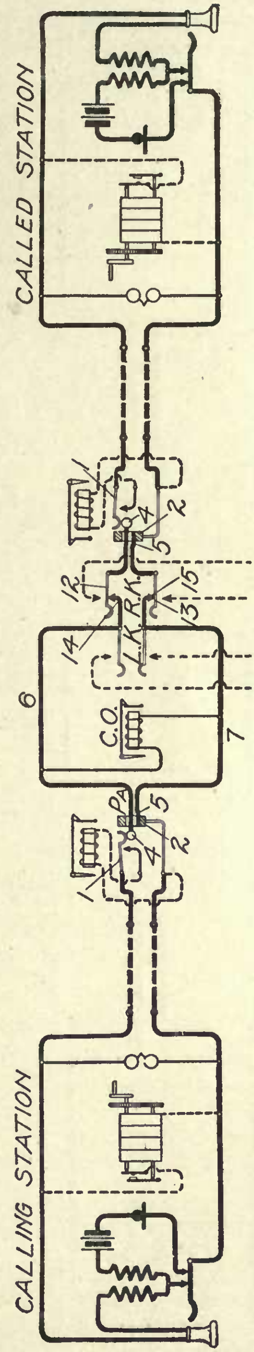


Fig. 244. Subscribers Connected for Conversation

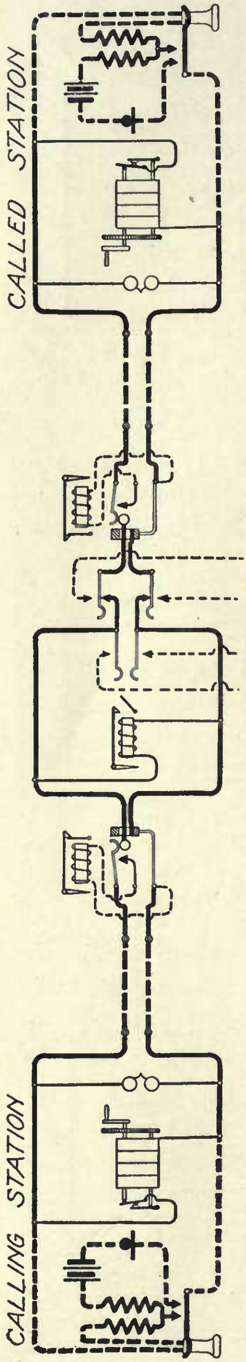


Fig. 245. Clearing-Out Signal

tion coil at the calling station, it passes through the receiver of that station through the upper limb of the line to the spring *1* of the line jack belonging to that line at the central office; thence through the tip *4* of the answering plug to the conductor *6* of the cord; thence through the pair of contacts *14* and *12* forming one side of the ringing key to the tip *4* of the calling plug; thence to the tip spring *1* of the jack of the called subscriber's line; thence over the upper limb of his line through his receiver and through the secondary of the induction to one of the upper switch-hook contacts; thence through the hook lever to the lower side of the line, back to the central office and through the sleeve contact *2* of the jack and the sleeve contact *5* of the plug; thence through the other ringing key contacts *13* and *15*; thence through the strand *7* of the cord to the sleeve contact *5* and the sleeve contact *2* of the answering plug and jack, respectively; thence through the lower limb of the calling subscriber's line to the hook lever at his station; thence through one of the upper contacts of this hook to the secondary of the induction coil, from which point the current started.

Obviously, when the called subscriber is talking to the calling subscriber the same path is followed. It will be seen that at any time the operator may press her listening key *L.K.*, bridge her telephone set across the circuit of the two connected lines, and listen to the conversation or converse with either of the subscribers in case of necessity.

Clearing Out. At the close of the conversation, either one or both of the subscribers may send a clearing-out signal by turning their generators after hanging up their receivers. This condition is shown in Fig. 245. The apparatus at the central office remains in exactly the same position during conversation as that of Fig. 244, except that the clearing-out drop shutter is shown as having fallen. The two subscribers are shown as having hung up their receivers, thus cutting out their talking apparatus, and as operating their generators for the purpose of sending the clearing-out signals. In response to this act the operator pulls down both the calling and the answering plug, thus restoring them to their normal seats, and bringing both lines to the normal condition as shown in Fig. 240. The line drops are again brought into operative relation with their respective lines so as to be receptive to subsequent calls and the calling generators at the sub-stations are removed from the bridge circuits across the line by the opening of the automatic switch contacts associated with those generators.

Essentials of Operation. The foregoing sequence of operations while described particularly with respect to magneto switchboards is, with certain modifications, typical of the operation of nearly all manual switchboards. In the more advanced types of manual switchboards, certain of the functions described are sometimes done automatically, and certain other functions, not necessary in connection with the simple switchboard, are added. The essential mode of operation, however, remains the same in practically all manual switchboards, and for this reason the student should thoroughly familiarize himself with the operation and circuits of the simple switchboard as a foundation for the more complex and consequently more-difficult-to-understand switchboards that will be described later on.

Commercial Types of Drops and Jacks. *Early Drops.* Coming now to the commercial types of switchboard apparatus, the first subject that presents itself is that of magneto line signals or drops. The very early forms of switchboard drops had, in most cases, two-coil magnets, the cores of which were connected at their forward ends by an iron yoke and the armature of which was pivoted opposite the rear end of the two cores. To the armature was attached a latch rod which projected forwardly to the front of the device and was there adapted to engage the upper edge of the hinged shutter, so as to hold it in its raised or undisplayed position when the armature was unattracted. Such a drop, of Western Electric manufacture, is shown in Fig. 246.

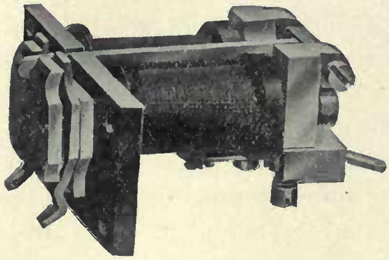


Fig. 246. Old-Style Drop

Liability to Cross-Talk:—This type of drop is suitable for use only on small switchboards where space is not an important consideration, and even then only when the drop is entirely cut out of the circuit during conversation. The reason for this latter requirement will be obvious when it is considered that there is no magnetic shield around the winding of the magnet and no means for preventing the stray field set up by the talking currents in one of the magnets from affecting by induction the windings of adjacent magnets contained in other talking circuits. Unless the drops are entirely cut out of the talking circuit, therefore, they are very likely to produce cross-talk between adjacent circuits. Furthermore, such form of drop is obviously not economical of space, two coils placed side by side consuming practically twice as much room as in the case of later drops wherein single magnet coils have been made to answer the purpose.

Tubular Drops. In the case of line drops, which usually can readily be cut out of the circuit during conversation, this cross-talk feature is not serious, but sometimes the line drops, and always the clearing-out drops must be left in connection with the talking circuit. On account of economy in space and also on account of this cross-talk feature, there has come into existence the so-called tubular or iron-clad drop, one of which is shown in section in Fig. 247. This was developed a good many years ago by Mr. E. P. Warner of the Western Electric Company, and has since, with modifications, become standard with practically all the manufacturing companies. In this there is but a single bobbin, and this is enclosed in a shell of soft Norway iron, which is closed at its front end and joined to the end of the core as indicated, so as to form a complete return magnetic path for the lines of force generated in the coil. The rear end of the shell and core are both cut off in the same plane and the armature is made in such form as to practically close this end of the shell. The armature carries a latch rod extending the entire length of the

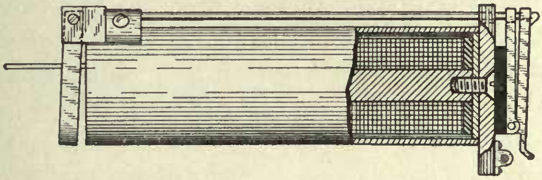


Fig. 247. Tubular Drop

shell to the front portion of the structure, where it engages the upper edge of the pivoted shutter; this, when released by the latch upon the attraction of the armature, falls so as to display a target behind it.

These drops may be mounted individually on the face of the switchboard, but it is more usual to mount them in strips of five or ten. A strip of five drops, as manufactured by the Kellogg Switchboard and Supply Company, is shown in Fig. 248. The front strip on which these drops are mounted is usually of brass or steel, copper plated, and is sufficiently heavy to provide a rigid support for the entire group of drops that are mounted on it. This construction

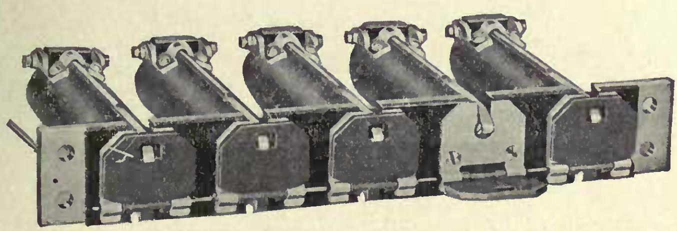


Fig. 248. Strip of Tubular Drops

greatly facilitates the assembling of the switchboard and also serves to economize space—obviously, the thing to economize on the face of a switchboard is space as defined by vertical and horizontal dimensions. These tubular drops, having but one coil, are readily mounted on 1-inch centers, both vertically and horizontally. Sometimes even smaller dimensions than this are secured. The greatest advantage of this form of construction, however, is in the absolute freedom from cross-talk between two adjacent drops. So completely is the magnetic field of force kept within the material of the shell, that there is practically no stray field and two such drops may be included in two different talking circuits and the drops mounted immediately adjacent to each other without producing any cross-talk whatever.

Night Alarm. Switchboard drops in falling make but little noise, and during the day time, while the operator is supposed to be needed continually at the board, the visual signal which they display is sufficient to attract her attention. In small exchanges, however, it is frequently not practicable to keep an operator at the switchboard at night or during other comparatively idle periods, and yet calls that do arrive during such periods must be attended to. For this reason some other than a visual signal is necessary, and this need is met by the so-called night-alarm attachment. This is merely an arrangement by which the shutter in falling closes a pair of contacts and thus completes the circuit of an ordinary vibrating bell or buzzer which will sound until the shutter is restored to its normal position. Such contacts are shown

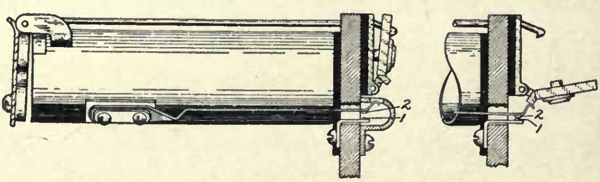


Fig. 249. Drop with Night-Alarm Contacts

in Fig. 249 at *1* and *2*. Night-alarm contacts have assumed a variety of forms, some of which will be referred to in the discussion of other types of drops and jacks.

Jack Mounting. Jacks, like drops, though frequently individually mounted are more often mounted in strips. An individually mounted jack is shown in Fig. 250, and a strip of ten jacks in Fig. 251. In such a strip of jacks, the strips supporting the metallic parts of the various jacks are usually of hard rubber reinforced by brass so as to give sufficient strength. Various forms of supports for these strips are used by different manufacturers, the means for fastening them in the switchboard frame usually consisting of brass lugs on the end of

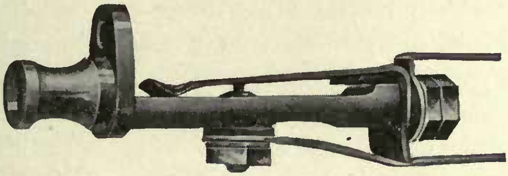


Fig. 250. Individual Jack

the jack strip adapted to be engaged by screws entering the stationary portion of the iron framework; or sometimes pins are fixed in the framework, and the jack is held in place by nuts engaging screw-threaded ends on such pins.

Methods of Associating Jacks and Drops. There are two general methods of arranging the drops and jacks in a switchboard. One of these is to place all of the jacks in a group together at the lower portion of the panel in front of the operator and all of the drops together in another group above the group of jacks. The other way is to locate each jack in immediate proximity to

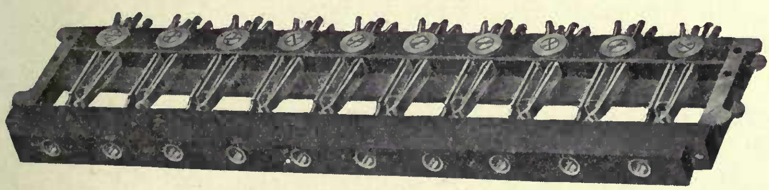


Fig. 251. Strip of Jacks

the drop belonging to the same line so that the operator's attention will always be called immediately to the jack into which she must insert her plug in response to the display of a drop. This latter practice has several advantages over the former. Where the drops are all mounted in one group and the jacks in another, an operator seeing a drop fall must make mental note of it and pick out the corresponding jack in the group of jacks. On the other hand, where the jacks and drops are mounted immediately adjacent to each other, the falling of a drop attracts the attention of the operator to the corresponding jack without further mental effort on her part.

The immediate association of the drops and jacks has another advantage—it makes possible such a mechanical relation between the drop and its associated jack that the act of inserting the plug into the jack in making the connection will automatically and mechanically restore the drop to its raised position. Such drops are termed *self-restoring drops*, and, since a drop and jack are often made structurally a unitary piece of apparatus, they are frequently called *combined* drops and jacks.

Manual vs. Automatic Restoration. There has been much difference of opinion on the question of manual versus automatic restoration of drops. Some have contended that there is no advantage in having the drops restored automatically, claiming that the operator has plenty of time to restore the drops by hand while receiving the order from the calling subscriber or performing some of her other work. Those who think this way have claimed that the only place where an automatically restored drop is really desirable is where, on account of the lack of space on the front of the switchboard, the drops are placed on such a portion of the board as to be not readily reached by the operator. This resulted in the electrically restored drop, mention of which will be made later.

Others have contended that even though the drop is mounted within easy reach of the operator, it is advantageous that the operator should be relieved of the burden of restoring it, claiming that even though there are times in the regular performance of the operator's duties when she may without interfering with other work restore the drops manually, such requirement results in a double use of her attention and in a useless strain on her which might better be devoted to the actual making of connections.

Until recently the various Bell operating companies have adhered, in their small exchange work, to the manual restoring method, while most of the so-called independent operating companies have adhered to the automatic self-restoring drops.

Methods of Automatic Restoration. Two general methods present themselves for bringing about the automatic restoration of the drop. First, the mechanical method, which is accomplished by having some moving part of the jack or of the plug as it enters the jack force the drop mechanically into its restored position. This usually means the mounting of the drop and the corresponding jack in juxtaposition, and this, in turn, has usually resulted in the unitary structure containing both the drop and the jack. Second, the electrical method wherein the plug in entering the jack controls a restoring circuit, which includes a battery or other source of energy and a restoring coil on the drop, the result being that the insertion of the plug into the jack closes this auxiliary circuit and thus energizes the restoring magnet, the armature of which pulls the shutter back into its restored position. This practice has been followed by Bell operating companies whenever conditions require the drop to be mounted out of easy reach of the operator; not otherwise.

Mechanical—Direct Contact with Plug. One widely used method of mechanical restoration of drops, once employed by the Western Telephone Construction Company with considerable success, was to hang the shutter in such position that it would fall immediately in front of the jack so that the operator in order to reach the jack with the plug would have to push the plug directly against the shutter and thus restore it to its normal or raised position. In this construction the coil of the drop magnet was mounted directly behind the jack, the latch rod controlled by the armature reaching forward, parallel with the jack, to the shutter, which, as stated, was hung in front of the jack. This resulted in a most compact arrangement so far as the space utilization on the front of the board was concerned and such combined drops and jacks were mounted on about 1-inch centers, so that a bank of one hundred combined drops and jacks occupied a space only a little over 10 inches square.

A modification of this scheme, as used by the American Electric Telephone Company, was to mount the drop immediately over the jack so that its shutter, when down, occupied a position almost in front of, but above, the jack opening. The plug was provided with a collar, which, as it entered the jack, engaged a cam on the base of the shutter and forced the latter mechanically into its raised position.

Neither of these methods of restoring—*i. e*, by direct contact between the shutter or part of it and the plug or part of it—is now as widely used as formerly. It has been found that there is no real need in magneto switchboards for the very great compactness which the hanging of the shutter directly in front of the drop resulted in, and the tendency in later years has been to make the combined drops and jacks more substantial in construction at the expense of some space on the face of the switchboard.

Kellogg Type:—A very widely used scheme of mechanical restoration is that employed in the Miller drop and jack manufactured by the Kellogg Switchboard and Supply Company, the principles of which may be understood in connection with Fig. 252. In this figure views of one of these combined drops and jacks in three different positions are shown. The jack is composed of the framework *B* and the hollow screw *A*, the latter forming the sleeve or thimble of the jack and being externally screw-threaded so as to engage and bind in place the front end of the framework *B*. The jack is mounted on the lower part of the brass mounting strip *C* but insulated therefrom. The tip spring of the jack is bent down as usual to engage the tip of the plug, as better shown in the lower cut of Fig. 252, and then continues in an extension *D*, which passes through a hole in the mounting plate *C*. This tip spring in its normal position rests against another spring as shown, which latter spring forms one terminal of the drop winding.

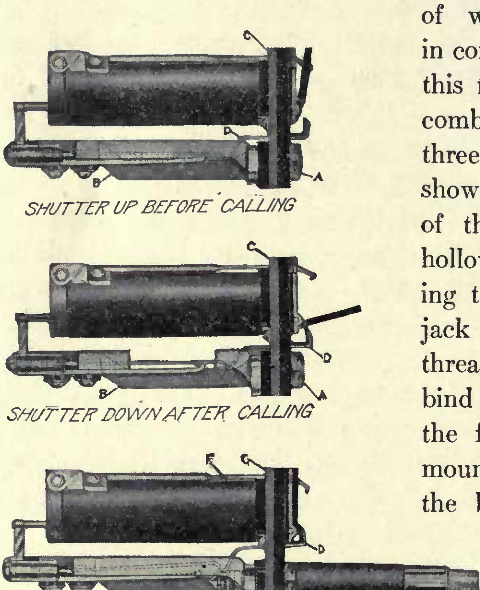


Fig. 252. Kellogg Drop and Jack

The drop or annunciator is of tubular form, and the shutter is so arranged on the front of the mounting strip *C* as to fall directly above the extension *D* of the tip spring. As a result, when the plug is inserted into the jack, the upward motion of the tip spring forces

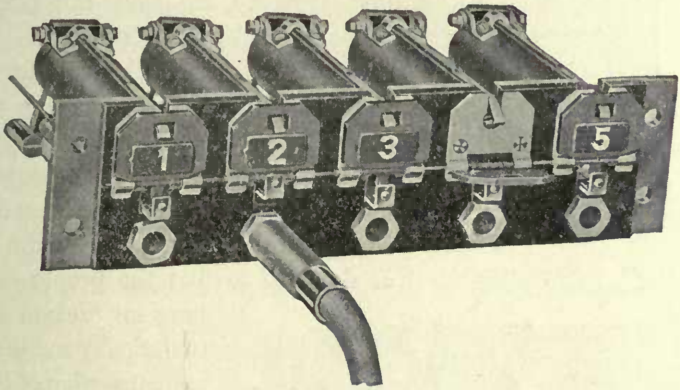


Fig. 253. Strip of Kellogg Drops and Jacks

the drop into its restored position, as indicated in the lower cut of the figure. These drops and jacks are usually mounted in banks of five, as shown in Fig. 253.

Western Electric Type:—The combined drop and jack of the Western Electric Company recently put on the market to meet the demands of the independent trade, differs from others principally in that it employs a spherical drop or target instead of the ordinary flat shutter. This piece of apparatus is shown in its three possible positions in Fig. 254. The shutter or target normally displays a black surface through a hole in the mounting plate. The sphere forming the target is out of balance, and when the latch is withdrawn from it by the action of the electromagnet it falls into the position shown in the middle cut of Fig. 254, thus displaying a red instead of a black surface to the view of the operator. When the operator plugs in, the plug engages the lower part of an S-shaped lever which acts on the pivoted sphere to restore it to its normal position. A perspective view of one of these combined line signals and jacks is shown in Fig. 255.

A feature that is made much of in recently designed drops and jacks for magneto service is that which provides for the ready removal of the drop coil, from the rest of the structure, for repair. The drop and jack of the Western Electric Company, just described, embodies this feature, a single screw being so arranged that its removal will permit the withdrawal of the coil without disturbing any of the other parts or connections. The coil windings terminate in two projections on the front head of the spool, and these register with spring clips on the inside of the shell so that the proper connections for the coil are automatically made by the mere insertion of the coil into the shell.

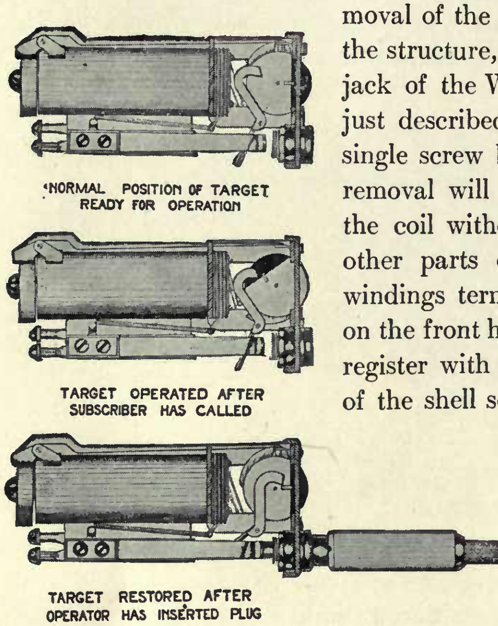


Fig. 254. Western Electric Drop and Jack

Dean Type:—The combined drop and jack of the Dean Electric Company is illustrated in Figs. 256 and 257. The two perspective views show the general features of the drop and jack and the method by which the magnet coil may be withdrawn from the shell. As will be seen the magnet is wound on a hollow core which slides over the iron core, the latter remaining permanently fixed in the shell, even though the coil be withdrawn.

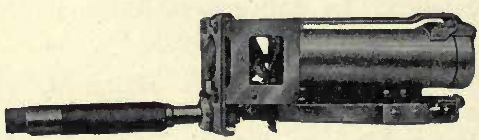


Fig. 255. Western Electric Drop and Jack

Fig. 258 shows the structural details of the jack employed in this combination and it will be seen that the restoring spring for the drop is not the tip spring itself, but another spring located above and insulated from it and mechanically connected therewith.

Monarch Type:—Still another combined drop and jack is that of the Monarch Telephone Manufacturing Company of Chicago, shown in sectional view in Fig. 259. This differs from the usual type in that the armature is mounted on the front end of the electromagnet, its latch arm retaining the shutter in its normal position when raised, and releasing it when depressed by the attraction of the armature. As is shown, there is within the core of the magnet an adjustable spiral spring which presses forward against the armature and which spring is compressed by the attraction of the armature of the magnet. The night-alarm contact is clearly shown immediately below the strip which supports the drop, this consisting of a spring adapted to be engaged by a lug on the shutter and pressed upwardly against a stationary contact when the shutter falls. The method of

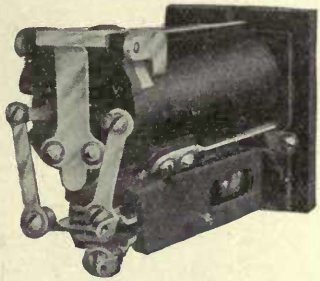


Fig. 256. Dean Drop and Jack

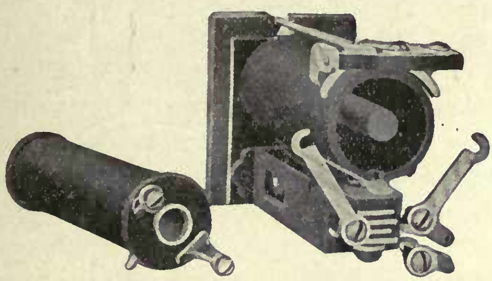


Fig. 257. Dean Drop and Jack

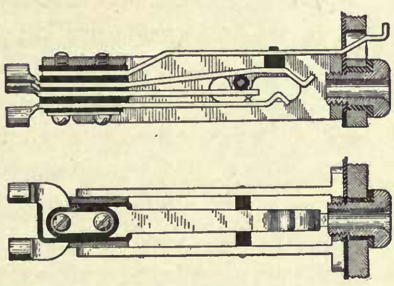


Fig. 258. Details of Dean Jack

restoration of the shutter in this case is by means of an auxiliary spring bent up so as to engage the shutter and restore it when the spring is raised by the insertion of a plug into the jack.

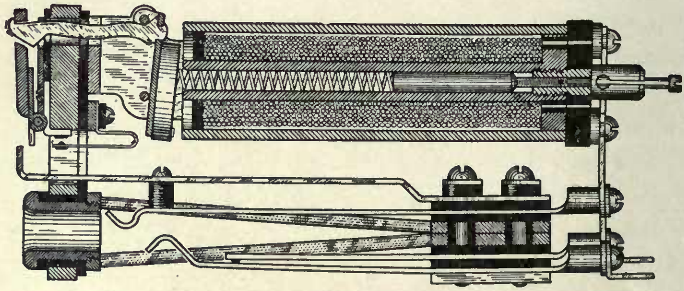


Fig. 259. Monarch Drop and Jack

Code Signaling. On bridging party lines, where the subscribers sometimes call other subscribers on the same line and sometimes call the switchboard so as to obtain a connection with another line, it is not always easy for the operator at the switchboard to distinguish whether the call is for her or for some other party on the line. On such lines, of course, code ringing is used and in most cases the operator's only way of distinguishing between calls for her and those for some sub-station parties on the line is by listening to the rattling noise which the drop armature makes. In the case of the Monarch drop the adjustable spring tension on the armature is intended to provide for such an adjustment as will permit the armature to give a satisfactory buzz in response to the alternating ringing currents, whether the line be long or short.

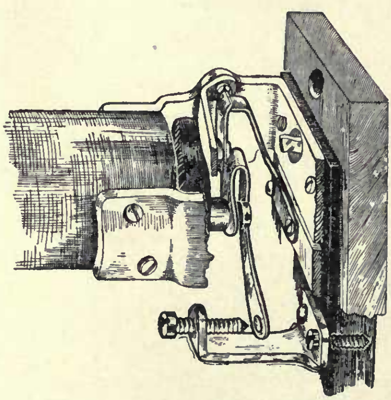


Fig. 260. Code Signal Attachment

The Monarch Company provides in another way for code signaling at the switchboard. In some cases there is a special attachment, shown in Fig. 260, by means of which the code signals are repeated on the night-alarm bell. This is in the nature of a special attachment placed on the drop, which consists of a light, flat spring attached to the armature and forming one side of a local circuit. The other side of the circuit terminates in a fixture which is mounted on the drop frame and is provided with a screw, having a platinum point forming the other contact point; this allows of considerable adjustment. At the point where the screw comes in contact with the spring there is a platinum rivet. When an operator is not always in attendance, this code-signaling attachment has some advantages

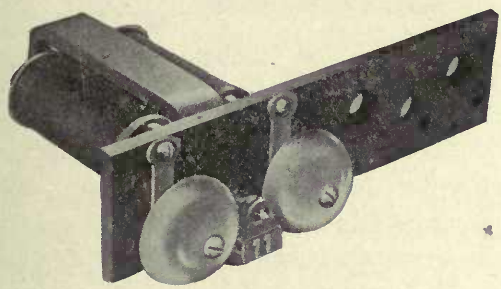


Fig. 261. Combined Drop and Ringer

over the drop as a signal interpreter, in that it permits the code signals to be heard from a distance. Of course, the addition of spring contacts to the drop armature tends to complicate the structure and perhaps to cut down the sensitiveness of the drop, which are offsetting disadvantages.

For really long lines, this code signaling by means of the drop is best provided for by employing a combined drop and ringer, although in this case whatever advantages are secured by the mechanical restoration of the shutter upon plugging in are lost. Such a device as manufactured by the Dean Electric Company is shown in Fig. 261. In this the ordinary polarized ringer is used, but in addition the tapper rod carries a latch which, when vibrated by the ringing of the bell, releases a shutter and causes it to fall, thus giving a visual as well as an audible signal.

Electrical. Coming now to the electrical restoration of drop shutters, reference is made to Fig. 262, which shows in side section the electrical restoring drop employed by the Bell companies and manufactured by the Western Electric Company. In this the coil *1* is a line coil, and it operates on the armature *2* to raise the latch lever

3 in just the same manner as in the ordinary tubular drop. The latch lever *3* acts, however, to release another armature *4* instead of a shutter. This armature *4* is pivoted at its lower end at the

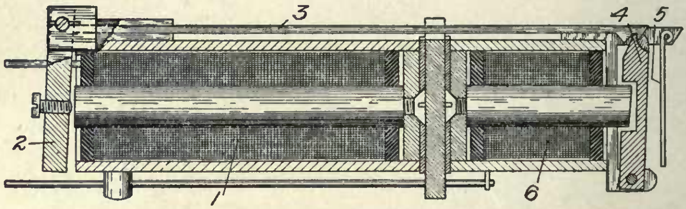


Fig. 262. Electrically Restored Drop

opposite end of the device from the armature *2* and, by falling outwardly when released, it serves to raise the light shutter *5*. The restoring coil of this device is shown at *6*, and when energized it attracts the armature *4* so as to pull it back under the catch of the latch lever *3* and also so as to allow the shutter *5* to fall into its normal position. The method of closing the restoring circuit is by placing coil *6* in circuit with a local battery and with a pair of contacts in the jack, which latter contacts are normally open but are bridged across by the plug when it enters the jack, thus energizing the restoring coil and restoring the shutter.

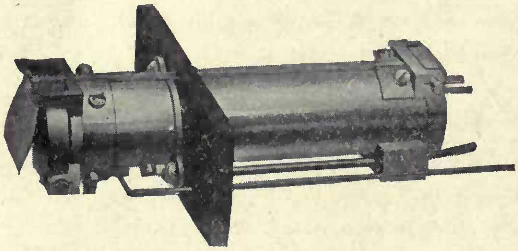


Fig. 263. Electrically Restored Drop

A perspective view of this Western Electric electrical restoring drop is shown in Fig. 263, a more complete mention being made of this feature under the discussion of magneto multiple switchboards, wherein it found its chief use. It is mentioned here to round out the methods that have been employed for accomplishing the automatic restoration of shutters by the insertion of the plug.

Switchboard Plugs. A switchboard plug such as is commonly used in simple magneto switchboards is shown in Fig. 264 and also in Fig. 235. The tip contact is usually of brass and is connected to a slender steel rod which runs through the center of the plug and terminates near the rear end of the plug in a connector for the tip conductor of the cord. This central core of steel is carefully insulated from the outer shell of the plug by means of hard rubber bushings, the parts being forced tightly together. The outer shell, of course, forms the other conductor of the plug, called the sleeve contact. A handle of tough fiber tubing is fitted over the rear end of the plug and this also serves to close the opening formed by cutting away a portion of the plug shell, thus exposing the connector for the tip conductor.

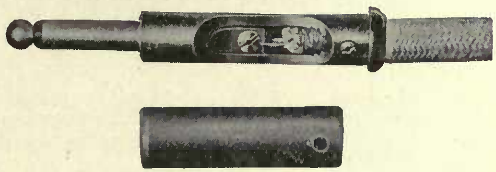


Fig. 264. Switchboard Plug

Cord Attachment. The rear end of the plug shell is usually bored out just about the size of the outer covering of the switchboard cord, and it is provided with a coarse internal screw thread, as shown. The cord is attached by screwing it tightly into this screw-threaded chamber, the screw threads in the brass being sufficiently coarse and of sufficiently small internal diameter to afford a very secure mechanical connection between the outer braiding of the cord and the plug. The connection between the tip conductor of the cord and the tip of the plug is made by a small machine screw connection as shown, while the connection between the sleeve conductor of the plug and the sleeve conductor of the cord is made by bending back the latter over the outer braiding of the cord before it is screwed into the shank of the plug. This results in the close electrical contact between the sleeve conductor of the cord and the inner metal surface of the shank of the plug.

Switchboard Cords. A great deal of ingenuity has been exerted toward the end of producing a reliable and durable switchboard cord. While great improvement has resulted, the fact remains that the cords of manual switchboards are today probably the most troublesome element, and they need constant attention and repairs. While no two manufacturers build their cords exactly alike, descriptions of a few commonly used and successful cords may be here given.

Concentric Conductors. In one the core is made from a double strand of strong lock stitch twine, over which is placed a linen braid. Then the tip conductor, which is of stranded copper tinsel, is braided on. This is then covered with two layers of tussah silk, laid in reverse wrappings, then there is a heavy cotton braid, and over the latter a linen braid. The sleeve conductor, which is also of copper tinsel, is then braided over the structure so formed, after which two reverse wrappings of tussah silk are served on, and this is covered by a cotton braid and this in turn by a heavy linen or polished

Fig. 265. Switchboard Cord

cotton braid. The plug end of the cord is reinforced for a length of from 12 to 18 inches by another braiding of linen or polished cotton, and the whole cord is treated with melted beeswax to make it moisture-proof and durable.

Steel Spiral Conductors. In another cord that has found much favor the two conductors are formed mainly by two concentric spiral wrappings of steel wire, the conductivity being reinforced by adjacent braidings of tinsel. The structure of such a cord is well shown in Fig. 265. Beginning at the right, the different elements shown are, in the order named, a strand of lock stitch twine, a linen braiding, into the strands of which are intermingled tinsel strands, the inner spiral steel wrapping, a braiding of tussah silk, a linen braiding, a loose tinsel braiding, the outer conductor of round spiral steel, a cotton braid, and an outside linen or polished cotton braid. The inner tinsel braiding and the inner spiral together form the tip conductor while the outer braiding and spiral together form the sleeve conductor. The cord is reinforced at the plug end for a length of about 14 inches by another braiding of linen. The tinsel used is, in each case, for the purpose of cutting down the resistance of the main steel conductor. These wrappings of steel wire forming the tip and sleeve conductors respectively, have the advantage of affording great flexibility, and also of making it certain that whatever strain the cord is subjected to will fall on the insulated braiding rather than on the spiral steel which has in itself no power to resist tensile strains.

Parallel Tinsel Conductors. Another standard two-conductor switchboard cord is manufactured as follows: One conductor is of very heavy copper tinsel insulated with one wrapping of sea island cotton, which prevents broken ends of the tinsel or knots from piercing through and short-circuiting with the other conductor. Over this is placed one braid of tussah silk and an outer braid of cotton. This combines high insulation with considerable strength. The other conductor is of copper tinsel, not insulated, and this is laid parallel to the thrice insulated conductor already described. Around these two conductors is placed an armor of spring brass wire in spiral form, and over this a close, stout braid of glazed cotton. This like the others is reinforced by an extra braid at the plug end.

Ringing and Listening Keys. The general principles of the ringing key have already been referred to. Ringing keys are of two general types, one having horizontal springs and the other vertical.

Horizontal Spring Type. Various Bell operating companies have generally adhered to the horizontal spring type except in

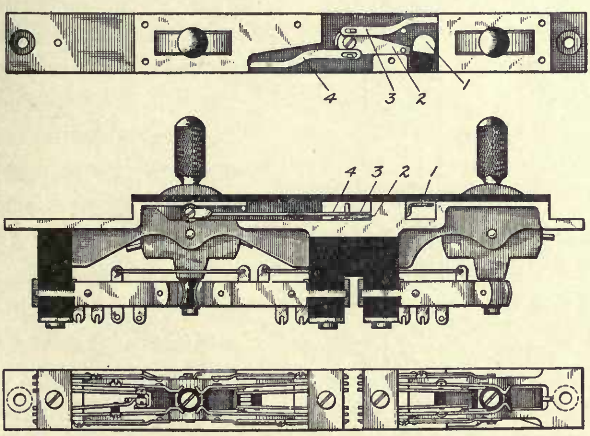


Fig. 266. Horizontal-Spring Listening and Ringing Key

individual and four-party-line keys. The construction of a Western Electric Company horizontal spring key is shown in Fig. 266. In this particular key, as illustrated, there are two cam levers operating upon three sets of springs. The cam lever at the left operates the ordinary ringing and listening set of springs according to whether it is pushed one way or the other. In ringing on single-party lines the cam lever at the left is the one to be used; while on two-party lines the lever at the left serves to ring the first party and the ringing key at the right the second party.

In order that the operator may have an indication as to which station on a two-party line she has called, a small target *1* carried on a lever *2* is provided. This target may display a black or a white field, according to which of its positions it occupies. The lever *2* is connected by the links *3* and *4* with the two key levers and the target is thus moved into one position or the other, according to which lever was last thrown into ringing position.

It will be noticed that the springs are mounted horizontally and on edge. This on-edge feature has the advantage of permitting ready inspection of the contacts and of avoiding the liability of dust gathering between the contacts. As will be seen, at the lower end of each switch lever there is a roller of insulating material which serves as a wedge, when forced between the two long springs of any set, to force them apart and into engagement with their respective outer springs.

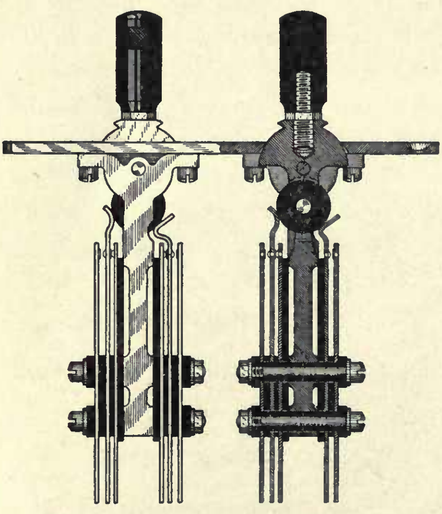


Fig. 267. Vertical-Spring Listening and Ringing Key

Vertical Spring Type. The other type of ringing and listening key employing vertical springs is almost universally used by the various independent manufacturing companies. A good example of this is shown in Fig. 267, which shows partly in elevation and partly in section a double key of the Monarch Company. The operation of this is obvious from its mode of construction. The right-hand set of springs of the right-hand key in this cut are the springs of the listening key, while the left-hand set of the right-hand key are those of the calling-plug ringing key. The left-hand set of the left-hand key may be those of a ring-back key on the answering plug, while the right-hand set of the left-hand key may be for any special purpose. It is obvious that these groups of springs may be grouped in different combinations or omitted in part, as required. This same general form of key is also manufactured by the Kellogg Company and the Dean Company, that of the Kellogg Company being illustrated in perspective, Fig. 268. The keys of this general type have the same advantages as those of the horizontal on-edge arrangement with respect to the gathering of dust, and while perhaps the contacts are not so readily get-at-able for inspection, yet they have the advantage of being somewhat more simple, and of taking up less horizontal space on the key shelf.

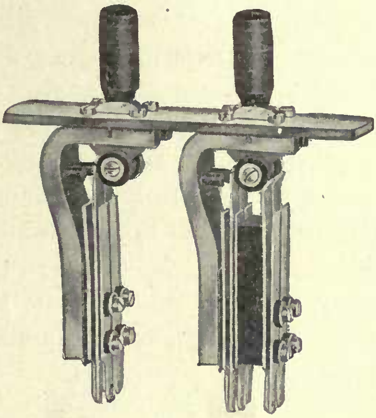


Fig. 268. Vertical Listening and Ringing Key

Party-Line Ringing Keys. For party-line ringing the key matter becomes somewhat more complicated. Usually the arrangement is such that in connection with each calling plug there are a number of keys, each arranged with respect to the circuits of the plug so as to send out the proper combination and direction of current, if the polarity system is used; or the proper frequency of current if the harmonic system is used; or the proper number of impulses if the step-by-step or broken-line system is used. The number of different kinds of arrangements and combinations is legion, and we will here illustrate only an example of a four-party line ringing key adapted for harmonic ringing. A Kellogg party-

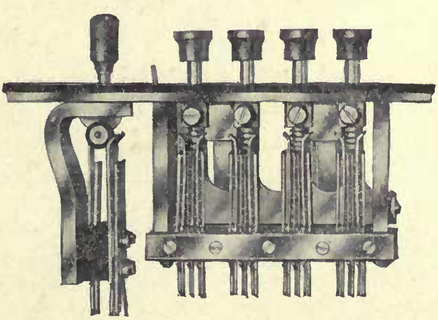


Fig. 269. Four-Party Listening and Ringing Key

line listening and ringing key is shown in Fig. 269. In this, besides the regular listening key, are shown four push-button keys, each adapted, when depressed, to break the connection back of the key, and at the same time connect the proper calling generator with the calling plug.

Self-Indicating Keys. A complication that has given a good deal of trouble in the matter of party-line ringing is due to the fact that it is sometimes necessary to ring a second or a third time on a party-line connection, because the party called may not respond the first time. The operator is not always able to remember which one of the four keys associated with the plug connected with the desired party she has pressed on the first occasion and, therefore, when it becomes necessary to ring again, she may ring the wrong party. This is provided for in a very ingenious way in the key shown in Fig. 269, by making the arrangement such that after a given key has been depressed to its full extent in ringing, and then released, it does not come quite back to its normal position but remains slightly depressed. This always serves as an indication to the operator, therefore, as to which key she depressed last, and in the case of a re-ring, she merely presses the key that is already down a little way. On the next call if she is required to press another one of the four keys, the one which remained down a slight distance on the last call will be released and the one that is fully depressed will be the one that remains down as an indication.

Such keys, where the key that was last used leaves an indication to that effect, are called *indicating* ringing keys. In other forms the indication is given by causing the key lever to move a little target which remains exposed until some other key in the same set is moved. The key shown in Fig. 266 is an example of this type.

NOTE. The matter of automatic ringing and other special forms of ringing will be referred to and discussed at their proper places in this work, but at this point they are not pertinent as they are not employed in simple switchboards.

Operator's Telephone Equipment. Little need be said concerning the matter of the operator's talking apparatus, *i. e.*, the operator's transmitter and receiver, since as transmitters and receivers they are practically the same as those in ordinary use for other purposes. The watch-case receiver is nearly always employed for operators' purposes on account of its lightness and compactness. It is used in connection with a head band so as to be held continually at the operator's ear, allowing both of her hands to be free.

The transmitter used by operators does not in itself differ from the transmitters employed by subscribers, but the methods by which it is supported differ, two general practices being followed. One of these is to suspend the transmitter by flexible conducting cords so as to be adjustable in a vertical direction. A good illustration of this is given in Fig. 270. The other method, and one that is coming into more and more favor, is to mount the transmitter on a

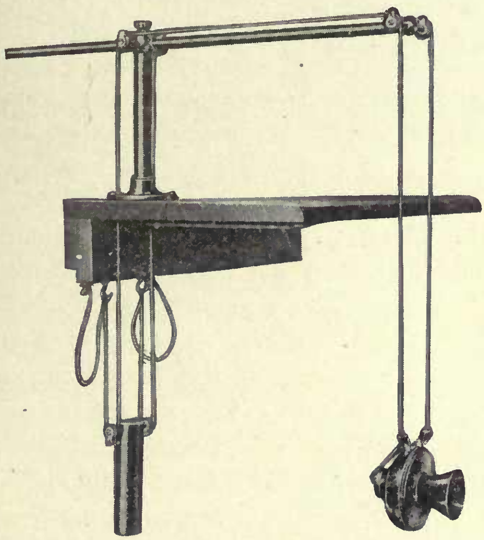


Fig. 270. Operator's Transmitter Suspension

light bracket suspended by a flexible band from the neck of the operator, a breast plate being furnished so that the transmitter will rest on her breast and be at all times within proper position to receive her speech. To facilitate this, a long curved mouthpiece is commonly employed, as shown clearly in Fig. 47.

Cut-in Jack. It is common to terminate that portion of the apparatus which is worn on the operator's person—that is, the receiver only if the suspended type of transmitter is employed, and the receiver and transmitter if the breast plate type of transmitter is employed—in a plug, and a flexible cord connecting the plug terminates with the apparatus. The portions of the operator's talking circuit that are located permanently in the switchboard cabinet are in such cases terminated in a jack, called an operator's *cut-in jack.* This is usually mounted on the front rail of the switchboard cabinet just below the key shelf. Such a cut-in jack is shown in Fig. 271 and it is merely a specialized form of spring jack adapted to receive the short, stout plug in which the operator's transmitter, or transmitter and receiver, terminate. By this arrangement the operator is enabled readily to connect or disconnect her talking apparatus, which is worn on her person, whenever she comes to the board for work or leaves it at the end of her work. A complete operator's telephone set, or that portion that is carried on the person of the operator, together with the cut-in plug, is shown in Fig. 272.

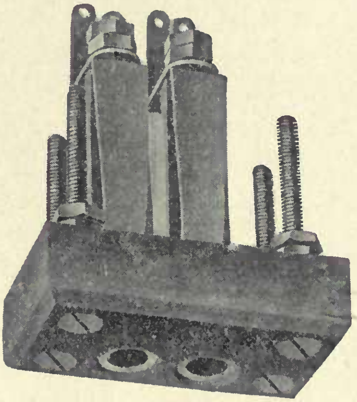


Fig. 271. Operator's Cut-In Jack

Circuits of Complete Switchboard. We may now discuss the circuits of a complete simple magneto switchboard. The one shown in Fig. 273 is typical. Before going into the details of this, it is well to inform the student that this general form of circuit representation is one that is commonly employed in showing the complete circuits of any switchboard. Ordinarily two subscribers' lines are shown, these connecting their respective subscribers' stations with two different line equipments at the central office. The jacks and signals of these line equipments are turned around so as to face each other, in order to clearly represent how the connection between them

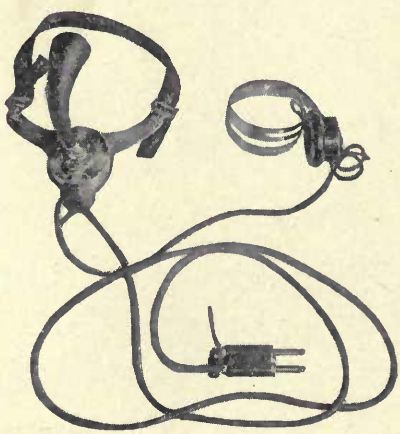


Fig. 272. Operator's Talking Set

may be made by means of the cord circuit. The elements of the cord circuit are also spread out, so that the various parts occupy relative positions which they do not assume at all in practice. In other words it must be remembered that, in circuit diagrams, the relative positions of the parts are sacrificed in order to make clear the circuit connections. However, this does not mean that it is often not possible to so locate the pieces of apparatus that they will in a certain way indicate relative positions, as may be seen in the case

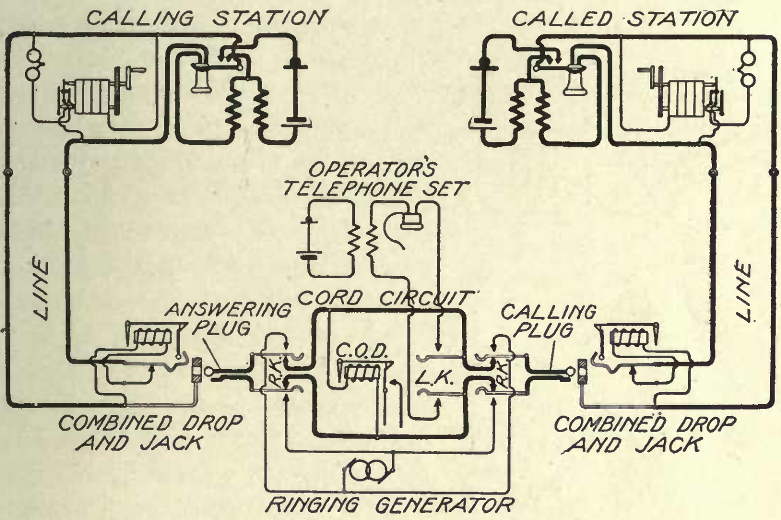


Fig. 273. Circuit of Simple Magneto Switchboard

of the drop and jack in Fig. 273, the drop being shown immediately above the jack, which is the position in which these parts are located in practice.

Little need be said concerning this circuit in view of what has already been said in connection with Figs. 240 to 245. It will be seen in the particular sub-station circuit here represented, that the talking apparatus is arranged in the usual manner and that the ringer and generator are so arranged that when the generator is operated the ringer will be cut out of circuit, while the generator will be placed across the circuit; while, when the generator is idle, the ringer is bridged across the circuit and the generator is cut out.

The line terminates in each case in the tip and sleeve contacts of the jack, and in the normal condition of the jack the line drop is bridged across the line. The arrangement by which the drop is restored and at the same time cut out of circuit when the operator plugs in the jack, is obvious from the diagrammatic illustration. The cord circuit is the same as that already discussed, with the exception that two ringing keys are provided, one in connection with the calling plug, as is universal practice, and the other in connection with the answering plug as is sometimes practiced in order that the operator may, when occasion requires, ring back the calling subscriber without the necessity of changing the plug in the jack. The outer contacts of these two ringing keys are connected to the terminals of the ringing generator and, when either key is operated, the connection between the plug, on which the ringing is to be done, and the rest of the cord circuit will be broken, while the generator will be connected with the terminals of the plug. The listening key and talking apparatus need no further explanation, it being obvious that when the key is operated the subscriber's telephone set will be bridged across the cord circuit and, therefore, connected with either or both of the talking subscribers.

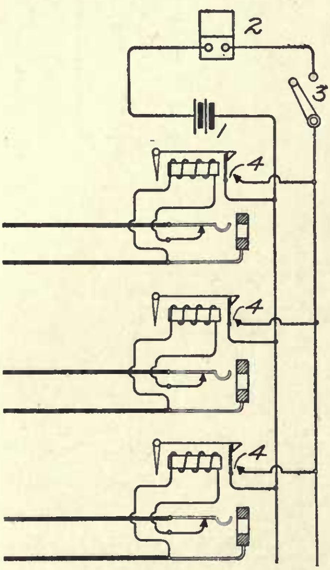


Fig. 274. Night-Alarm Circuit

Night-Alarm Circuits. The circuit of Fig. 273, while referred to as a complete circuit, is not quite that. The night-alarm circuit is not shown. In order to clearly indicate how a single battery and bell, or buzzer, may serve in connecting a number of line drops, reference is made to Fig. 274 which shows the connection between three different line drops and the night-alarm circuit. The night-alarm apparatus consists in the battery *1* and the buzzer, or bell, *2*. A switch *3* adapted to be manually operated is connected in the circuit with the battery and the buzzer so as to open this circuit when the night alarm is not needed, thus making it inoperative. During the portions of the day when the operator is needed constantly at the board it is customary to leave this switch *3* open, but during the night period when she is not required constantly at the board this switch is closed so that an audible signal will be given whenever a drop falls. The night-alarm contact *4* on each of the drops will be closed whenever a shutter falls, and as the two members of this contact, in the case of each drop, are connected respectively with the two sides of the night-alarm circuit, any one shutter falling will complete the necessary conditions for causing the buzzer to sound, assuming of course that the switch *3* is closed.

Night Alarm with Relay. A good deal of trouble has been caused in the past by uncertainty in the closure of the night-alarm circuit at the drop contact. Some of the companies have employed the form of circuit shown in Fig. 275 to overcome this. Instead of the night-alarm buzzer being placed directly in the circuit that is closed by the drop, a relay *5* and a high-voltage battery *6* are placed in this circuit. The buzzer and the battery for operating it are placed in a local circuit controlled by this relay. It will be seen by reference to Fig. 275 that when the shutter falls, it will, by closing the contact *4*, complete the circuit from the battery *6* through the relay *5*—assuming switch *3* to be closed—and thus cause the operation of the relay. The relay, in turn, by pulling up its armature, will close the circuit of the buzzer *2* through the battery *7* and cause the buzzer to sound.

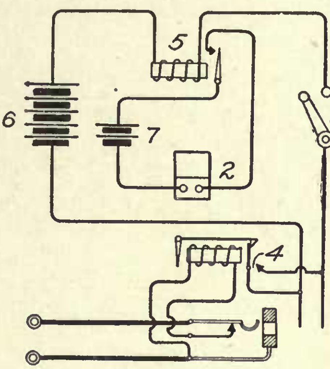


Fig. 275. Night-Alarm Circuit with Relay

The advantage of this method over the direct method of operating the buzzer is that any imperfection in the night-alarm contact at the drop is much less likely to prevent the flow of current of the high-voltage battery *6* than of the low-voltage battery *1*, shown in connection with Fig. 274. This is because the higher voltage is much more likely to break down any very thin bit of insulation, such as might be caused by a minute particle of dust or oxide between contacts that are supposed to be closed by the falling of the shutter. It has been common to employ for battery *6* a dry-cell battery giving about 20 or 24 volts, and for the operation of the buzzer itself, a similar battery of about two cells giving approximately 3 volts.

Night-Alarm Contacts. The night-alarm contact *4* of the drop shown diagrammatically in Figs. 274 and 275 would, if taken literally, indicate that the shutter itself actually forms one terminal of the circuit and the contact against which it falls, the other. This has not been found to be a reliable way of closing the night-alarm contacts and this method is indicated in these figures and in other figures in this work merely as a convenient way of representing the matter diagrammatically. As a matter of fact the night-alarm contacts are ordinarily closed by having the shutter fall against one spring, which is thereby pressed into engagement with another spring or contact, as shown in Fig. 249. This method employs the shutter only as a means for mechanically causing the one spring to press against the other, the shutter itself forming no part of the circuit. The reason why it is not a good plan to have the shutter itself act as one terminal of the circuit is that this necessitates the circuit connections being led to the shutter through the trunnions on which the shutter is pivoted. This is bad because, obviously, the shutter must be loosely supported on its trunnions in order to give it sufficiently free movement, and, as is well known, loose connections are not conducive to good electrical contacts.

Grounded- and Metallic-Circuit Lines. When grounded circuits were the rule rather than the exception, many of the switchboards were particularly adapted for their use and could not be used with metallic-circuit lines. These grounded-circuit switchboards provided but a single contact in the jack and a single contact on the plug, the cords having but a single strand reaching from one plug to the other. The ringing keys and listening keys were likewise single-contact keys rather than double. The clearing-out drop and the operator's talking circuit and the ringing generator were connected between the single strand of the cord and the ground as was required.

The grounded-circuit switchboard has practically passed out of existence, and while a few of them may be in use, they are not manufactured at present. The reason for this is that while many grounded circuits are still in use, there are very few places where there are not some metallic-circuit lines, and while the grounded-circuit switchboard will not serve for metallic-circuit lines, the metallic-circuit switchboard will serve equally well for either metallic-circuit or grounded lines, and will interconnect them with equal facility. This fact will be made clear by a consideration of Figs. 276, 277, and 278.

Connection between Two Similar Lines. In Fig. 276 a common magneto cord circuit is shown connecting two metallic-circuit lines;

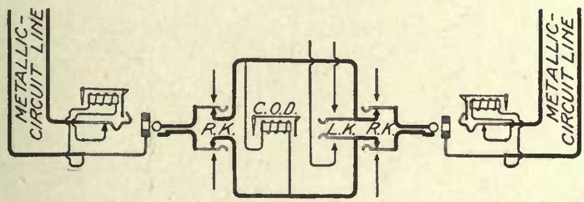


Fig. 276. Connection Between Metallic Lines

in Fig. 277 the same cord circuit is shown connecting two grounded lines. In this case the line wire *1* of the left-hand line is, when the plugs are inserted, continued to the tip of the answering plug, thence through the tip strand of the cord circuit to the tip of the calling plug, then to the tip spring of the right-hand jack and out to the single con-

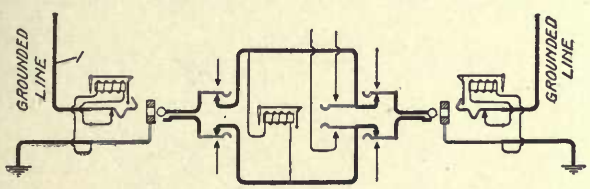


Fig. 277. Connection Between Grounded Lines

ductor of that line. The entire sleeve portion of the cord circuit becomes grounded as soon as the plugs are inserted in the jacks of such a line. Hence, we see that the sleeve contacts of the plug and the sleeve conductor of the cord are connected to ground through the permanent ground connection of the sleeve conductors of the jack as soon as the plug is inserted into the jack. Thus, when the cord circuit of a metallic-circuit switchboard is used to connect two grounded circuits together, the tip strand of the cord is the connecting link between the two conductors, while the sleeve strand of the cord merely serves to ground one side of the clearing-out drop and one side each of the operator's telephone set and the ringing generator when their respective keys are operated.

Connection between Dissimilar Lines. Fig. 278 shows how the same cord circuit and the same arrangement of line equipment may be used for connecting a grounded line to a metallic-circuit line. The metallic circuit line is shown on the left and the grounded line on the right. When the two plugs are inserted into the respective jacks of this figure, the right-hand conductor of the metallic circuit shown on the left will be continued through the tip strand of the cord circuit to the line conductor of the grounded line shown on the right. The left-hand conductor of the metallic-circuit line will be connected to ground because it will be continued through the sleeve strand of the cord circuit to the sleeve contact of the calling plug and thence to the sleeve contact of the jack of the grounded line, which sleeve contact is shown to be grounded. The talking circuit between the two connected lines in this case may be traced as follows: From the subscriber's station at the left through the right-hand limb of the metallic-circuit line, through the tip contact and tip conductor of the cord circuit, to the single limb of the grounded-circuit line, thence to the sub-station of that line and through the talking apparatus there to ground. The return path from the right-hand

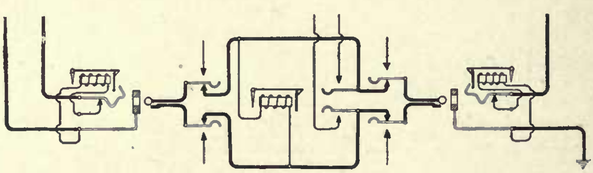


Fig. 278. Connection Between Dissimilar Lines

station is by way of ground to the ground connection at the central office, thence to the sleeve contact of the grounded line jack, through the sleeve conductor of the cord circuit, to the sleeve contact of the metallic-circuit line jack, and thence by the left-hand limb of the metallic-circuit line to the subscriber's station.

A better way of connecting a metallic-circuit line to a grounded line is by the use of a special cord circuit involving a repeating coil, such a connection being shown in Fig. 279. The cord circuit in this case differs in no respect from those already shown except that a repeating coil is associated with it in such a way as to conductively divide the answering side from the calling side. Obviously, whatever currents come over the line connected with the answering plug will pass through the windings *1* and *2* of this coil and will induce corresponding currents in the windings *3* and *4*, which latter currents

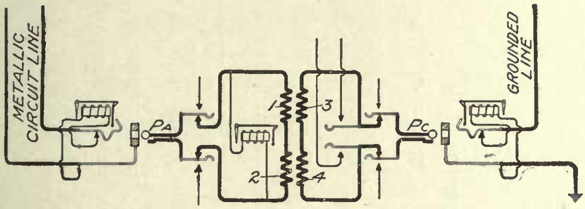


Fig. 279. Connection of Dissimilar Lines through Repeating Coil

will pass out over the circuit of the line connected with the calling plug. When a grounded circuit is connected to a metallic circuit in this manner, no ground is thrown onto the metallic circuit. The balance of the metallic circuit is, therefore, maintained.

To ground one side of a metallic circuit frequently so unbalances it as to cause it to become noisy, that is, to have currents flowing in it, by induction or from other causes, other than the currents which are supposed to be there for the purpose of conveying speech.

Convertible Cord Circuits. The consideration of Fig. 279 brings us to the subject of so-called convertible cord circuits. Some switchboards, serving a mixture of metallic and grounded lines, are provided with cord circuits which may be converted at will by the operator from the ordinary type shown in Fig. 276 to the type shown in Fig. 279. The advantage of this will be obvious from the following consideration. When a call originates on any line, either grounded or metallic, the operator does not know which kind of a line is to be called for. She, therefore, plugs into this line with any one of her answering plugs and completes the connection in the usual way. If the call is for the same kind of a circuit as that over which the call originated, she places the converting key in such a position as will connect the conductors of the cord circuit straight through; while if the connection is for a different kind of a line than that on which the call originated she throws the converting key into such a position as to include the repeating coil. A study of Fig. 280 will show that when the converting key, which is commonly referred to as the repeating-coil key, is in one position, the cord conductors will be cut straight through, the repeating coil being left open in both its windings; and when it is thrown to its other position, the connection be-

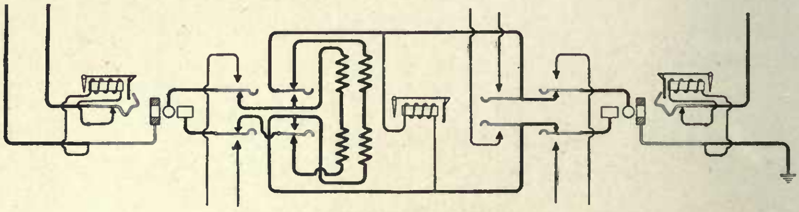


Fig. 280. Convertible Cord Circuit

tween the answering and calling sides of the cord circuit will be severed and the repeating coil inserted so as to bring about the same effects and circuit arrangements as are shown in Fig. 279.

Cord-Circuit Considerations. *Simple Bridging Drop Type.* The matter of cord circuits in magneto switchboards is deserving of much attention. So far as talking requirements are concerned, the ordinary form of cord circuit with a clearing-out drop bridged across the two strands is adequate for nearly all conditions except those where a grounded- and a metallic-circuit line are connected together, in which case the inclusion of a repeating coil has some advantages.

From the standpoint of signaling, however, this type of cord circuit has some disadvantages under certain conditions. In order to simplify the discussion of this and other cord-circuit matters, reference will be made to some diagrams from which the ringing and listening keys and talking apparatus have been entirely omitted. In Fig. 281 the regular bridging type of clearing-out drop-cord circuit is shown, this being the type already discussed as standard. For ordinary practice it is all right. Certain difficulties are experienced with it, however, where lines of various lengths and various types of sub-station apparatus are connected. For instance, if a long

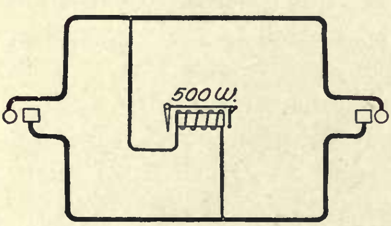


Fig. 281. Bridging Drop-Cord Circuit

bridging line be connected with one end of this cord circuit and a short line having a low-resistance series ringer be connected with the other end, then a station on the long line may have some difficulty in throwing the clearing-out drop, because of the low-resistance shunt that is placed around it through the short line and the low-resistance ringer. In other words, the clearing-out drop is shunted by a comparatively low-resistance line and ringer and the feeble currents arriving from a distant station over the long line are not sufficient to operate the drop thus handicapped. The advent of the various forms of party-line selective signaling and the use of such systems in connection with magneto switchboards has brought in another difficulty that sometimes manifests itself with this type of cord circuit. If two ordinary magneto telephones are connected to the two ends of this cord circuit, it is obvious that when one of the subscribers has hung up his receiver and the other subscriber rings off, the bell of the other subscriber will very likely be rung even though the clearing-out drop operates properly; it would be better in any event not to have this other subscriber's bell rung, for he may understand it to be a recall to his telephone. When, however, a party line is connected through such a cord circuit to an ordinary line having bridging instruments, for instance, the difficulty due to ringing off becomes even greater. When the subscriber on the magneto line operates his generator to give the clearing-out signal, he is very likely to ring some of the bells on the other line and this, of course, is an undesirable thing. This may happen even in the case of harmonic bells on the party line, since it is possible that the subscriber on the magneto line in turning his generator will, at some phase of the operation, strike just the proper frequency to ring some one of the bells on the harmonic party line. It is obvious, therefore, that there is a real need for a cord circuit that will prevent *through ringing.*

One way of eliminating the through-ringing difficulty in the type of cord circuit shown in Fig. 281 would be to use such a very low-wound clearing-out drop that it would practically short-circuit the line with respect to ringing currents and prevent them from passing on to the other line. This, however, is not a good thing to do, since a winding sufficiently low to shunt the effective ringing current would also be too low for good telephone transmission.

Series Drop Type. Another type of cord circuit that was largely used by the Stromberg-Carlson Telephone Manufacturing Company at one time is shown in Fig. 282. In this the clearing-out drop was not bridged but was placed in series in the tip side of the line and was shunted by a condenser. The resistance of the clearing-out drop was 1,000 ohms and the capacity of the condenser was 2 microfarads. It is obvious that this way of connecting the clearing-out drop was subject to the *ringing-through* difficulty, since the circuit through which the clearing-out current necessarily passed included the telephone instrument of the line that was not sending the clearing-out signal. This form was also objectionable because it was necessary for the subscriber to ring through the combined resistance of two lines, and in case the other line happened to be open, no clearing-out signal would be received. While this circuit, therefore, was perhaps not quite so likely as the other to tie up the subscriber, that is, to leave him connected without the ability to send a clearing-out signal, yet it was sure to ring through, for the clearing-out drop could not be thrown without the current passing through the other subscriber's station.

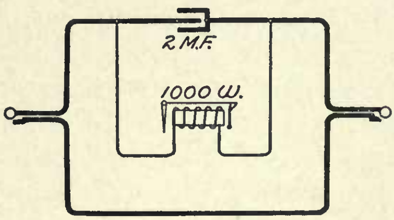


Fig. 282. Series Drop-Cord Circuit

Non-Ring-Through Type. An early attempt at a non-ring-through cord is shown in Fig. 283, this having once been standard with the Dean Electric Company. It made use of two condensers of 1 microfarad each, one in each side of the cord circuit. The clearing-out drop was of 500 ohms resistance and was connected from the answering side of the tip conductor to the calling side of the sleeve conductor. In this way whatever clearing-out current reached the central office passed through at least one of the condensers and the clearing-out drop. In order for the clearing-out current to pass on

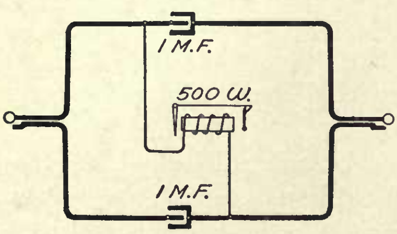


Fig. 283. Dean Non-Ring-Through Cord Circuit

beyond the central office it was necessary for it to pass through the two condensers in series. This arrangement had the advantage of giving a positive ring-off, regardless of the condition of the connected line. Obviously, even if the line was short-circuited, the ringing currents from the other line would still be forced through the clearing-out drop on account of the high effective resistance of the 1-microfarad condenser connected in series with the short-circuited line. Also the clearing-out signal would be properly received if the connected line were open, since the clearing-out drop would still be directly across the cord circuit. This arrangement also largely prevented through ringing, since the currents would pass through the 1-microfarad condenser and the 500-ohm drop more readily than through the two condensers connected in series.

In Fig. 284 is shown the non-ring-through arrangement of cord circuit adopted by the Monarch Company. In this system the clearing-out drop has two windings, either of which will operate the armature. The two windings are bridged across the cord circuit, with a ½-microfarad condenser in series in the tip strand between the two winding connections. While the low-capacity condenser will allow the high-frequency talking current to pass readily without affecting it to any appreciable extent, it offers a high resistance to a low-frequency ringing current, thus preventing it from passing out on a connected line and forcing it through one of the windings of the coil. There is a tendency to transformer action in this arrangement, one of the windings serving as a primary and the other as a secondary, but this has not prevented the device from being highly successful.

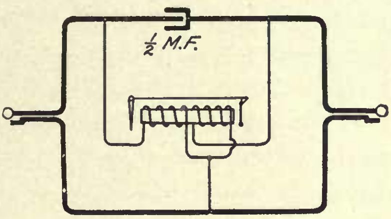


Fig. 284. Monarch Non-Ring-Through Cord Circuit

A modification of this arrangement is shown in Fig. 285, wherein a double-wound clearing-out drop is used, and a ½-microfarad condenser is placed in series in each side of the cord circuit between the winding connections of the clearing-out drop. This circuit should give a positive ring-off under all conditions and should prevent through ringing except as it may be provided by the transformer action between the two windings on the same core.

Another rather ingenious method of securing a positive ring-off and yet of preventing in a certain degree the undesirable ringing-through feature is shown in the cord circuit, Fig. 286. In this two non-inductive coils *1* and *2* are shown connected in series in the tip and sleeve strands of the coils, respectively. Between the neutral point of these two non-inductive windings is connected the clearing-out drop circuit. Voice currents find ready path through these non-inductive windings because of the fact that, being non-inductive, they present only their straight ohmic resistance. The impedance of the clearing-out drop prevents the windings being shunted across the two sides of the cord circuit. With this circuit a positive ring-off is assured even though the line connected with the one sending the clearing-out signal is short-circuited or open. If it is short-circuited, the shunt around the clearing-out drop will still have the resistance of two of the non-inductive windings included in it, and thus the drop will never be short-circuited by a very low-resistance path. Obviously, an open circuit in the line will not prevent the clearing-out signal being received. While this is an ingenious scheme, it is not one to be highly recommended since the non-inductive windings, in order to be effective so far as signaling is concerned, must be of considerable resistance and this resistance is in series in the talking circuit. Even non-inductive resistance is to be avoided in the talking circuit when it is of considerable magnitude and where there are other ways of solving the problem.

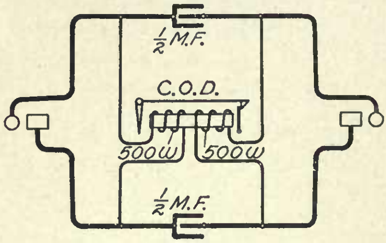


Fig. 285. Non-Ring-Through Cord Circuit

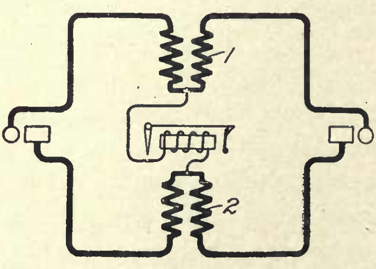


Fig. 286. Cord Circuit with Differential Windings

Double Clearing-out Type. Some people prefer two clearing-out drops in each cord circuit, so arranged that the one will be responsive to currents sent from the line with which the answering plug is connected and the other responsive only to currents sent from the line with which the calling plug is connected. Such a scheme, shown in Fig. 287, is sometimes employed by the Dean, the Monarch, and the Kellogg companies. Two 500-ohm clearing-out drops of ordinary construction are bridged across the cord circuit and in each side of the cord circuit there is included between the drop connections a 1-microfarad condenser. Ringing currents originating on the line with which the answering plug is connected will pass through the clearing-out drop, which is across that side of the cord circuit, without having to pass through any condensers. In order to reach the other clearing-out drop the ringing current must pass through the two 1-microfarad condensers in series, this making in effect only $\frac{1}{2}$-microfarad.

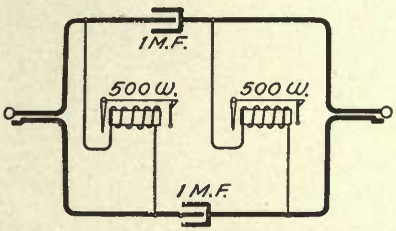


Fig. 287. Double Clearing-Out Drops

As is well known, a $\frac{1}{2}$-microfarad condenser not only transmits voice currents with ease but also offers a very high apparent resistance to ringing currents. With the double clearing-out drop system the operator is enabled to tell which subscriber is ringing off. If both shutters fall she knows that both subscribers have sent clearing-out signals and she, therefore, pulls down the connection without the usual precaution of listening to see whether one of the subscribers may be waiting for another connection. This double clearing-out system is analogous to the complete double-lamp supervision that will be referred to more fully in connection with common-battery circuits. There is not the need for double supervision in magneto work, however, that there is in common-battery work because of the fact that in magneto work the subscribers frequently fail to remember to ring off, this act being entirely voluntary on their part, while in common-battery work, the clearing-out signal is given automatically by the subscriber when he hangs up his receiver, thus accomplishing the desired end without the necessity of thoughtfulness on his part.

Another form of double clearing-out cord circuit is shown in Fig. 288. In this the calling and the answering plugs are separated by repeating coils, a condenser of 1-microfarad capacity being inserted between each pair of windings on the two ends of the circuit.

The clearing-out drops are placed across the calling and answering cords in the usual manner. The condenser in this case prevents the drop being short-circuited with respect to ringing currents and yet

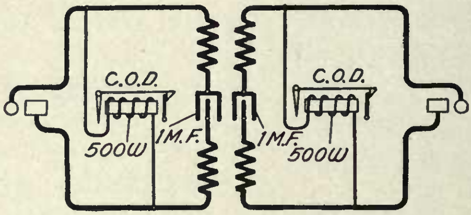


Fig. 288. Double Clearing-Out Drops

permits the voice currents to flow readily through it. The high impedance of the drop forces the voice currents to take the path through the repeating coil rather than through the drop. This circuit has the advantage of a repeating-coil cord circuit in permitting the connection of metallic and grounded lines without causing the unbalancing of the metallic circuits by the connection to them of the grounded circuits.

Recently there has been a growing tendency on the part of some manufacturers to control their clearing-out signals by means of relays associated with cord circuits, these signals sometimes being ordinary clearing-out drops and sometimes incandescent lamps.

In Fig. 289 is shown the cord circuit sometimes used by the L. M. Ericsson Telephone Manufacturing Company. A high-wound

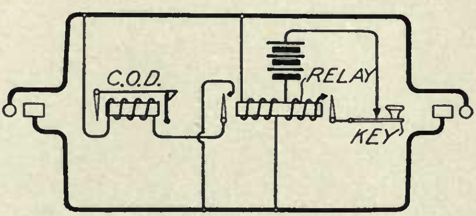


Fig. 289. Relay-Controlled Clearing-Out Drop

relay is normally placed across the cord and this, besides having a high-resistance and impedance winding has a low-resistance locking winding so arranged that when the relay pulls up its armature it will close a local circuit including this locking winding and local battery. When once pulled up the relay will, therefore, stay up due to the energizing of this locking coil. Another contact operated by the relay closes the circuit of a low-wound clearing-out drop placed across the line, thus bridging it across the line. The condition of high impedance is maintained across the cord circuit normally while the subscribers are talking; but when either of them rings off, the high-wound relay pulls up and locks, thus completing the circuit of the clearing-out drop across the cords. The subsequent impulses sent from the subscribers' generators operate this drop. The relay is restored or unlocked and the clearing-out drop disconnected from the cord circuit by means of a key which opens the locking circuit of the relay. This key is really a part of the listening key and serves to open this locking circuit whenever the listening key is operated. The clearing-out drop is also automatically restored by the action of the listening key, this connection being mechanical rather than electrical.

Recall Lamp:—The Monarch Company sometimes furnishes what it terms a recall lamp in connection with the clearing-out drops on its magneto switchboards. The circuit arrangement is shown in Fig. 290, wherein the drop is the regular double-wound clearing-out drop like that of Fig. 284. The armature carries a contact spring adapted to close the local circuit of a lamp whenever it is attracted. The object of this is to give the subscriber, whose line still remains connected by a cord circuit, opportunity to recall the central office if the operator has not restored the clearing-out drop.

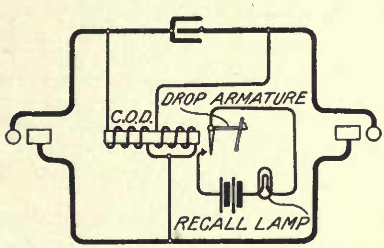


Fig. 290. Cord Circuit with Recall Lamp

Lamp-Signal Type. There has been a tendency on the part of some manufacturing companies to advocate, instead of drop signals, incandescent lamp signals for the cord circuits, and sometimes for the line circuits on magneto boards. In most cases this may be looked upon as a "frill." Where line lamps instead of drops have been used on magneto switchboards, it has been the practice to employ, instead of a drop, a locking relay associated with each lamp, which was so arranged that when the relay was energized by the magneto current from the subscriber's station, it would pull up and lock, thus closing the lamp circuit.

The local circuit, or locking circuit, which included the lamp was carried through a pair of contacts in the corresponding jacks so arranged that when the plug was inserted in answer to the call, this locking lamp circuit would be open, thereby extinguishing the lamp and also unlocking the relay. There seems to be absolutely no good reason why lamp signals should be substituted for mechanical drops in magneto switchboards. There is no need for the economy in space which the lamp signal affords, and the complications brought in by the locking relays, and the requirements for maintaining a local battery suitable for energizing the lamps are not warranted for ordinary cases.

In Fig. 291 is shown a cord circuit, adaptable to magneto switchboards, provided with double lamp signals instead of clearing-out

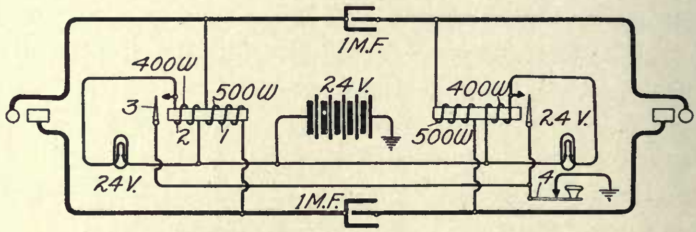


Fig. 291. Cord Circuit with Double Lamp Signals

drops. Two high-wound locking relays are bridged across the line, the cord strands being divided by 1-microfarad condensers. When the high-wound coil of either relay is energized by the magneto current from the subscriber's station, the relay pulls up and closes a locking circuit including a battery and a coil *2*, the contact *3* of the locking relay, and also the contact *4* of a restoring key. This circuit may be traced from the ground through battery, coil *2*, contact *3* controlled by the relay, and contact *4* controlled by the restoring key, and back to ground. In multiple with the locking coil *2* is the lamp, which is illuminated, therefore, whenever the locking circuit is closed. Pressure on the restoring key breaks the locking circuit of either of the lamps, thereby putting out the lamp and at the same time restoring the locking relay to its normal position.

Lamps vs. Drops in Cord Circuits. So much has been said and written about the advantages of incandescent lamps as signals in switchboards and about the merits of the common-battery method of supplying current to the subscribers, that there has been a tendency for people in charge of the operation of small exchanges to substitute the lamp for the drop in a magneto switchboard in order to give the general appearance of common-battery operations. There has also been a tendency to employ the common-battery system of operation in many places where magneto service should have been used, a mistake which has now been realized and corrected. In places where the simple magneto switchboard is the thing to use, the simpler it is the better, and the employment of locking relays and lamp signals and the complications which they carry with them, is not warranted.

Switchboard Assembly. The assembly of all the parts of a simple magneto switchboard into a complete whole deserves final consideration. The structure in which the various parts are mounted, referred to as the cabinet, is usually of wood.

Functions of Cabinet. The purpose of the cabinet is not only to form a support for the various pieces of apparatus but also to protect them from dust and mechanical injury, and to hold those parts that must be manipulated by the operator in such relation that they may be most convenient for use, and thus best adapted for carrying out their various functions. Other points to be provided for in the design of the cabinet and the arrangement of the various parts within are: that all the apparatus that is in any way liable to get out of order may be readily accessible for inspection and repairs; and that provision shall be made whereby the wiring of these various pieces of apparatus may be done in a systematic and simple way so as to minimize the danger of crossed, grounded, or open circuits, and so as to provide for ready repair in case any of these injuries do occur.

Wall-Type Switchboards. The simplest form of switchboard is that for serving small communities in rural districts. Ordinarily the telephone industry in such a community begins by a group of farmers along a certain road building a line connecting the houses of several of them and installing their own instruments. This line is liable to be extended to some store at the village or settlement, thus affording communication between these farmers and the center of their community. Later on those residing on other roads do the same thing and connect their lines to the same store or central point. Then it is that some form of switchboard is established, and perhaps the storekeeper's daughter or wife is paid a small fee for attendance.

A switchboard well-adapted for this class of service where the number of lines is small, is shown in Fig. 292. In this the operator's

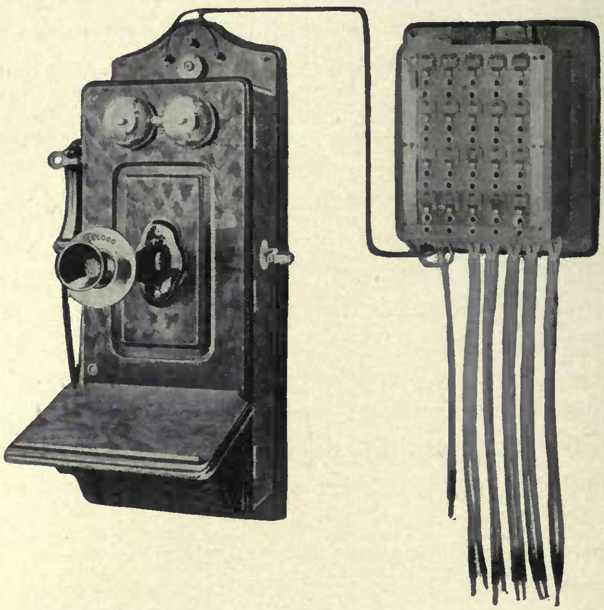


Fig. 292. Wall Switchboard with Telephone

talking apparatus and her calling apparatus are embodied in an ordinary magneto wall telephone. The switchboard proper is mounted alongside of this, and the two line binding posts of the telephone are connected by a pair of wires to terminals of the operator's plug, which plug is shown hanging from the left-hand portion of the switchboard. The various lines centering at this point terminate in the combined drops and jacks on the switchboard, of which there are 20 shown in this illustration. Beside the operator's plug there are a number of pairs of plugs shown hanging from the switchboard cabinet. These are connected straight through in pairs, there being no clearing-out drops or keys associated with them in the arrangement. Each line shown is provided with an extra jack, the purpose of which will be presently understood.

The method of operation is as follows: When a subscriber on a certain line desires to get connection through the switchboard he turns his generator and throws the drop. The operator in order to communicate with him inserts the plug in which her telephone terminates into the jack, and removes her receiver from its hook. Having learned that it is for a certain subscriber on another line, she withdraws her plug from the jack of the calling line and inserts it into the jack of the called line, then, hanging up her receiver, she turns the generator crank in accordance with the proper code to call that subscriber. When that subscriber responds she connects the two lines by inserting the two plugs of a pair into their respective jacks, and the subscribers are thus placed in communication. The extra jack associated with each line is merely an open jack having its terminals connected respectively with the two sides of the line. Whenever an operator desires to listen in on two connected lines she does so by inserting the operator's plug into one of these extra jacks of the connected lines, and she may thus find out whether the subscribers are through talking or whether either one of them desires another connection. The drops in such switchboards are commonly high wound and left permanently bridged across the line so as to serve as clearing-out drops. The usual night-alarm attachment is provided, the buzzer being shown at the upper right-hand portion of the cabinet.

Fig. 293. Combined Telephone and Switchboard

Another type of switchboard commonly employed for this kind of service is shown in Fig. 293, in which the telephone and the switchboard cabinet are combined. The operation of this board is practically the same as that of Fig. 292, although it has manually-restored drops instead of self-restoring drops; the difference between these two types, however, is not material for this class of service. For such work the operator has ample time to attend to the restoring of the

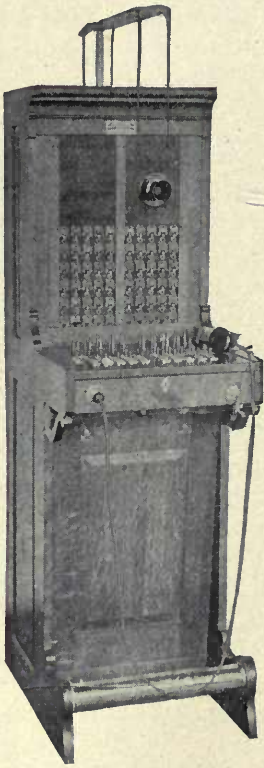


Fig. 294. Upright Magneto Switchboard

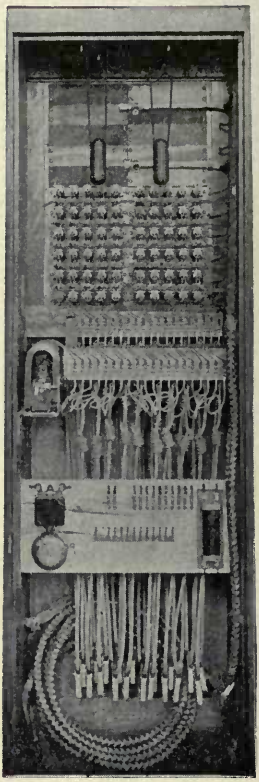


Fig. 295. Upright Magneto Switchboard—Rear View

drop and the only possible advantage in the combined drop-and-jack for this class of work is that it prevents the operator from forgetting to restore the drops. However, she is not likely to do this with the night-alarm circuit in operation, since the buzzer or bell would continue to ring as long as the drop was down.

Upright Type Switchboard. By far the most common type of magneto switchboard is the so-called upright type, wherein the drops and jacks are mounted on the face of upright panels rising from a horizontal shelf, which shelf contains the plugs, the keys, and any other apparatus which the operator must manipulate. Front and rear views of such a switchboard, as manufactured by the Kellogg Company, are shown in Figs. 294 and 295. This particular board is provided with fifty combined drops and jacks and, therefore,

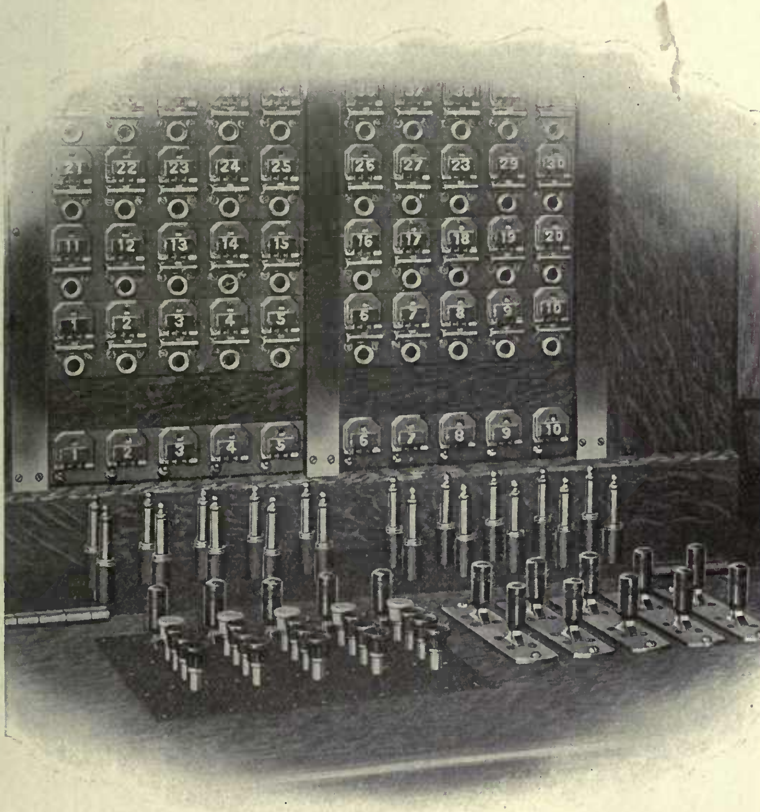


Fig. 296. Details of Drop, Jack, Plug, and Key Arrangement

equipped for fifty subscribers' lines. The drops and jacks are mounted in strips of five, and arranged in two panels. The clearing-out drops, of which there are ten, are arranged at the bottom of the two panels in a single row and may be seen immediately above the switchboard plugs. There are ten pairs of cords and plugs with their associated ringing and listening keys, the plugs being

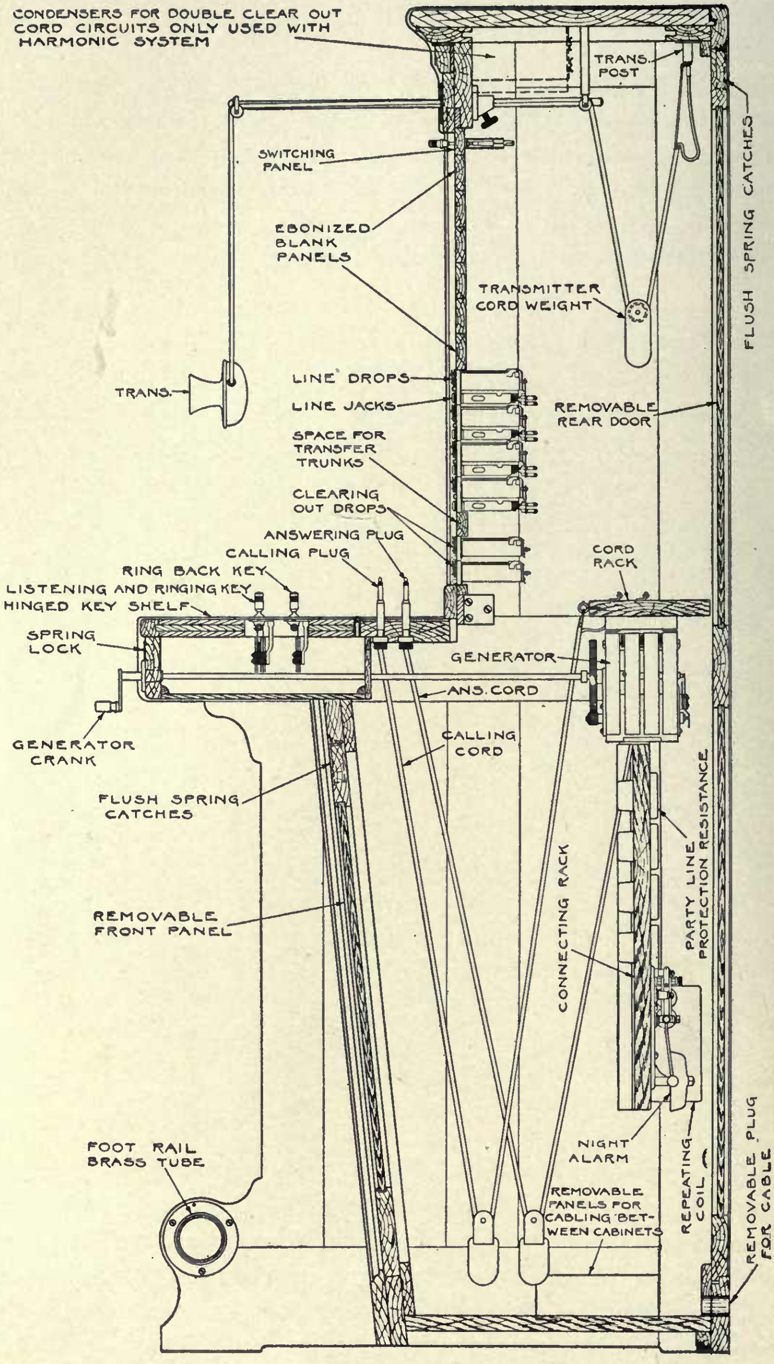


Fig. 297. Cross-Section of Upright Switchboard

mounted on the rear portion of the shelf, while the ringing and listening keys are mounted on the hinged portion of the shelf in front of the plugs.

A better idea of the arrangement of drops, jacks, plugs, and keys may be had from an illustration of a Dean magneto switchboard shown in Fig. 296. The clearing-out drops and the arrangement of the plugs and keys are clearly shown. The portion of the switchboard on which the plugs are mounted is always immovable, the plugs being provided with seats through which holes are bored of sufficient size to permit the switchboard cord to pass beneath the shelf. When one of these plugs is raised, the cord is pulled up through this hole thus allowing the plug to be placed in any of the jacks.

The key arrangement shown in this particular cut is instructive. It will be noticed that the right-hand five pairs of plugs are provided with ordinary ringing and listening keys, while the left-hand five are provided with party-line ringing keys and listening keys. The listening key in each case is the one in the rear and is alike for all of the cord pairs. The right-hand five ringing keys are so arranged that pressing the lever to the rear will ring on the answering cord, while pressing it toward the front will cause ringing current to flow on the calling plug. In the left-hand five pairs of cords shown in this cut, the pressure of any one of the keys causes a ringing current of a certain frequency to flow on the calling cord, this frequency depending upon which one of the keys is pressed.

Fig. 298. Cord Weight

An excellent idea of the grouping of the various pieces of apparatus in a complete simple magneto switchboard may be had from Fig. 297. While the arrangement here shown is applicable particularly to the apparatus of the Dean Electric Company, the structure indicated is none-the-less generally instructive, since it represents good practice in this respect. In this drawing the stationary plug shelf with the plug seat is clearly shown and also the hinged key shelf. The hinge of the key shelf is an important feature and is universally found in all switchboards of this general type. The key shelf may be raised and thus expose all of the wiring leading to the keys, as well as the various contacts of the keys themselves, to inspection.

As will be seen, the switchboard cords leading from the plugs extend down to a point near the bottom of the cabinet where they pass through pulley weights and then up to a stationary cord rack. On this cord rack are provided terminals for the various conduc-

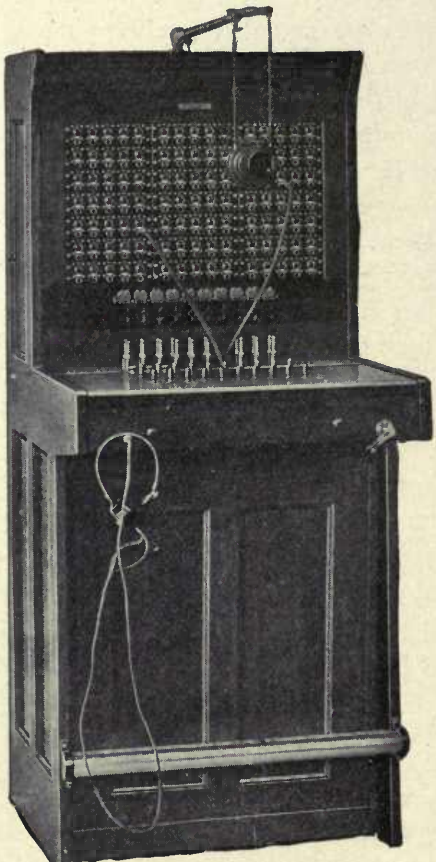


Fig. 299. Magneto Switchboard, Target Signals

tors in the cord, and it is at this point that the cord conductors join the other wires leading to the other portions of the apparatus as required. A good form of cord weight is shown in Fig. 298; and obviously the function of these weights is to keep the cords taut at all times and to prevent their tangling.

The drawing, Fig. 297, also gives a good idea of the method of mounting the hand generator that is ordinarily employed with such magneto switchboards. The shaft of the generator is merely continued out to the front of the key shelf where the usual crank is provided, by means of which the operator is able to generate the

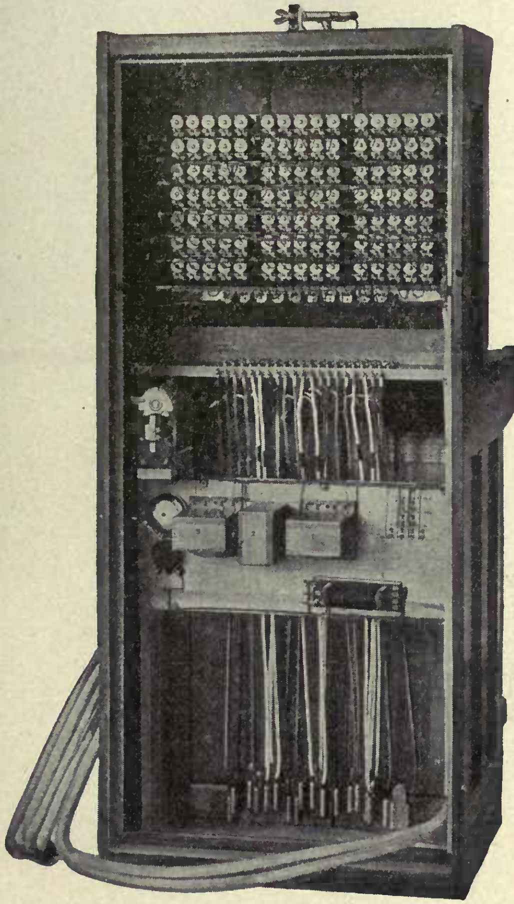


Fig. 300. Rear View of Target Signal, Magneto Switchboard

necessary ringing current. Beside the hand generator at each operator's position, it is quite common in magneto boards, of other than the smallest sizes, to employ some form of ringing generator, either a power-driven generator or a pole changer driven by battery current for furnishing ringing current without effort on the part of the operator

Switchboards as shown in Figs. 294 and 295, are called single-position switchboards because they afford room for a single operator. Ordinarily for this class of work a single operator may handle from one to two hundred lines, although of course this depends on the

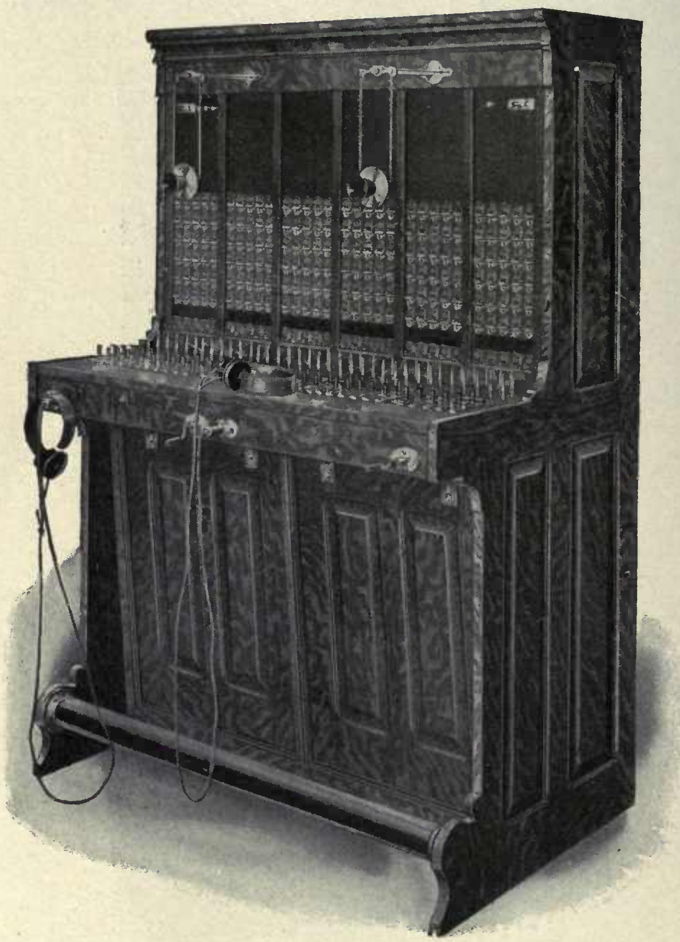


Fig. 301. Dean Two-Position Switchboard

amount of traffic on the line, and this, in turn, depends on the character of the subscribers served, and also on the average number of stations on a line. Another single-position switchboard is shown in Figs. 299 and 300, being a front and rear view of the simple magneto switchboard of the Western Electric Company, which is provided with the target signals of that company rather than the usual form of drop.

Where a switchboard must accommodate more lines than can be handled by a single operator, the cabinet is made wider so as to afford

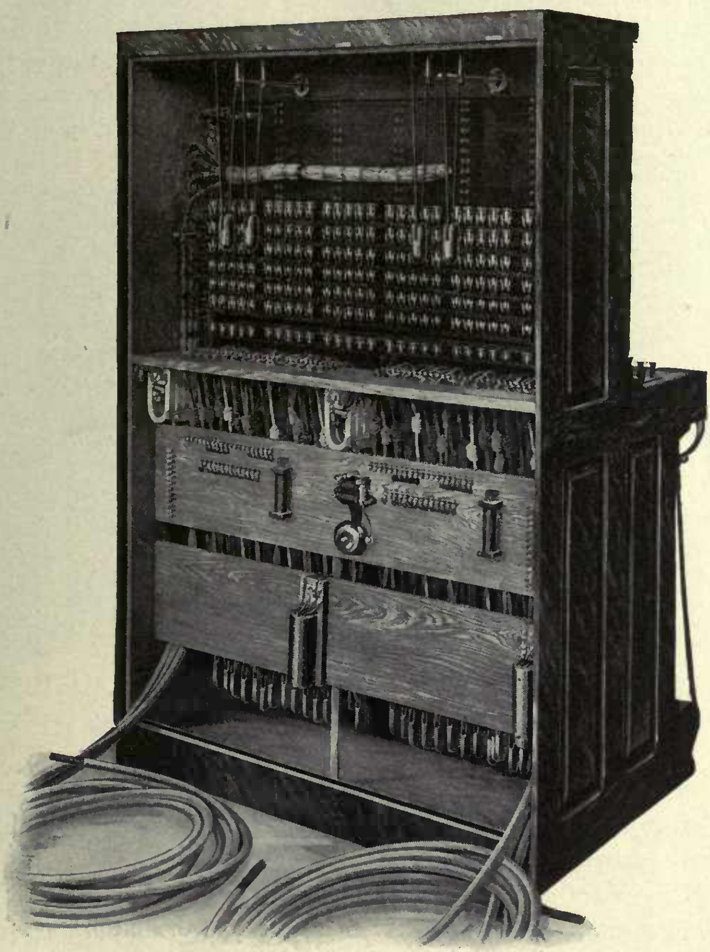


Fig. 302. Rear View of Dean Two-Position Switchboard

room for more than one operator to be seated before it. Sometimes this is accomplished by building the cabinet wider, or by putting two such switchboard sections as are shown in Figs. 294 or 299 side by side. A two-position switchboard section is shown in front and rear views in Figs. 301 and 302.

Sectional Switchboards. The problem of providing for growth in a switchboard is very much the same as that which confronts one in buying a bookcase for his library. The Western Electric Company has met this problem, for very small rural exchanges, in much the same way that the sectional bookcase manufacturers have provided for the possible increase in bookcase capacity. Like the sectional bookcase, this sectional switchboard may start with the smallest of equipment—a single sectional unit—and may be added to vertically

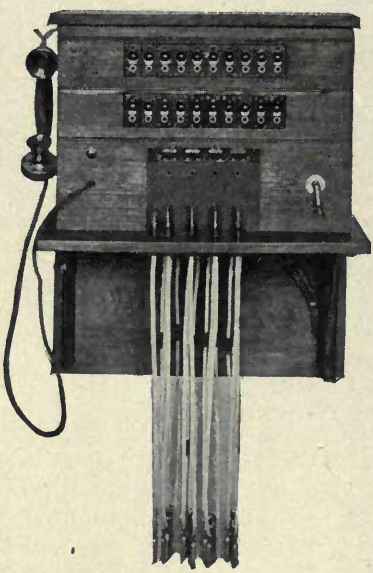


Fig. 303. Sectional Switchboard—Wall Type

as the requirements increase, the original equipment being usable in its more extended surroundings.

This line of switchboards is illustrated in Figs. 303 to 306. The beginning may be made with either a wall type or an upright type of switchboard, the former being mounted on brackets secured to the wall, and the latter on a table. A good idea of the wall type is shown in Fig. 303. Three different kinds of sectional units are involved in this: first, the unit which includes the cords, plugs, clearing-out drops, listening jacks, operator's telephone set and generator; second, the unit containing the line equipment, including a strip of ten magneto line signals and their corresponding jacks; third, the finishing top, which includes no equipment except the support for the operator's talking apparatus.

The first of the units in Fig. 303 forms the foundation on which the others are built. Two of the line-equipment units are shown; these provide for a total of twenty lines. The top rests on the upper line-equipment unit, and when it becomes necessary to add one or more line-equipment units as the switchboard grows, this

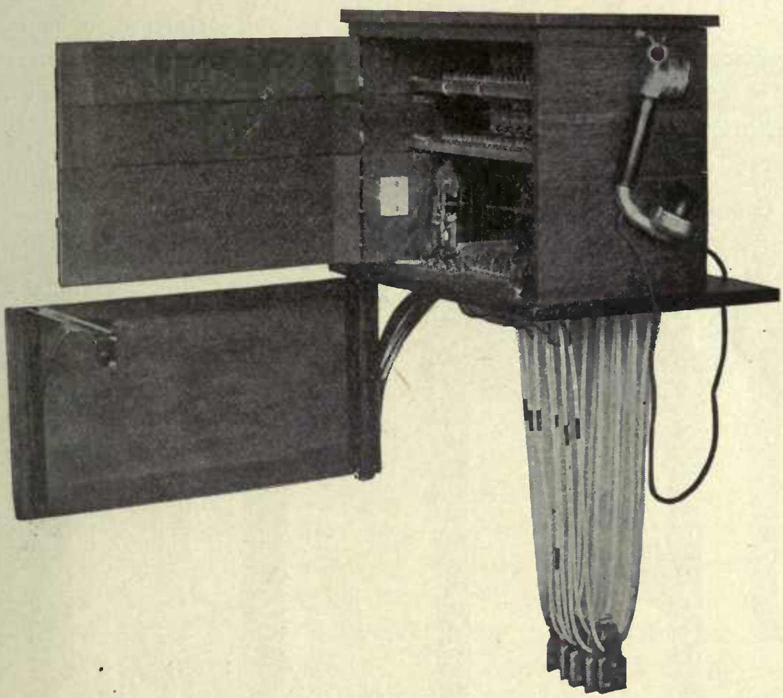


Fig. 304. Sectional Switchboard—Wall Type

top is merely taken off, the other line-equipment units put in place on top of those already existing, and the top replaced. The wall type of sectional switchboard is so arranged that the entire structure may be swung out from the wall, as indicated in Fig. 304, exposing all of the apparatus and wiring for inspection. Each of the sectional units is provided with a separate door, as indicated, so that the rear door equipment is added to automatically as the sections are added. In the embodiment of the sectional switchboard idea shown in these two figures just referred to, no ringing and listening keys are provided, but the operator's telephone and generator terminate in a special plug—the left-hand one shown in Fig. 303—and when the operator desires to converse with the connected subscribers, she does so by inserting the operator's plug into one of the jacks immediately below the clearing-out drop corresponding to the pair of plugs used in making the connection. The arrangement in this case is exactly the same in principle as that described in Fig. 292. The operator's generator is so arranged in connection with this left-hand operator's plug that the turning of the generator crank automatically switches the operator's telephone set off and switches the generator on, just the same as a switch hook may do in a subscriber's series telephone.

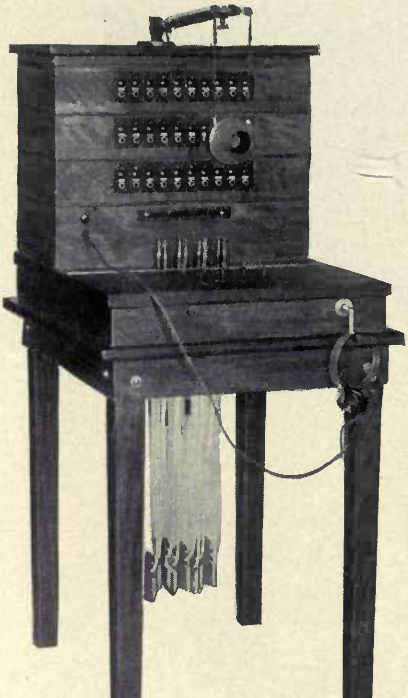


Fig. 305. Sectional Switchboard—Table Type

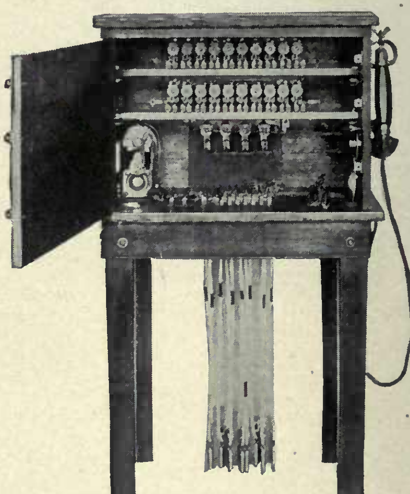


Fig. 306. Sectional Switchboard—Table Type

The upright type of sectional switchboard is shown in Figs. 305 and 306, which need no explanation in view of the foregoing, except to say that, in the particular instrument illustrated, ringing and listening keys are provided instead of the jack-and-plug arrangement of the wall type. In this case also, the top section carries an arm for supporting a swinging transmitter instead of the hook support for the combined transmitter and receiver.

CHAPTER XXII

THE SIMPLE COMMON-BATTERY SWITCHBOARD

Advantages of Common-Battery Operation. The advantages of the common-battery system of operation, alluded to in Chapter XIII, may be briefly summarized here. The main gain in the common-battery system of supply is the simplification of the subscribers' instruments, doing away with the local batteries and the magneto generators, and the concentration of all these many sources of current into one single source at the central office. A considerable saving is thus effected from the standpoint of maintenance, since the simpler common-battery instrument is not so likely to get out of order and, therefore, does not have to be visited so often for repairs, and the absence of local batteries, of course, makes the renewal of the battery parts by members of the maintenance department, unnecessary. Another decided advantage in the common-battery system is the fact that the centralized battery stands ready always to send current over the line when the subscriber completes the circuit of the line at his station by removing his receiver from its hook. The common-battery system, therefore, lends itself naturally to the purposes of automatic signaling, since it is only necessary to place at the central office a device in the circuit of each line that will be responsive to the current which flows from the central battery when the subscriber removes his receiver from its hook. It is thus that the subscriber is enabled automatically to signal the central office when he desires a connection; and as will be shown, it is by the same sort of means, associated with the cord circuits used in connecting his line with some other line, that the operator is automatically notified when a disconnection is desired, the cessation of current through the subscriber's line when he hangs up his receiver being made to actuate certain responsive devices which are associated with the cord at that time connected with his line, and which convey the proper disconnect signal to the operator.

Concentration of sources of energy into a single large unit, the simplification of the subscriber's station equipment, and the ready adaptability to automatic signaling from the subscriber to the central office are, therefore, the reasons for the existence of the common-battery system.

Common Battery vs. Magneto. It must not be supposed, however, that the common-battery system always has advantages over the magneto system, and that it is superior to the magneto or local-battery system for all purposes. It is the outward attractiveness of the common-battery system and the arguments in its favor, so readily made by over-zealous salesmen, that has led, in many cases, to the adoption of this system when the magneto system would better have served the purpose of utility and economy.

To say the least, the telephone transmission to be had from common-battery systems is no better than that to be had from local-battery systems, and as a rule, assuming equality in other respects, it is not as good. It is perhaps true, however, that under average conditions common-battery transmission is somewhat better, because whereas the local batteries at the subscribers' stations in the local-battery system are not likely to be in uniformly first-class condition, the battery in a common-battery system will be kept up to its full voltage except under the grossest neglect.

The places in which the magneto, or local-battery, system is to be preferred to the common-battery system, in the opinion of the writers, are to be found in the small rural communities where the lines have a rather great average length; where a good many subscribers are likely to be found on some of the lines; where the sources of electrical power available for charging storage batteries are likely either not to exist, or to be of a very uncertain nature; and where it is not commercially feasible to employ a high-grade class of attendants, or, in fact, any attendant at all other than the operator at the central office.

In large or medium-sized exchanges it is always possible to procure suitable current for charging the storage batteries required in common-battery systems, and it is frequently economical, on account of the considerable quantity of energy that is thus used, to establish a generating plant in connection with the central office for developing the necessary electrical energy. In very small rural places there are frequently no available sources of electrical energy, and the expense of establishing a power plant for the purpose cannot be justified. But even if there is an electric light or railway system in the small town, so that the problem of available current supply does not exist, the establishment of a common-battery system with its storage battery and the necessary charging machinery requires the daily attendance at the central office of some one to watch and care for this battery, and this, on account of the small gross revenue that may be derived from a small telephone system, often involves a serious financial burden.

There is no royal road to a proper decision in the matter, and no sharp line of demarcation may be drawn between the places where common-battery systems are superior to magneto and *vice versâ*. It may be said, however, that in the building of all new telephone plants having over about 500 local subscribers, the common-battery system is undoubtedly superior to the magneto. If the plant is an old one, however, and is to be re-equipped, the continuance of magneto apparatus might be justified for considerably larger exchanges than those having 500 subscribers.

Telephone operating companies who have changed over the equipment of old plants from magneto to common battery have sometimes been led into rather serious difficulty, owing to the fact that their lines, while serving tolerably well for magneto work, were found inadequate to meet the more exacting demands of common-battery work. Again in an old plant the change from magneto to common-battery equipment involves not only the change of switchboards, but also the change of subscribers' instruments that are otherwise good, and this consideration alone often, in our opinion, justifies the replacing of an old magneto board with a new magneto board, even if the exchange is of such size as to demand a small multiple board.

Where the plant to be established is of such size as to leave doubt as to whether a magneto or a common-battery switchboard should be employed, the questions of availability of the proper kind of power for charging the batteries, the proper kind of help for maintaining the batteries and the more elaborate central-office equipment, the demands and previous education of the public to be served, all are factors which must be considered in reaching the decision.

It is not proper to say that anything like all exchanges having fewer than 500 local lines, should be equipped with magneto service. Where all the lines are short, where suitable power is available, and where a good grade of attendants is available—as, for instance, in the case of private telephone exchanges that serve some business establishment or other institution located in one building or a group of buildings—the common-battery system is to be recommended and is largely used, even though it may have but a dozen or so subscribers' lines. It is for such uses, and for use in those regular public-service exchange systems where the conditions are such as to warrant the common-battery system, and yet where the number of lines and the traffic are small enough to be handled by such a small group of operators that any one of them may reach over the entire face of the board, that the simple non-multiple common-battery system finds its proper field of usefulness.

Line Signals. The principles and means by which the subscriber is enabled to call the central-office operator in a common-battery system have been referred to briefly in Chapter III. We will review these at this point and also consider briefly the way in which the line signals are associated with the connective devices in the subscribers' lines.

Direct-Line Lamp. The simplest possible way is to put the line signal directly in the circuit of the line in series with the central-office battery, and so to arrange the jack of the corresponding line that the circuit through the line signal will be open when the operator inserts a plug into that jack. This arrangement is shown in Fig. 307 where the subscriber's station at the left is indicated in the simplest of its forms. It is well to repeat here that in all common-battery manual systems, the subscriber's station equipment, regardless of the arrangement or type of its talking and signaling apparatus, must have these features: First, that the line shall be normally open to direct currents at the subscriber's station; second, that the line shall be closed to direct currents when the subscriber removes his receiver from its hook in making or in answering a call; third, that the line normally, although open to direct currents, shall afford a proper path for alternating or varying currents through the signal receiving device at the sub-station. The subscriber's station arrangement shown in Fig. 307, and those immediately following, is the simplest arrangement that possesses these three necessary features for common-battery service.

Considering the arrangement at the central office, Fig. 307, the two limbs of the line are permanently connected to the tip and sleeve contacts of the jack. These two main contacts of the jack normally engage two anvils so connected that the tip of the jack is ordinarily connected through its anvil to ground, while the sleeve of the jack is normally connected through its anvil to a circuit leading through the line signal—in this case a lamp—and the

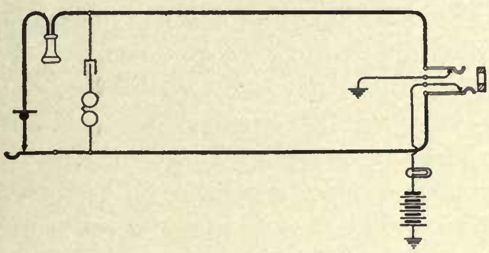


Fig. 307. Direct-Line Lamp

common battery, and thence to ground. The operation is obvious. Normally no current may flow from the common battery through the signal because the line is open at the subscriber's station. The removal of the subscriber's receiver from its hook closes the circuit of the line and allows the current to flow through the lamp, causing it to glow. When the operator inserts the plug into the jack, in response to the call, the circuit through the lamp is cut off at the jack and the lamp goes out.

This arrangement, termed the direct-line lamp arrangement, is largely used in small common-battery telephone systems where the lines are very short, such as those found in factories or other places where the confines of the exchange are those of a building or a group of neighboring buildings. Many of the so-called private-branch exchanges, which will be considered more in detail in a later chapter, employ this direct-line lamp arrangement.

Direct-Line Lamp with Ballast. Obviously, however, this direct-line lamp arrangement is not a good one where the lines vary widely in length and resistance. An incandescent lamp, as is well known, must not be subjected to too great a variation in current. If the current that is just right in amount to bring it to its intended degree of illumination is increased by a comparatively small amount, the life of the lamp will be greatly shortened, and too great an increase will result in the lamp's burning out immediately. On the other hand, a current that is too small will not result in the proper illumination of the lamp, and a current of one-half the proper normal value will just suffice to bring the lamp to a dull red glow. With lines that are not approximately uniform in length and resistance the shorter lines would afford too great a flow of current to the lamps and the longer lines too little, and there is always the danger present, unless means are taken to prevent it, that if a line becomes short-circuited or grounded near the central office, the lamp will be subjected to practically the full battery potential and, therefore, to such a current as will burn it out. One of the very ingenious and, we believe, promising methods that has been proposed to overcome this difficulty is that of the iron-wire ballast, alluded to in Chapter III. This, it will be remembered, consists of an iron-wire resistance enclosed in a vacuum chamber and so proportioned with respect to the flow of current that it will be subjected to a considerable heating effect by the amount of current that is proper to illuminate the lamp. As has already been pointed out, carbon has a negative temperature coefficient, that is, its resistance decreases when heated. Iron, on the other hand, has a positive temperature coefficient, its resistance in-

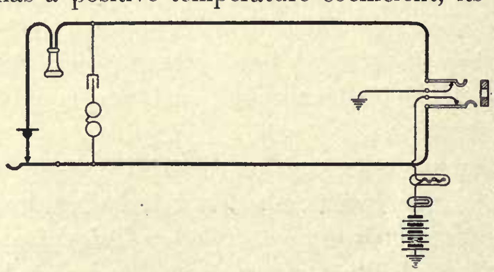


Fig 308 Direct-Line Lamp with Ballast

creasing when heated. When such an iron-wire ballast is put in series with the incandescent lamp forming the line signal, as shown in Fig. 308, it is seen that the resistance of the carbon in the lamp filament and of the iron in the ballast will act in opposite ways when the current increases or decreases. An increase of current will tend to heat up the iron wire of the ballast and, therefore, increase its resistance, and the ballast is so proportioned that it will hold the current that may flow through the lamp within the proper maximum and minimum limits, regardless of the resistance of the line in which the lamp is used. This arrangement has not gone into wide use up to the present time.

Line Lamp with Relay. By far the most common method of associating the line lamp with the line is to employ a relay, of

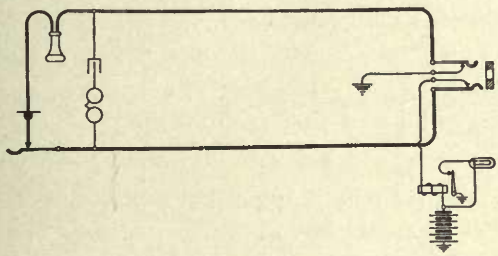


Fig. 309. Line Lamp with Relay

which the actuating coil is in the line circuit, this relay serving to control a local circuit containing the battery and the lamp. This arrangement and the way in which these parts are associated with the jack are clearly indicated in Fig. 309. Here the relay may receive any amount of current, from the smallest which will cause it to pull up its armature, to the largest which will not injure its winding by overheat. Relays may be made which will attract their armatures at a certain minimum current and which will not burn out when energized by currents about ten times as large, and it is thus seen that a very large range of current through the relay winding is permissible, and that, therefore, a very great latitude as to line resistance is secured. On the other hand, it is obvious that the lamp circuit, being entirely local, is of uniform resistance, the lamp always being subjected, in the arrangement shown, to practically the full battery potential, the lamp being selected to operate on that potential.

Pilot Signals. In the circuits of Figs. 307, 308, and 309, but a single line and its associated apparatus is shown, and it may not be altogether clear to the uninitiated how it is that the battery shown in those figures may serve, without interference of any function, a larger number of lines than one. It is to be remembered that this battery is the one which serves not only to operate the line signals, but also to supply talking current to the subscribers and to supply current for the operation of the cord-circuit signals after the cord circuits are connected with the lines.

In Fig. 310 this matter is made clear with respect to the association of this common battery with the lines for operating the line signals, and also another important feature of common-battery work is brought out, viz, the pilot lamp and its association with a group of line lamps. Three subscribers' lines only are shown, but this serves clearly to illustrate the association of any larger number of lines with the common battery. Ignoring at first the pilot relay and the pilot lamp, it will be seen that each of the tip-spring anvils of the jacks is connected to a common wire *1* which is grounded. Each of the sleeve-contact anvils is connected through the coil of the line relay to another common wire *2*, which connects with the live side of the common battery. Obviously, therefore, this arrangement corresponds with that of Fig. 309, since the battery may furnish current to energize any one of the line relays upon the closure of the circuit of the corresponding line. Each of the relay armatures in Fig. 310 is connected to ground.

Here we wish to bring out an important thing about telephone circuit diagrams which is sometimes confusing to the beginner, but which really, when understood, tends to prevent confusion. The showing of a separate ground for each of the line-relay armatures does not mean that literally each one of these armatures is connected by a separate wire to earth, and it is to be understood that the three separate grounds shown in connection with these relay armatures is meant to indicate just such a set of affairs as is shown in connection with the tip-spring anvils of the jacks, all of which are connected to a common wire which, in turn, is grounded. Obviously, the result is the same, but in the case of this particular diagram it is seen that a great deal of crossing of lines is prevented by showing a separate ground at each one of the relay armatures. The same practice is followed in connection with the common battery. Sometimes it is very inconvenient in a complicated diagram to run all of the wires that are supposed to connect with one terminal of the battery across the diagram to represent this connection. It is permissible, therefore, and in fact desirable, that separate battery symbols be shown wherever by so doing the diagram will be simplified, the understanding being, in the absence of other information or of other indications, that the same battery is referred to, just as the same ground is referred to in connection with the relay armatures in the figure under discussion.

Each line lamp in Fig. 310 is shown connected on one hand to its corresponding line relay contact and on the other hand to a common wire which leads through the winding of the pilot relay to the live side of the battery. It is obvious here that whenever any one of the line relays attracts its armature the local circuit containing the corresponding lamp and the common battery will be closed and the lamp illuminated.

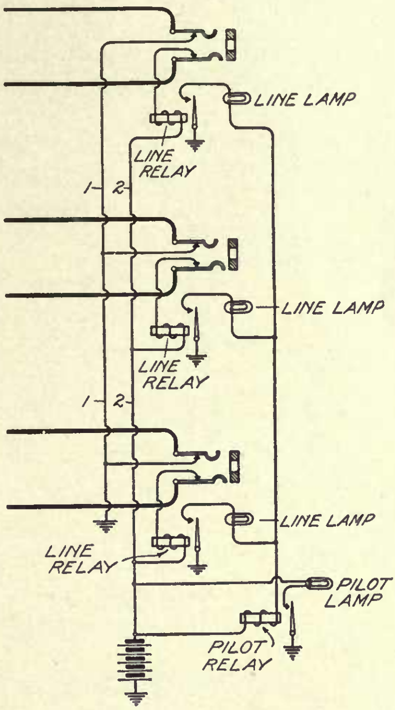


Fig. 310. Pilot-Lamp Operation

Whenever any line relay operates, the current, which is supplied to its lamp, must come through the pilot-relay winding, and if a number of line relays are energized, then the current flow of the corresponding lamps must flow through this relay winding. Therefore, this relay winding must be of low resistance, so that the drop through its winding may not be sufficient to interfere with the proper burning of the lamps, even though a large number of lamps be fed simultaneously through it. The pilot relay must be so sensitive that the current, even through one lamp, will cause it to attract its armature. When it does attract its armature it causes illumination of the pilot lamp in the same way that the line relays cause the illumination of the line lamps.

The pilot lamp, which is commonly associated with a group of line lamps that are placed on any one operator's position of the switchboard, is located in a conspicuous place in the switchboard cabinet and is provided with a larger lens so as to make a more striking signal. As a result, whenever any line lamp on a given position lights, the pilot lamp does also and serves to attract the attention, even of those located in distant portions of the room, to the fact that a call exists on that position of the board, the line lamp itself, which is simultaneously lighted, pointing out the particular line on which the call exists.

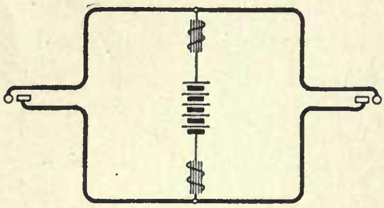


Fig. 311. Battery Supply Through Impedance Coils

Pilot lamps, in effect, perform similar service to the night alarm in magneto boards, but, of course, they are silent and do not attract attention unless within the range of vision of the operator. They are used not only in connection with line lamps, but also in connection with the cord-circuit lamps or signals, as will be pointed out.

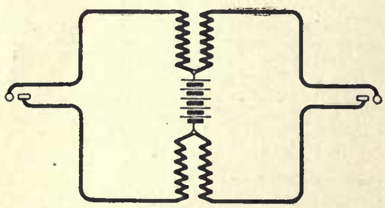


Fig. 312. Battery Supply through Repeating Coils

Cord Circuit. *Battery Supply.* Were it not for the necessity of providing for cord-circuit signals in common-battery switchboards, the common-battery cord circuit would be scarcely more complex than that for magneto working. Stripped of all details, such as signals, ringing and listening keys, and operator's equipment, cord circuits of three different types are shown in Figs. 311, 312, and 313. These merely illustrate the way in which the battery is associated with the cord circuits and through them with the line circuits for supplying current for talking purposes to the subscribers. It is thought that this matter will be clear in view of the discussion of the methods by which current is supplied to the subscribers' transmitters in common-battery systems as discussed in Chapter XIII. While the arrangements in this respect of Figs. 311, 312, and 313 illustrate

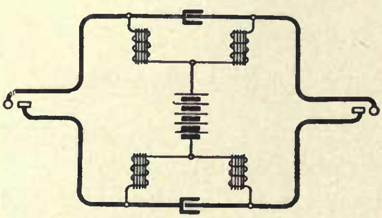


Fig. 313. Battery Supply with Impedance Coils and Condensers

only three of the methods, these three are the ones that have been most widely and successfully used.

Supervisory Signals. The signals that are associated with the cord circuits are termed supervisory signals because of the fact that by their means the operator is enabled to supervise the condition of the lines during times when they are connected for conversation. The operation of these supervisory signals may be best understood by considering the complete circuits of a simple switchboard and must be studied in conjunction with the circuits of the lines as well as those of the cords.

Complete Circuit. Such complete circuits are shown in Fig. 314. The particular arrangement indicated is that employed by the Kel-

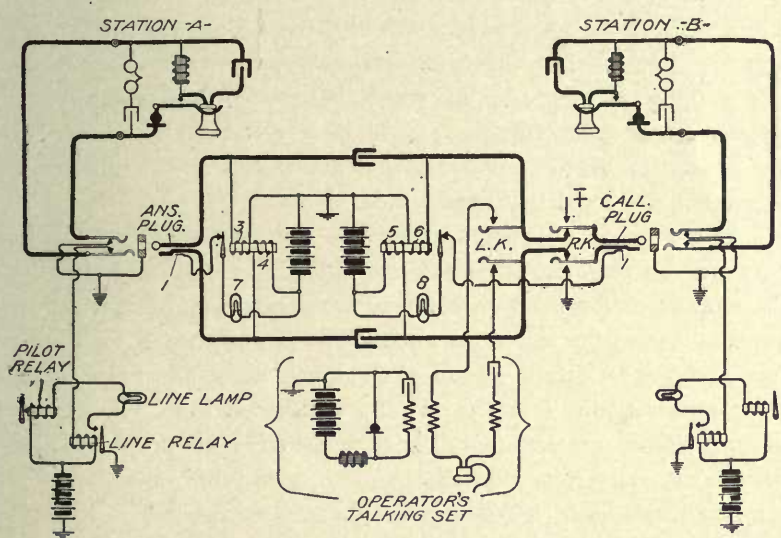


Fig. 314. Simple Common-Battery Switchboard

logg Company, and except for minor details may be considered as typical of other makes also. Two subscribers' lines are shown extending from Station A and Station B, respectively, to the central office. The line wires are shown terminating in jacks in the same manner as indicated in Figs. 307, 308, and 309, and their circuits are normally continued from these jacks to the ground on one side and to the line relay and battery on the other. The jack in this case has three contacts adapted to register with three corresponding contacts in each of the plugs. The thimble of the jack in this case forms no part of the talking circuit and is distinct from the two jack springs which form the line terminals. It and the auxiliary contact *1* in each of the plugs with which it registers, are solely for the purpose of co-operating in the control of the supervisory signals.

The tip and sleeve strands of the cord are continuous from one plug to the other except for the condensers. The two batteries indicated in connection with the cord circuit are separate batteries, a characteristic of the Kellogg system. One of these batteries serves to supply current to the tip and sleeve strand of the cord circuit through the two windings *3* and *4*, respectively, of the supervisory relay connected with the answering side of the cord circuit, while the other battery similarly supplies current through the windings *5* and *6* of the supervisory relay associated with the calling side of the cord circuit. The windings of these relays, therefore, act as impedance coils and the arrangement by which battery current is supplied to the cord circuits and, therefore, to the lines of the connected subscribers, is seen to be the combined impedance coil and condenser arrangement discussed in Chapter XIII.

As soon as a plug is inserted into the jack of a line, the line relay will be removed from the control of the line, and since the two strands of the cord circuit now form continuations of the two line conductors, the supervisory relay will be substituted for the line relay and will be under control of the line. Since all of the current which passes to the line after a plug is inserted must pass through the cord-circuit connection and through the relay windings, and since current can only flow through the line when the subscriber's receiver is off its hook, it follows that the supervisory relays will only be energized after the corresponding plug has been inserted into a jack of the line and after the subscriber has removed his receiver. Unlike the line relays, the supervisory relays open their contacts to break the local circuits of the supervisory lamps *7* and *8* when the relay coils are energized, and to close them when de-energized; but the armatures of the supervisory relays do alone control the circuits of the supervisory lamps. These circuits are normally held open in another place, that is, between the plug contacts *1* and the jack thimbles. It is only, therefore, when a plug is inserted into a jack and when the supervisory relay is de-energized, that the supervisory lamp may be lighted. When a plug is inserted into a jack and when the corresponding supervisory relay is de-energized, the circuit may be traced from ground at the cord-circuit batteries through the left-hand battery, for instance, through lamp *7*, thence through the contacts of the supervisory relay to the contact *1* of the plug, thence through the thimble of the jack to ground. When a plug is inserted into the jack, therefore, the necessary arrangements are completed for the supervisory lamp to be under the control of the subscriber. Under this condition, whenever the subscriber's receiver is on its hook, the circuit of the line will be broken, the supervisory relay will be de-energized, and the supervisory lamp will be lighted. When, on the other hand, the subscriber's receiver is off its hook, the circuit of the line will be complete, the supervisory relay will be energized, and the supervisory lamp will be extinguished.

Salient Features of Supervisory Operation. It will facilitate the student's understanding of the requirements and mode of operation of common-battery supervisory signals in manual systems, whether simple or multiple, if he will firmly fix the following facts in his mind. In order that the supervisory signal may become operative at all, some act must be performed by the operator—this being usually the act of plugging into a jack—and then, until the connection is taken down, the supervisory signal is under the control of the subscriber, and it is displayed only when the subscriber's receiver is placed on its hook.

Cycle of Operations. We may now trace through the complete cycle of operations of the simple common-battery switchboard, the circuits of which are shown in Fig. 314. Assume all apparatus in its normal condition, and then assume that the subscriber at Station A removes his receiver from its hook. This pulls up the line relay and lights the line lamp, the pilot relay also pulling up and lighting the common pilot lamp which is not shown. In response to this call, the operator inserts the answering plug and throws her listening key *L.K.* The operator's talking set is thus bridged across the cord circuit and she is enabled to converse with the calling subscriber. The answering supervisory lamp *7* did not light when the operator inserted the answering plug into the jack, because, although the contacts in the lamp circuit were closed by the plug contact *1* engaging the thimble of the jack, the lamp circuit was held open by the attraction of the supervisory relay armature, the subscriber's receiver being off its hook. Learning that the called-for subscriber is the one at Station B, the operator inserts the calling plug into the jack at that station and presses the ringing key *R.K.*, in order to ring the bell. The act of plugging in, it will be remembered, cuts off the line-signaling apparatus from connection with that line. As the subscriber at Station B was not at his telephone when called and his receiver was, therefore, on its hook, the insertion of the calling plug did not energize the supervisory relay coils *5* and *6*, and, therefore, that relay did not attract its armature. The supervisory lamp *8* was thus lighted, the circuit being from ground through the right-hand cord-circuit battery, lamp *8*, back contacts of the supervisory relay, third strand of the cord to contact *1* of the calling plug, and thence to ground through the thimble of the jack. The lighting of this lamp is continued until the party at Station B responds by removing his receiver from its hook, which completes the line circuit, energizes relay windings *5* and *6*, causes that relay to attract its armature, and thus break the circuit of the lamp *8*. Both supervisory lamps remain out as long as the two subscribers are conversing, but when either one of them hangs up his receiver the corresponding supervisory relay becomes de-energized and the corresponding lamp lights. When both of the lamps become illuminated, the operator knows that both subscribers are through talking and she takes down the connection.

Countless variations have been worked in the arrangement of the line and cord circuits, but the general mode of operation of this particular circuit chosen for illustration is standard and should be thoroughly mastered. The operation of other arrangements will be readily understood from an inspection of the circuits, once the fundamental mode of operation that is common to all of them is well in mind.

Lamps. The incandescent lamps used in connection with line and supervisory signals are specially manufactured, but differ in no sense from the larger lamps employed for general lighting purposes, save in the details of size, form, and method of mounting. Usually these lamps are rated at about one-third candle-power, although they have a somewhat larger candle-power as a rule. They are manufactured to operate on various voltages, the most usual operating pressures being 12, 24, and 48 volts. The 24-volt lamp consumes about one-tenth of an ampere when fully illuminated, the lamp thus consuming about 2.4 watts. The 12- and 48-volt lamps consume about the same amount of energy and corresponding amounts of current.

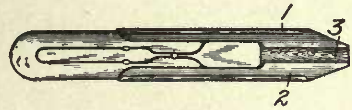


Fig. 315. Switchboard Lamp

Lamp Mounting. The usual form of screw-threaded mounting employed in lamps for commercial lighting was at first applied to the miniature lamps used for switchboard work, but this was found unsatisfactory and these lamps are now practically always provided with two contact strips, one on each side of the glass bulb, these strips forming respectively the terminals for the two ends of the filament within. Such a construction of a common form of lamp is shown in Fig. 315, where these terminals are indicated by the numerals *1* and *2*, *3* being a dry wooden block arranged between the terminals at one end for securing greater rigidity between them.

The method of mounting these lamps is subject to a good deal of variation in detail, but the arrangement is always such that the lamp is slid in between two metallic contacts forming terminals of the circuit in which the lamp is to operate. Such an arrangement

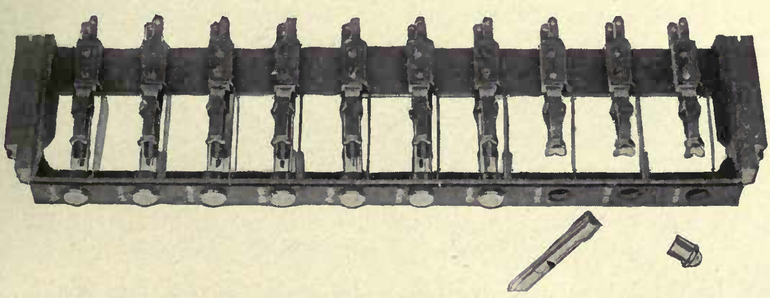


Fig. 316. Line Lamp Mounting

of springs and the co-operating mounting forming a sort of socket for the reception of switchboard lamps is referred to as a *lamp jack.* These are sometimes individually mounted and sometimes mounted in strips in much the same way that jacks are mounted in strips. A strip of lamp jacks as manufactured by the Kellogg Company is shown in Fig. 316. The opalescent lens is adapted to be fitted in front of the lamp after it has been inserted into the jack. Fig. 317 gives an excellent view of an individually-mounted lamp jack with its lamp and lens, this also being of Kellogg manufacture. This figure shows a section of the plug shelf which is bored to receive a lamp. In order to protect the lamps and lenses from breakage, due to the striking of the plugs against them, a metal shield is placed over the lens, as shown in this figure, this being so cut away as to allow sufficient openings for the light to shine through. Sometimes instead of employing lenses in front of the lamps, a flat piece of translucent material is used to cover the openings of the lamp, this being protected by suitable perforated strips of metal. A strip of lamp jacks employing this feature is shown in Fig. 318, this being of Dean manufacture. An advantage of this for certain types of work is that the flat translucent plate in front of the lamp may readily carry designating marks, such as the number of the line or something to indicate the character of the line, which marks may be readily changed as required.

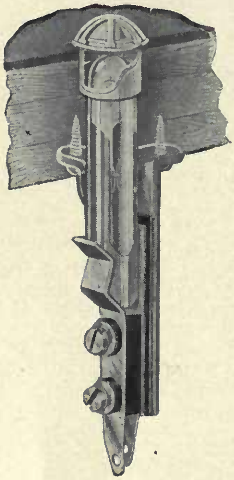


Fig. 317. Supervisory Lamp Mounting

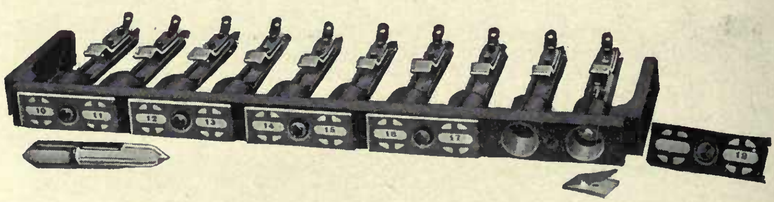


Fig. 318. Line Lamp Mounting

In the types made by some manufacturers the only difference between the pilot lamp and the line lamp is in the size of the lens in front of it, the jack and the lamp itself being the same for each, while others use a larger lamp for the pilot. In Fig. 319 are shown two individual lamp jacks, the one at the top being for supervisory lamps and the one at the bottom being provided with a large lens for serving as a pilot lamp.

Mechanical Signals. As has been stated the so-called mechanical signals are sometimes used in small common-battery switchboards instead of lamps. Where this is done the coil of the signal,

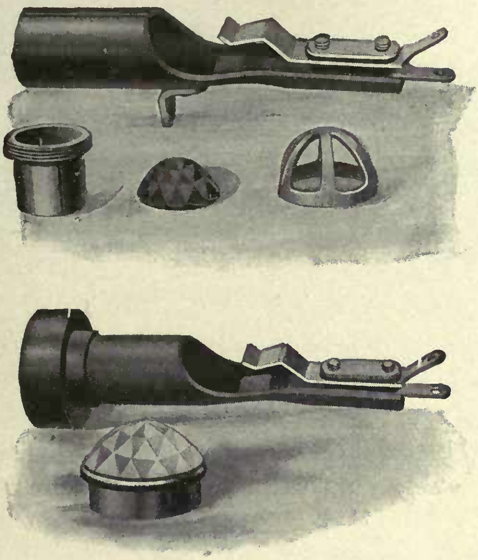


Fig. 319. Individual Lamp Jacks

if it is a line signal, is substituted in the line circuit in place of the relay coil. If the signals are used in connection with cord circuits for supervisory signals, their coils are put in the circuit in place of the supervisory relay coils. (These signals are referred to in Chapter III in connection with Fig. 23.) They are so arranged that the attraction of the armature lifts a target on the end of a lever, and this causes a display of color or form. The release of the armature allows this target to drop back, thus obliterating the display. Such signals, often called *visual signals* and *electromagnet signals,* should be distinguished from the drops considered in connection with magneto switchboards in which the attraction of the armature causes the display of the signal by the falling of a drop, the signal remaining displayed until restored by some other means, the restoration depending in no wise on when the armature is released.

Western Electric. The mechanical signal of the Western Electric Company, shown in Fig. 320, has a target similar to that shown in Fig. 254 but without a latch. It is turned to show a different color by the attraction of the armature and allowed to resume its normal position when the armature is released.

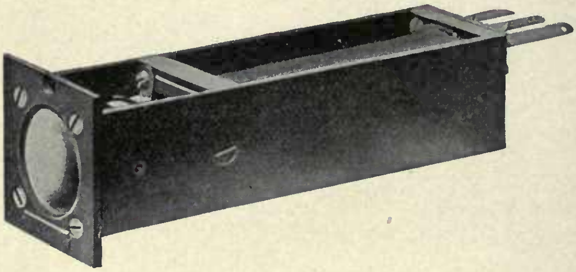


Fig. 320. Mechanical Signal

Kellogg. Fig. 321 gives a good idea of a strip of mechanical signals as manufactured by the Kellogg Company. This is known as the *gridiron* signal on account of the cross-bar striping of its target. The white bars on the target normally lie just behind the cross-bars on the shield in front, but a slight raising of the target—

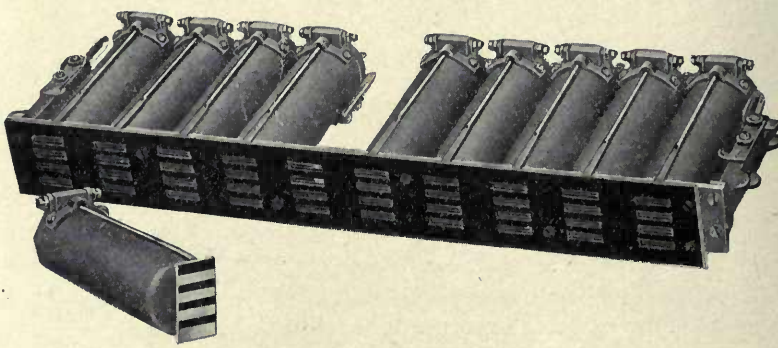


Fig. 321. Strip of Gridiron Signals

about one-eighth of an inch—exposes these white bars to view, opposite the rectangular openings in the front shield.

Monarch. In Fig. 322 is shown the visual signal manufactured by the Monarch Telephone Company.

Relays. The line relays for common-battery switchboards likewise assume a great variety of forms. The well-known type of relay employed in telegraphy would answer the purpose well but for the amount of room that it occupies, as it is sometimes necessary to group a large number of relays in a very small space. Nearly all present-day relays are of the single-coil type, and in nearly all cases the movement of the armature causes the movement of one or more switching springs, which are thus made to engage or disengage their

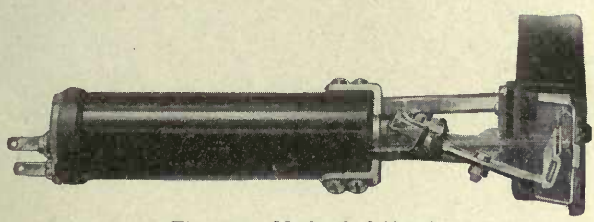


Fig. 322. Mechanical Signal

associated spring or springs. One of the most widely used forms of relays has an L-shaped armature hung across the front of a forwardly projecting arm of iron, on the knife-edge corner of which it rocks as moved by the attraction of the magnet. The general form of this relay was illustrated in Fig. 95. Sometimes this relay is made up in single units and frequently a large number of such single units are mounted on a single mounting plate. This matter will be dealt with more in detail in the discussion of common-battery multiple switchboards. In other cases these relays are built *en bloc,* a rectangular strip of soft iron long enough to afford space for ten relays side by side being bored out with ten cylindrical holes to

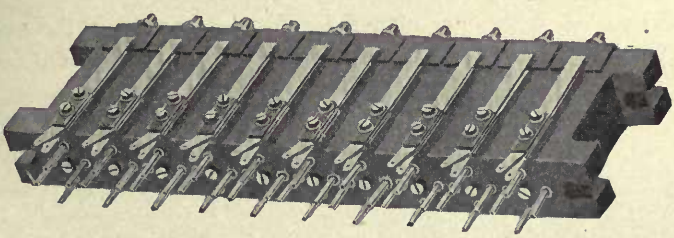


Fig. 323. Strip of Relays

receive the electromagnets. The iron of the block affords a return path for the lines of force. The L-shaped armatures are hung over the front edge of this block, so that their free ends lie opposite the magnet cores within the block. This arrangement as employed by the Kellogg Company is shown in two views in Figs. 323 and 324.

A bank of line relays especially adapted for small common-battery switchboards as made by the Dean Company, is shown in Fig. 325.

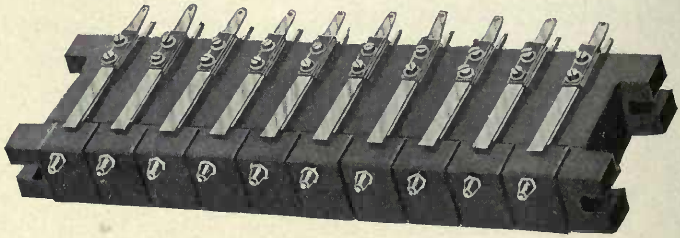


Fig. 324. Strip of Relays

Jacks. The jacks in common-battery switchboards are almost always mounted in groups of ten or twenty, the arrangement being similar to that discussed in connection with lamp strips. Ordinarily

Fig. 325. Bank of Relays

in common-battery work the jack is provided with two inner contacts so as to cut off both sides of the signaling circuit when the operator plugs in. A strip of such jacks is shown in Fig. 326.

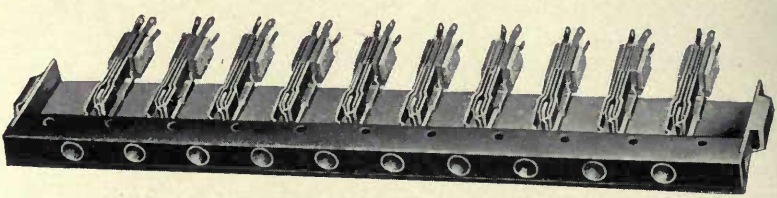


Fig. 326. Strip of Cut-Off Jacks

Ringing and listening keys for simple common-battery switchboards differ in no essential respect from those employed in magneto boards.

Switchboard Assembly. The general assembly of the parts of a simple common-battery switchboard deserves some attention. The form of the switchboard need not differ essentially from that employed in magneto work, but ordinarily the cabinet is somewhat smaller on account of the smaller amount of room required by its lamps and jacks. An excellent idea of the line jacks and lamps, plugs, keys, and supervisory signals may be obtained from Fig. 327,

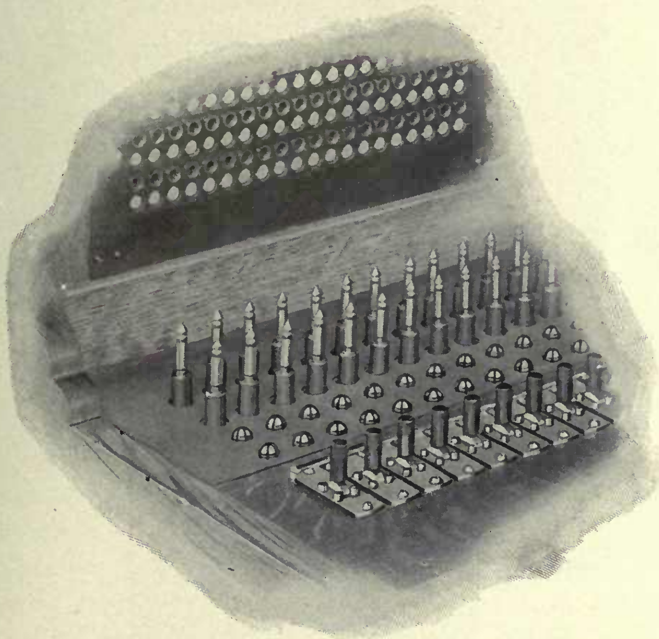


Fig. 327. Details of Lamp, Plug, and Key Mounting

which is a detail view taken from a Kellogg board. In the vertical panel of the board above the plug shelf are arranged the line jacks and the lamps in rows of twenty each, each lamp being immediately beneath its corresponding jack. Such jacks are ordinarily mounted on $\frac{1}{2}$-inch centers both vertically and horizontally, so that a group of one hundred lamps and line jacks will occupy a space only slightly over 10 by 5 inches. Such economy of space is not required in the simple magneto board, because the space might easily be made larger without in any way taxing the reach of the operator. The reason for this comparatively close mounting is a result, not of the requirements of the simple non-multiple common-battery board itself, but of the fact that the jack strips and lamp strips, which are required in very large numbers in multiple boards, have to be mounted extremely close together, and as the same lamp strips and jack strips are often available for simple switchboards, an economy in manufacture is effected by adherence to the same general dimensions.

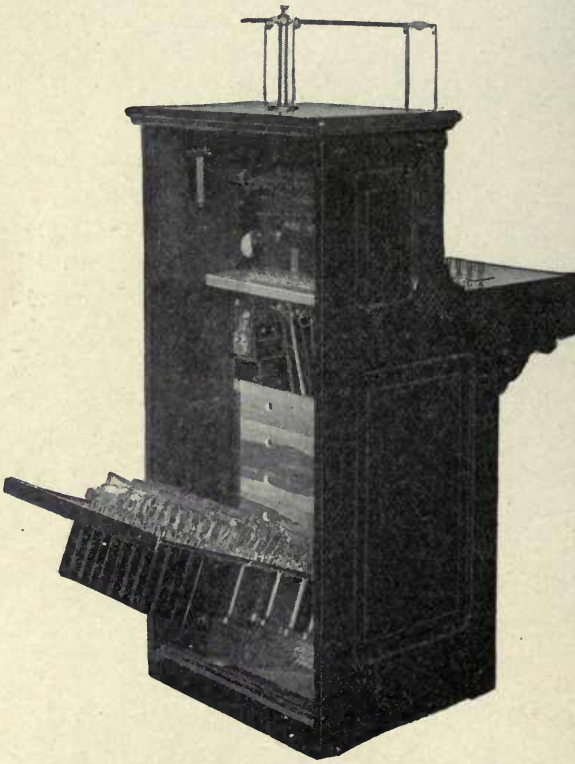


Fig. 328. Simple Common-Battery Switchboard with Removable Relay Panel

A rear view of a common form of switchboard cabinet, known as the *upright type* and manufactured by the Dean Company, is shown in Fig. 328. In this all the relays are mounted on a hinged rack, which, when opened out as indicated, exposes the wiring to view for inspection or repairs. Access to both sides of the relays is thus given to the repairman who may do all his work from the rear of the board without disturbing the operator.

Fig. 329 shows a three-position cabinet of Kellogg manufacture, this being about the limit in size of boards that could properly be called simple. Obviously, where a switchboard cabinet must be made of greater length than this, *i. e.*, than is required to accommodate three operators, it becomes too long for the operators to reach all over it without undue effort or without moving from their

Fig. 329 Three-Position Lamp Board

seats. The so-called *transfer board* and the *multiple board* (to be considered in subsequent chapters), constitute methods of relief from such a condition in larger exchanges.

CHAPTER XXIII

TRANSFER SWITCHBOARD

When the traffic originating in a switchboard becomes so great as to require so many operators that the board must be made so long that any one of the operators cannot reach over its entire face, the simple switchboard does not suffice. Either some form of transfer switchboard or of multiple switchboard must be used. In this chapter the transfer switchboard will be briefly discussed.

The transfer switchboard is so named because its arrangement is such that some of the connections through it are handled by means of two operators, the operator who answers the call transferring it to another operator who completes the connection desired.

Limitations of Simple Switchboard. Conceive a number of simple magneto switchboards, or a number of common-battery switchboards, arranged side by side, their number being so great as to form, by their combination, a board too long for the ordinary cords and plugs to reach between its extremities. On each of these simple switchboards, which we will say are each of the one-position type, there terminates a group of subscribers' lines so great in number, considering the traffic on them, that the efforts of one operator will just about be taxed to properly attend to their calls during the busiest hours of the day. If, now, these subscribers would be sufficiently accommodating to call for no other subscribers than those whose lines terminate on the same switchboard section or on one of the immediately adjacent switchboard sections, all would be well, but subscribers will not be so restricted. They demand universal service; that is, they demand the privilege of having their own lines connected with the line of any other person in the exchange. Obviously, in the arrangement just conceived, any operator may answer any call originating at her own board and complete the connection with the desired subscriber if that subscriber's jack terminates on her own section or on one of the adjacent ones. Beyond that she is powerless unless other means are provided.

Transfer Lines. In the transfer board these other means consist in the provision of groups of local trunk lines or transfer lines extending from each switchboard position to each other non-adjacent switchboard position. When an operator receives a call for some line on a non-adjacent position, having answered this call with her answering plug, she inserts the calling plug into the jack of one of these transfer lines that leads to the proper other section. The operator at that section is notified either verbally or by signal, and she completes the connection between the other end of the transfer line and the line of the called subscriber; the connection between the two subscribers thus being effected through the cords of the two operators in question linked together by the transfer line. Such a transfer line as just described, requiring the connection at each of its ends by one of the plugs of the operator's cord pair, is termed a *jack-ended trunk* or a *jack-ended transfer line* because each of its ends terminates in a jack.

There is another method of accomplishing the same general result by the employment of the so-called *plug-ended trunk* or *plug-ended transfer line*. In this the trunk or transfer line terminates at one end, the answering end, in a jack as before, and the connection

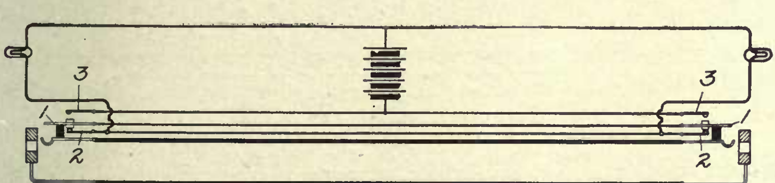


Fig. 330. Jack-Ended Transfer Circuit

is made with it by the answering operator by means of the calling plug of the pair with which she answered the originating call. The other end of this trunk, instead of terminating in a jack, ends in a plug and the second operator involved in the connection, after being notified, picks up this plug and inserts it in the jack of the called subscriber, thus completing the connection without employing one of her regular cord pairs.

Jack-Ended Trunk. In Fig. 330 are shown the circuits of a commonly employed jack-ended trunk for transfer boards. The talking circuit, as usual, is shown in heavy lines and terminates in the tip and sleeve of the transfer jacks at each end. The auxiliary contacts in these jacks and the circuits connecting them are absolutely independent of the talking circuit and are for the purpose of signaling only, the arrangement of the jacks being such that when a plug is inserted, the spring *1* will break from spring *2* and make with spring *3*. Obviously, the insertion of a plug in either of the jacks will establish such connections as to light both lamps, since the engagement of spring *1* with spring *3* in either of the jacks will connect both of the lamps in multiple across the battery, this connection including always the contacts *1* and *2* of the other jack. From this it follows that the insertion of a plug in the other end of the trunk will, by breaking contact between springs *1* and *2*, put out both the lamps. One plug inserted will, therefore, light both lamps; two plugs inserted or two plugs withdrawn will extinguish both lamps.

If an operator located at one end of this trunk answers a call and finds that the called-for subscriber's line terminates within reach of the operator near the other end of this trunk, she will insert a calling plug, corresponding to the answering plug used in answering a call, into the jack of this trunk and thus light the lamp at both its ends. The operator at the other end upon seeing this transfer lamp illuminated inserts one of her answering plugs into the jack, and by means of her listening key ascertains the number

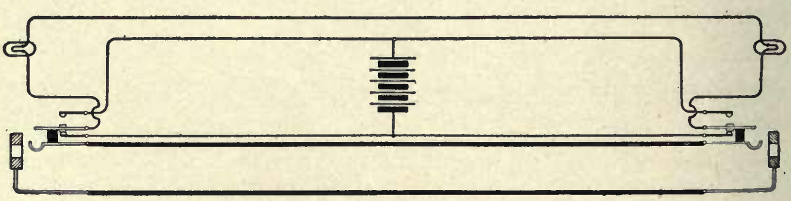


Fig. 331. Jack-Ended Transfer Circuit

of the subscriber desired, and immediately inserts her calling plug into the jack of the subscriber wanted and rings him in the usual manner. The act of this second operator in inserting her answering plug into the jack extinguishes the lamp at her own end and also at the end where the call originated, thus notifying the answering operator that the call has been attended to. As long as the lamps remain lighted, the operators know that there is an unattended connection on that transfer line. Such a transfer line is called a *two-way* line or a *single-track* line, because traffic over it may be in either direction. In Fig. 331 is shown a trunk that operates in a similar way except that the two lamps, instead of being arranged in multiple, are arranged in series.

Plug-Ended Trunk. In Fig. 332 is shown a plug-ended trunk, this particular arrangement of circuits being employed by the Monarch Company in its transfer boards. This is essentially a one-way trunk, and traffic over it can pass only in the direction of the arrow. Traffic in the opposite direction between any two opera-

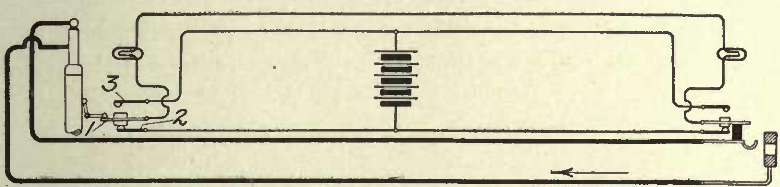


Fig. 332. Jack- and Plug-Ended Transfer Circuit

tors is handled by another trunk or group of trunks similar to this but "pointed" in the other direction. For this reason such a system is referred to as a *double-track* system. The operation of signals is the same in this case as in Fig. 330, except that the switching device at the left-hand end of the trunk instead of being associated with the jack is associated with the plug seat, which is a switch closely associated with the seat of a plug so as to be operated whenever the plug is withdrawn from or replaced in its seat. The operation of this arrangement is as follows: Whenever an operator at the right-hand end of this trunk receives a call for a subscriber whose line terminates within the reach of the operator at the left-hand end of the trunk, she inserts the calling plug of the pair used in answering the calling subscriber into the jack of the trunk, and thus lights both of the trunk lamps. The operator at the other end of the trunk, seeing the trunk lamp lighted, raises the plug from its seat and, having learned the wishes of the calling subscriber, inserts this plug into the jack of the called subscriber without using one of her regular pairs. When she raised the trunk plug from its seat, she permitted the long spring *1* of the plug seat switch to rise, thus extinguishing both lamps and giving the signal to the originating operator that the trunk connection has received attention. On taking down the connection, the withdrawal of the plug from the right hand of the trunk lights both lamps, and the restoring of the trunk plug to its normal seat again extinguishes both lamps.

Plug-Seat Switch. The plug-seat switch is a device that has received a good deal of attention not only for use with transfer systems, but also for use in a great variety of ways with other kinds of manual switching systems. The placing of a plug in its seat or withdrawing it therefrom offers a ready means of accomplishing some switching or signaling operation automatically. The plug-seat switch has, however, in spite of its possibilities, never come into wide use, and so far as we are aware the Monarch Telephone Manufacturing Company is the only company of prominence which incorporates it in its regular output. The Monarch plug-switch mechan-

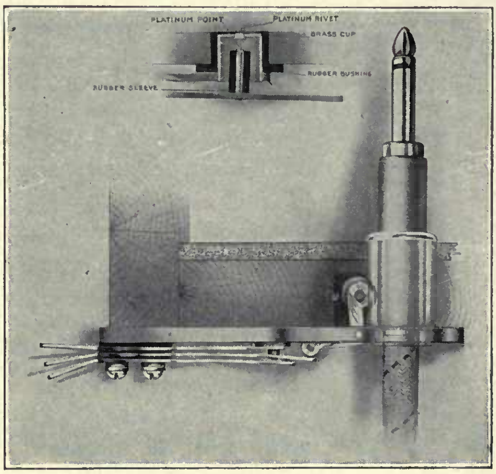


Fig. 333. Plug-Seat Switch

ism is shown in Fig. 333, and its operation is obvious. It may be stated at this point that one of the reasons why the plug-seat switch has not been more widely adopted for use, is the difficulty that has been experienced due to lint from the switchboard cords collecting on or about the contact points. In the construction given in the detailed cut, upper part, Fig. 333, is shown the means adopted by the Monarch Company for obviating this difficulty. The contact points are carried in the upper portion of an inverted cup mounted on the under side of the switchboard shelf, and are thus protected, in large measure, from the damaging influence of dust and lint.

Methods of Handling Transfers. One way of giving the number of the called subscriber to the second operator in a transfer system is to have that operator listen in on the circuit after it is continued to her position and receive the number either from the first operator or from the subscriber. Receiving it from the first operator has the disadvantage of compelling the first operator to wait on the circuit until the second operator responds; receiving it from the subscriber has the disadvantage of sometimes being annoying to him. This, however, is to be preferred to the loss of time on the part of the originating operator that is entailed by the first method. A better way than either of these is to provide between the various operators working in a transfer system, a so-called *order-wire* system. An

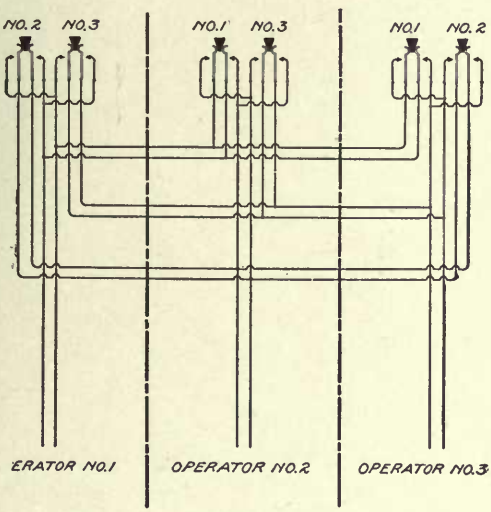


Fig. 334. Order-Wire Arrangement

order wire, as ordinarily arranged, is a circuit terminating at one end permanently in the head receiver of an operator, and terminating at the other end in a push button which, when depressed, will connect the telephone set of the operator at that end with the order wire. The operator at the push-button end of the order wire may, therefore, at will, communicate with the other operator in spite of anything that the other operator may do. An order-wire system suitable for transfer switchboards consists in an order wire leading from each operator's receiver to a push button at each of the other operator's positions, so that every operator has it within her power to depress a key or button and establish communication with a corresponding operator. When, therefore, an operator in a transfer system answers a call that must be completed through a transfer circuit, she establishes connection with that transfer circuit and then informs the operator at the other end of that circuit by order wire of the number of the trunk and the number of the subscriber with which that trunk is to be connected. Fig. 334 shows a system of order-wire buttons by means of which each operator may connect her telephone set with that of every other operator in the room, the number in this case being confined to three. Assuming that each pair of wires leading from the lower portion of this figure terminates respectively in the operator's talking apparatus of the three respective operators, then it is obvious that operator No. 1, by depressing button No. 2, will connect her telephone set with that of operator No. 2; likewise that any operator may communicate with any other operator by depressing the key bearing the corresponding number.

Limitations of Transfer System. It may be stated that the transfer system at present has a limited place in the art of telephony. The multiple switchboard has outstripped it in the race for popular approval and has demonstrated its superiority in practically all large manual exchange work This is not because of lack of effort on the part of telephone engineers to make the transfer system a success in a broad way. A great variety of different schemes, all embodying the fundamental idea of having one operator answer the call and another operator complete it through a trunk line, have been tried. In San Francisco, the Sabin-Hampton system was in fairly successful service and served many thousands of lines for a number of years. It was, however, afterwards replaced by modern multiple switchboards.

Examples of Obsolete Systems. The Sabin-Hampton system was unique in many respects and involved three operators in each connection. It was one of the very first systems which employed automatic signaling throughout and did away with the subscribers' generators. It did not, however, dispense with the subscribers' local batteries.

Another large transfer system, used for years in an exchange serving at a time as many as 5,000, was employed at Grand Rapids, Michigan This was later replaced by an automatic switchboard.

Field of Usefulness. The real field of utility for the transfer system today is to provide for the growth of simple switchboards that have extended beyond their originally intended limits. By the adding of additional sections to the simple switchboard and the establishment of a comparatively cheap transfer system, the simple boards

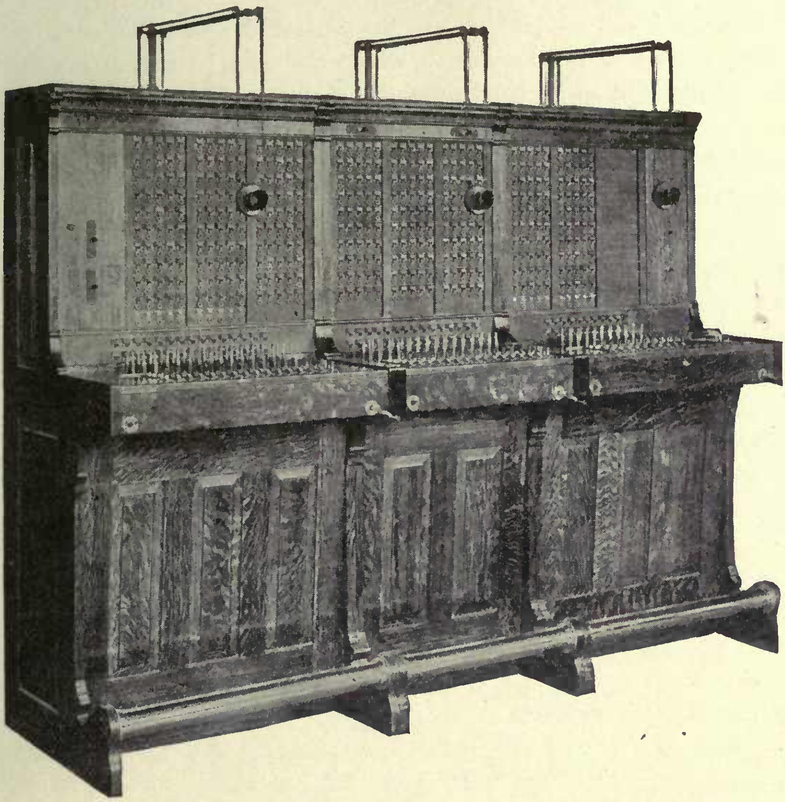


Fig. 335. Three-Position Transfer Switchboard

may be made to do continued service without wasting the investment in them by discarding them and establishing a completely new system. However, switchboards are sometimes manufactured in which the transfer system is included as a part of the original equipment. In Fig. 335 is shown a three-position transfer switchboard, manufactured by the Monarch Telephone Company. At first glance the switchboard appears to be exactly like those described in Chapter XXI, but on close observation, the transfer jacks and signals may be seen in the first and third positions, just below the line jacks and signals. There is no transfer equipment in the second position of this switchboard because the operator at that position is able to reach the jacks of all the lines and, therefore, is able to complete all calls originating on her position without the use of any transfer equipment. Referring to Fig. 301, which illustrates a two-position simple switchboard, it may readily be seen that if the demands for telephone service in the locality in which this switchboard is installed should increase so as to require the addition of more switchboard positions, this switchboard could readily be converted to a transfer switchboard by placing the necessary transfer jacks and signals in the vacant space between the line jacks and clearing-out drops.

CHAPTER XXIV

PRINCIPLES OF THE MULTIPLE SWITCHBOARD

Field of Utility. The multiple switchboard, unlike the transfer board, provides means for each operator to complete, without assistance, a connection with any subscriber's line terminating in the switchboard no matter how great the number of lines may be. It is used only where the simple switchboard will not suffice; that is, where the number of lines and the consequent traffic is so great as to require so many operators and, therefore, so great a length of board as to make it impossible for any one operator to reach all over the face of the board without moving from her position.

The Multiple Feature. The fundamental feature of the multiple switchboard is the placing of a jack for every line served by the switchboard within the reach of every operator. This idea underlying the multiple switchboard may be best grasped by merely considering the mechanical arrangement and grouping of parts without regard to their details of operation. The idea is sometimes elusive, but it is really very simple. If the student at the outset will not be frightened by the very large number of parts that are sometimes involved in multiple switchboards, and by the great complexity which is apparent in the wiring and in the action of these parts; and will remember that this apparent complexity results from the great number of repetitions of the same comparatively simple group of apparatus and circuits, much will be done toward a mastery of the subject.

The multiple switchboard is divided into sections, each section being about the width and height that will permit an ordinary operator to reach conveniently all over its face. The usual width of a section brought about by this limitation is from five and one-half to six feet. Such a section affords room for three operators to sit side by side before it. Now each line, instead of having a single jack as in the simple switchboard, is provided with a number of jacks and one of these is placed on each of the sections, so that each one of the operators may have within her reach a jack for each line. It is from the fact that each line has a multiplicity of jacks, that the term multiple switchboard arises.

Number of Sections. Since there is a jack for each line on each section of the switchboard, it follows that on each section there are as many jacks as there are lines; that is, if the board were serving 5,000 lines there would be 5,000 jacks. Let us see now what it is that determines the number of sections in a multiple switchboard. In the final analysis, it is the amount of traffic that arises in the busiest period of the day. Assume that in a particular office serving 5,000 lines, the subscribers call at such a very low rate that even at the busiest time of the day only enough calls are made to keep, say, three operators busy. In this case there would be no need for the multiple switchboard, for a single section would suffice. The three operators seated before that section would be able to answer and complete the connections for all of the calls that arose. But subscribers do not call at this exceedingly low rate. A great many more calls would arise on 5,000 lines during the busiest hour than could be handled by three operators and, therefore, a great many more operators would be required. Space has to be provided for these operators to work in, and as each section accommodates three operators the total number of sections must be at least equal to the total number of required operators divided by three.

Let us assume, for instance, that each operator can handle 200 calls during the busy hour. Assume further that during the busy hour the average number of calls made by each subscriber is two. One hundred subscribers would, therefore, originate 200 calls within this busy hour and this would be just sufficient to keep one operator busy. Since one operator can handle only the calls of one hundred subscribers during the busy hour, it follows that as many operators must be employed as there are hundreds of subscribers whose lines are served in a switchboard, and this means that in an exchange of 5,000 subscribers, 50 operators' positions would be required, or $16\frac{2}{3}$ sections. Each of these sections would be equipped with the full 5,000 jacks, so that each operator could have a connection terminal for each line.

The Multiple. These groups of 5,000 jacks, repeated on each of the sections are termed multiple jacks, and the entire equipment of these multiple jacks and their wiring is referred to as the multiple. It will be shown presently that the multiple jacks are only used for enabling the operator to connect with the called subscriber. In other words these jacks are for the purpose of enabling each operator to have within her reach any line that may be called for regardless of what line originates the call. We will now consider what arrangements are provided for enabling the operator to receive the signal indicating a call and what provisions are made for her to answer the call in response to such a signal.

Line Signals. Obviously it is not necessary to have the line signals repeated on each section of the board as are the multiple jacks. If a line has one definite place on the switchboard where its signal may be received and its call may be answered, that suffices. Each line, therefore, in addition to having its multiple jacks distributed one on each section of the switchboard, has a line signal and an individual jack immediately associated with it, located on one only of the sections. This signal usually is in the form of a lamp and is termed the line signal, and this jack is termed the answering jack since it is by means of it that the operator always answers a call in response to the line signal.

Distribution of Line Signals. It is evident that it would not do to have all of these line signals and answering jacks located at one section of the board for then they would not be available to all of the operators. They are, therefore, distributed along the board in such a way that one group of them will be available to one operator, another group to another operator, and so on; the number of answering jacks and signals in any one group being so proportioned with respect to the number of calls that come in over them during the busy hour that it will afford just about enough calls to keep the operator at that position busy.

We may summarize these conditions with respect to the jack and line-signal equipment of the multiple switchboard by saying that each line has a multiple jack on each section of the board and in addition to this has on one section of the board an answering jack and a line signal. These answering jacks and line signals are distributed in groups along the face of the board so that each operator will receive her proper quota of the originating calls which she will answer and, by virtue of the multiple jack, be able to complete the connections with the desired subscribers without moving from her position.

Cord Circuits. Each operator is also provided with a number of pairs of cords and plugs with proper supervisory or clearing-out signals and ringing and listening keys, the arrangement in this respect being similar to that already described in connection with the simple switchboard.

Guarding against Double Connections. From what has been said it is seen that a call originating on a given line may be answered at one place only, but an outgoing connection with that line may be made at any position. This fact that a line may be connected with when called for at any one of the sections of the switchboard makes necessary the provision that two or more connections will not be made with the same line at the same time. For instance, if a call came in over a line whose signal was located on the first position of the switchboard for a connection with line No. 1,000, the operator at the first position would connect this calling line with No. 1,000 through the multiple jack on the first section of the switchboard Assume now that some line, whose signal was located on the 39th position of the switchboard, should call also for line No. 1,000 while that line was still connected with the first calling subscriber. Obviously confusion would result if the operator at the 39th position, not knowing that line No. 1,000 was already busy, should connect this second line with it, thereby leaving both of the calling subscribers connected with line No. 1,000, and as a result all of these three subscribers connected together.

The provisions for suitable means for preventing the making of a connection with a line that is already switched at some other section of the switchboard, has offered one of the most fertile fields for invention in the whole telephone art. The ways that have been proposed for accomplishing this are legion. Fortunately common practice has settled on one general plan of action and that is to so arrange the circuits that whenever a line is switched at one section, such an electrical condition will be established on the forward contacts of all of its multiple jacks that any operator at any other section in attempting to make a connection with that line will be notified of the fact that it is already switched by an audible signal, which she will receive in her head receiver. On the other hand the arrangement is such that when a line is not busy, *i. e.*, it is not switched at any of the positions of the switchboard, the operator on attempting to make a connection with such a line will receive no such guarding signal and will, therefore, proceed with the connection.

We may liken a line in a multiple switchboard to a lane having a number of gates giving access to it. One of these gates—the answering jack—is for the exclusive use of the proprietor of that lane. All of the other gates to the lane—the multiple jacks—are for affording means for the public to enter. But whenever any person enters one of these gates, a signal is automatically put up at all of the other gates forbidding any other person to enter the lane as long as the first person is still within.

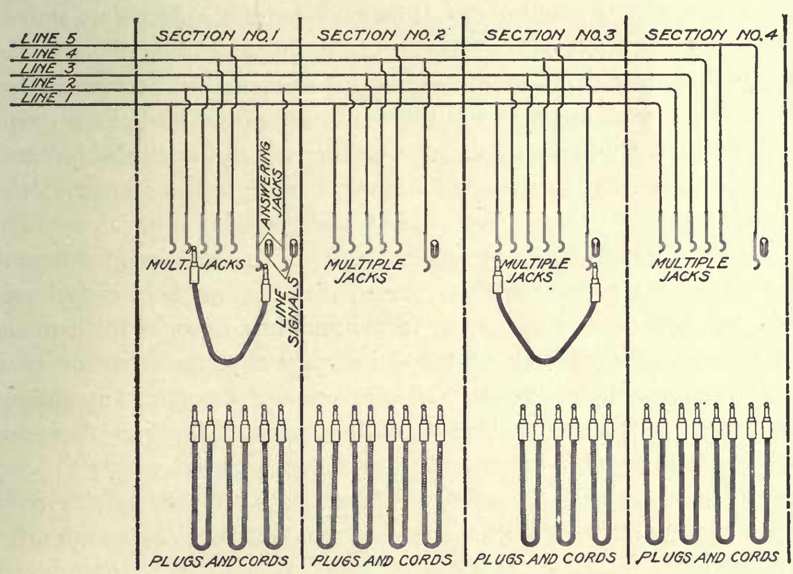


Fig. 336. Principle of Multiple Switchboard

Diagram Showing Multiple Board Principle. For those to whom the foregoing description of the multiple board is not altogether clear, the diagram of Fig. 336 may offer some assistance. Five subscribers' lines are shown running through four sections of a switchboard. Each of these lines is provided with a multiple jack on each section of the board. Each line is also provided with an answering jack and a line signal on one of the sections of the board. Thus the answering jacks and the line signals of lines *1* and *2* are shown in Section I, that of line *4* is shown in Section II, that of line *3* in Section III, and that of line *5* in Section IV. At Section I, line *1* is shown in the condition of having made a call and having had this call answered by the operator inserting one of her plugs into its answering jack. In response to the instructions given by the subscriber, the operator has inserted the other plug of this same pair in the multiple jack of line *2*, thus connecting these two lines for conversation. At Section III, line *3* is shown as having made a call, and the operator as having answered by inserting one of her plugs into the answering jack. It happens that the subscriber on line *3* requests a connection with line *1*, and the condition at Section III is that where the operator is about to apply the tip of the calling plug to the jack of line *1* to ascertain whether or not that line is busy. As before stated, when the contact is made between the tip of the calling plug and the forward contact of the multiple jack, the operator will receive a click in the ear (by means that will be more fully discussed in later chapters), this click indicating to her that line *1* is not available for connection because it is already switched at some other section of the switchboard.

Busy Test. The busy signal, by which an operator in attempting to make a connection is informed that the line is already busy, has assumed a great variety of forms and has brought forth many inventions. It has been proposed by some that the insertion of a plug into any one of the jacks of a line would automatically close a little door in front of each of the other jacks of the line, therefore making it impossible for any other operator to insert a plug as long as the line is in use. It has been proposed by others to ring bells or to operate buzzers whenever the attempt was made by an operator to plug into a line that was already in use. Still others have proposed to so arrange the circuits that the operator would get an electric shock whenever she attempted to plug into a busy line. The scheme that has met with universal adoption, however, is that the operator shall, when the tip of her calling plug touches the forward contact of the jack of a line that is already switched, receive a click in her telephone which will forbid her to insert the plug. The absence of this click, or silence in her telephone, informs her that she may safely make the connection.

Principle. The means by which the operator receives or fails to receive this click, according to whether the line is busy or idle, vary widely, but so far as the writers are aware they all have one fundamental feature in common. The tip of the calling plug and the test contact of all of the multiple jacks of an idle line must be absolutely at the same potential before the test, so that no current will flow through the test circuit when the test is actually made. The test thimbles of all the jacks of a busy line must be at a different potential from the tip of the test plug so that a current will flow and a click result when the test is made.

Potential of Test Thimbles. It has been found an easy matter to so arrange the contacts in the jacks of a multiple switchboard that whenever the line is idle the test thimbles of that line will be a certain potential, the same as that of all the unused calling plug tips. It has also been easy to so arrange these contacts that the insertion of a plug into any one of the jacks will, by virtue of the contacts established, change the potential of all the test thimbles of that line so that they will be at a different potential from that of the tips of the calling plugs. It has not been so easy, however, to provide that these conditions shall exist under all conditions of practice. A great many busy tests that looked well on paper have been found faulty in practice. As is always the case in such instances, this has been true because the people who considered the scheme on paper did not foresee all of the conditions that would arise in practice. Many busy-test systems will operate properly while everything connected with the switchboard and the lines served by it remains in proper order. But no such condition as this can be depended on in practice. Switchboards, no matter how perfectly made and no matter with how great care they may be installed and maintained, will get out of order. Telephone lines will become grounded or short-circuited or crossed or opened. Such conditions, in a faulty busy-test system, may result in a line that is really idle presenting a busy test, and thus barring the subscriber on that line from receiving calls from other lines just as completely as if his line were broken. On the other hand, faulty conditions either in the switchboard or in the line may make a line that is really busy, test idle, and thus result in the confusion of having two or more subscribers connected to the same line at the same time.

Busy-Test Faults. To show how elusive some of the faults of a busy test may be, when considered on paper, it has come within the observation of the writers that a new busy-test system was thought well enough of by a group of experienced engineers to warrant its installation in a group of very large multiple switchboards, the cost of which amounted to hundreds of thousands of dollars, and yet when so installed it developed that a single short-circuited cord in a position would make the test inoperative on all the cords of that position—obviously an intolerable condition. Luckily the remedy was simple and easily applied.

In a well-designed busy-test system there should be complete silence when the test is made of an idle line, and always a well-defined click when the test is made of a busy line. The test on busy lines should result in a uniform click regardless of length of lines or the condition of the apparatus. It does not suffice to have a little click for an idle line and a big click for a busy line, as practice has shown that this results in frequent errors on the part of the operators.

Good operating requires that the tip of the calling plug be tapped against the test thimble several times in order to make sure of the state of the called line.

In some multiple switchboards the arrangement has been such that the jacks of a line would test busy as soon as the subscriber on that line removed his receiver from its hook to make a call, as well as while any plug was in any jack of that line. The advocates of this added feature, in connection with the busy test, have claimed that the receiver, when removed from its hook in making a call, should make the line test busy and that a line should not be connected with when the subscriber's receiver was off its hook any more than it should be when it was already connected with at some other section of the switchboard. While it is true that a line may be properly termed busy when the subscriber has removed his receiver in order to make a call, it is not true that there is any real necessity for guarding against a connection with it while he is waiting for the operator to answer. Leaving the line unguarded for this brief period may result in the subscriber, who intended to make the call, having to defer his call until he has conversed with the party who is trying to reach him. This cannot be said to be a detriment to the service, however, since the second party gets the connection he desires much sooner than he otherwise would, and the first party may still make his first intended call as soon as he has disposed of the party who reached him while he was waiting for his own operator to answer. It may be said, therefore, in connection with this matter of making the line test busy as soon as a subscriber has removed his receiver from the hook, that it is not considered an essential, and in case of those switchboard systems which naturally work out that way it is not considered a disadvantage.

Field of Each Operator. It was stated earlier in this chapter that as each section accommodated three operators, the total number of sections in a switchboard will be at least one-third the total number of required operators. This thought needs further development, for to stop at that statement is to arrive somewhat short of the truth. In order to do this it is necessary to consider the field in the multiple, reached by each operator. The section is of such size, or should be, that an operator seated in the center position of it may, without undue effort, reach all over the multiple. But the operator at the right-hand position cannot reach the extreme left portion of the multiple of that section, nor can the operator at the left reach the extreme right. How then may each operator reach a jack for every line? Remembering that the multiple jacks are arranged exactly the same in each section, each jack always occupying the same relative position, it is easy to see that while the operator at a right-hand position of a section cannot reach the left-hand third of the multiple in her own section, she may reach the left-hand third of the multiple in the section at her right, and this, together with the center and right-hand thirds of her own section, represents the entire number of lines. So it is with the left-hand operator at any section, she reaches two-thirds of all the lines in the multiple of her own section and one-third in that of the section at her left.

End Positions. This makes it necessary to inquire about the operators at the end positions of the entire board. To provide for these the multiple is extended one-third of a section beyond them, so as to supply at the ends of the switchboard jacks for those lines which the end operators cannot reach on their own sections. Sometimes instead of adding these end sections to the multiple for the end operators, the same result is accomplished by using only the full and regular sections of the multiple, and leaving the end positions without operators' equipment, as well as without answering jacks. line signals, and cords and plugs, so that in reality the end operator is at the middle position of the end section. This, in our opinion, is the better practice, since it leaves the sections standard, and makes it easier to extend the switchboard in length, as it grows, by the mere addition of new sections without disturbing any of the old multiple.

Influence of Traffic. We wish again to emphasize the fact that it is the traffic during the busiest time of day and not the number of lines that determine the size of a multiple switchboard so far as its length is concerned. The number of lines determines the size of the multiple in any one section, but it is the amount of traffic, the number of calls that are made in the busiest period, that determines the number of operators required, and thus the number of positions. Had this now very obvious fact been more fully realized in the past, some companies would be operating at less expense, and some manufacturers would have sold less expensive switchboards.

The whole question as to the number of positions boils down to how many answering jacks and line signals may be placed at each operator's position without overburdening the operator with incoming traffic at the busy time of day. Obviously, some lines will call more frequently than others, and hence the proper number of answering jacks at the different positions will vary. Obviously, also, due to changes in the personnel of the subscribers, the rates of calling of different groups of lines will change from time to time, and this may necessitate a regrouping of the line signals and answering jacks on the positions; and changes in the personnel of the operators or in their skill also demand such regrouping.

Intermediate Frame. The intermediate distributing frame is provided for this purpose, and will be more fully discussed in subsequent chapters. Suffice it to say here that the intermediate distributing frame permits the answering jacks and line signals to be shifted about among the operators' positions, so that each position will have just enough originating traffic to keep each of the operators economically busy during the busiest time of the day.

CHAPTER XXV

THE MAGNETO MULTIPLE SWITCHBOARD

Field of Utility. The principles of the multiple switchboard set forth in the last chapter were all developed long before the common-battery system came into existence, and consequently all of the first multiple switchboards were of the magneto type. Although once very widely used, the magneto multiple switchboard has almost passed out of existence, since it has become almost universal practice to equip exchanges large enough to employ multiple boards with common-battery systems. Nevertheless there is a field for magneto multiple switchboards, and in this field it has recently been coming into increasing favor. In those towns equipped with magneto systems employing simple switchboards or transfer switchboards, and which require new switchboards by virtue of having outgrown or worn out their old ones, the magneto multiple switchboard is frequently found to best fit the requirements of economy and good practice. The reason for this is that by its use the magneto telephones already in service may be continued, no change being required outside of the central office. Furthermore, with the magneto multiple switchboard no provision need be made for a power plant, which, in towns of small size, is often an important consideration. Again, many companies operate over a considerable area, involving a collection of towns and hamlets. It may be that all of these towns except one are clearly of a size to demand magneto equipment and that magneto equipment is the standard throughout the entire territory of the company. If, however, one of the towns, by virtue of growth, demands a multiple switchboard, this condition affords an additional argument for the employment of the magneto multiple switchboard, since the same standards of equipment and construction may be maintained throughout the entire territory of the operating company, a manifest advantage. On the other hand, it may be said that the magneto multiple switchboard has no proper place in modern exchanges of considerable size—say, having upward of one thousand subscribers—at least under conditions found in the United States.

Notwithstanding the obsolescence of the magneto multiple switchboard for large exchanges, a brief discussion of some of the early magneto multiple switchboards, and particularly of one of the large ones, is worth while, in that a consideration of the defects of those early efforts will give one a better understanding and appreciation of the modern multiple switchboard, and particularly of the modern multiple common-battery switchboard, the most highly organized of all the manual switching systems. Brief reference will, therefore, be made to the so-called series multiple switchboard, and then to the branch terminal multiple switchboard, which latter was the highest type of switchboard development at the time of the advent of common-battery working.

Series-Multiple Board. In Fig. 337 are shown the circuits of a series magneto multiple switchboard as developed by the engineers of the Western Electric Company during the eighties. As is usual, two subscribers' lines and a single cord circuit are shown. One side of each line passes directly from the subscriber's station to one side of the drop, and also branches off to the sleeve contact of each of the jacks. The other side of the line passes first to the tip spring of the first jack, thence to the anvil of that jack and to the tip spring of the next jack, and so on in series through all of the jacks belonging in that line to the other terminal of the drop coil. Normally, therefore, the drop is connected across the line ready to be responsive to the signal sent from the subscriber's generator. The cord circuit is of the two-conductor type, the plugs being provided with tip and sleeve contacts, the tips being connected by one of the flexible conductors through the proper ringing and listening key springs, and the sleeve being likewise connected through the other flexible conductor and the other springs of the ringing and listening keys. It is obvious that when any plug is inserted into a jack, the circuit of the line will be continued to the cord circuit and at the same time the line drop will be cut out of the circuit, because of the lifting of the tip spring of the jack from its anvil. Permanently connected between the sleeve side of the cord circuit and ground is a retardation coil *1* and a battery. Another retardation coil *2* is connected between the ground and a point on the operator's telephone circuit between the operator's head receiver and the secondary of her induction coil. These two retardation coils have to do with the busy test, the action of which is as follows: normally, or when a line is not switched at the central office, the test thimbles will all be at substantially ground potential, *i. e.*, they are supposed to be. The point on the operator's receiver circuit which is grounded through the retardation coil *2* will also be of ground potential because of that connection to ground. In order to test, the operator always has to throw her

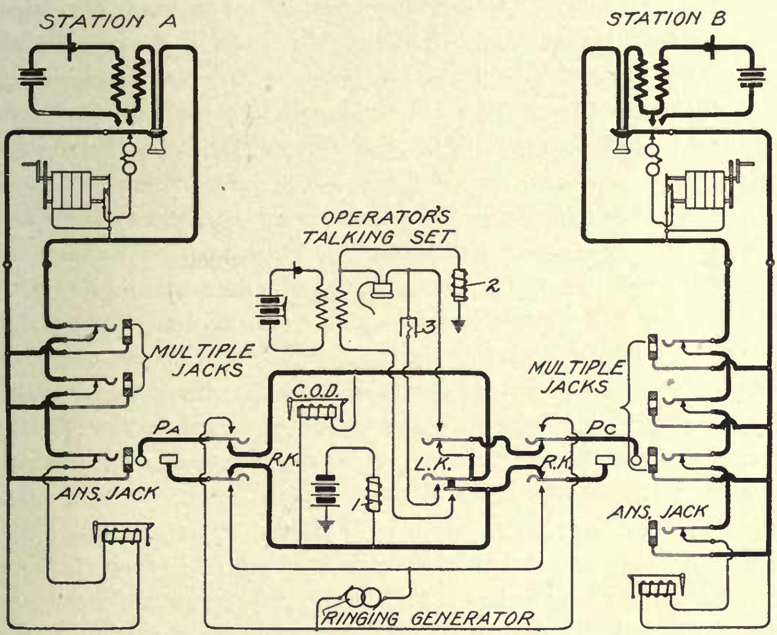


Fig. 337. Series Magneto Multiple Switchboard

listening key *L.K.* into the listening position. She also has to touch the tip of the calling plug P_c to a sleeve or jack of the line that is being tested. If, therefore, a test is made of an idle or non-busy line, the touching of the tip of the calling plug with the test thimble of that line will result in no flow of current through the operator's receiver, because there will be no difference of potential anywhere in the test circuit, which test circuit may be traced from the test thimble of the line under test to the tip of the calling plug, thence through the tip strand of the cord to the listening key, thence to the outer anvil of the listening key on that side, through the operator's receiver to ground through the impedance coil *2*. If, however, the line had already been switched at some other section by the insertion of either a calling or answering plug, all of the test thimbles of that line would have been raised to a potential above that of the ground, by virtue of the battery connected with the sleeve side of the cord circuit through the retardation coil *1*. If the operator had made a test of such a line, the tip of her testing plug would have found the thimble raised to the potential of the battery and, therefore, a flow of current would occur which would give her the busy click. The complete test circuit thus formed in testing a busy line would be from the ungrounded pole of the battery through the impedance coil *1* associated with the cord that was already in connection with the line, thence to the sleeve strand of that cord to the sleeve of the jack at which the line was already switched, thence through that portion of the line circuit to which all of the sleeve contacts were connected, and therefore to the sleeve or test thimble of the jack at which the test is made, thence through the tip of the calling plug employed in making the test through the tip side of that cord circuit to the outer listening key contact of the operator making the test, and thence to ground through the operator's receiver and the impedance coil *2*. The resultant click would be an indication to the operator that the line was already in use and that, therefore, she must not make the connection.

The condenser *3* is associated with the operator's talking set and with the extra spring in the listening key *L.K.* in such a manner that when the listening key is thrown, the tip strand of the cord circuit is divided and the condenser included between them. This is for the purpose of preventing any potentials, which might exist on the line with which the answering plug P_a was connected, from affecting the busy-test conditions.

Operation. The operation of the system aside from the busy-test feature is just like that described in connection with the simple magneto switchboard. Assuming that the subscriber at Station *A* makes the call, he turns his hand generator, which throws the drop on his line at the central office. The operator, seeing the signal, inserts the answering plug of one of her idle pairs of cords into the answering jack and throws her listening key *L.K.* This enables the operator to talk with the calling subscriber, and having found that he desires a connection with the line extending to Station *B*, she touches the tip of her calling plug to the multiple jack of that line that is within her reach, it being remembered that each one of the multiple jacks shown is on a different section. She leaves the listening key in the listening position when she does this. If the line is busy, the click will notify her that she must not make the connection, in which case she informs the calling subscriber that the line is busy and requests him to call again. If, however, she received no click, she would insert the calling plug into the jack, thus completing the connection between the two lines. She would then press the ringing key associated with the calling plug and that momentarily disconnects the calling plug from the answering plug and at the same time establishes connection between the ringing generator and the called line. The release of the ringing key again connects the calling and answering plugs and, therefore, connects the two subscribers' lines ready for conversation. All that is then necessary is that the called subscriber shall respond and remove his receiver from its hook, the calling subscriber already having done this. When the conversation is finished, both of the subscribers (if they remember it) will operate their ringing generators, which will throw the clearing-out drop as a signal to the operator for disconnection. If it should become necessary for the operator to ring back on the line of the calling subscriber, she may do so by pressing the ringing key associated with the calling plug.

Frequently this multiple switchboard arrangement was used with grounded lines, in which case the single line wire extending from the subscriber's station to the switchboard was connected with the tip spring of the first jack, the circuit being continued in series through the jack to the drop and thence to ground through a high non-inductive resistance.

Defects. This series multiple magneto system was used with a great many variations, and it had a good many defects. One of these defects was due to the necessary extending of one limb of the line through a large number of series contacts in the jacks. This is not to be desired in any case, but it was particularly objectionable in the early days before jacks had been developed to their present high state of perfection. A particle of dust or other insulating matter, lodging between the tip spring and its anvil in any one of the jacks, would leave the line open, thus disabling the line to incoming signals, and also for conversation in case the break happened to occur between the subscriber and the jack that was used in connecting with the line. Another defect due to the same cause was that the line through the switchboard was always unbalanced by the insertion of a plug, one limb of the line always extending clear through the switchboard to the drop and the other, when the plug was inserted, extending only part way through the switchboard and being cut off at the jack where the connection was made. The objection will be apparent when it is remembered that the wires in the line circuit connecting the multiple jacks are necessarily very closely bunched together and, therefore, there is very likely to be cross-talk between two adjacent lines unless the two limbs of each line are exactly balanced throughout their entire length.

Again the busy-test conditions of this circuit were not ideal. The fact that the test rings of the line were connected permanently with the outside line circuit subjected these test rings to whatever potentials might exist on the outside lines, due to any causes whatever, such as a cross with some other wire; thus the test rings of an idle line might by some exterior cause be raised to such a potential that the line would test busy. It may be laid down as a fundamental principle in good multiple switchboard practice that the busy-test condition should be made independent of any conditions on the line circuit outside of the central office, and such is not the case in this circuit just described.

Branch-Terminal Multiple Board. The next important step in the development of the magneto multiple switchboard was that which produced the so-called branch-terminal board. This came into wide use in the various Bell operating companies before the advent of the common-battery systems. Its circuits and the principles of operation may be understood in connection with Fig. 338. In the branch-terminal system there are no series contacts in the jacks and no unbalancing of the line due to a cutting off of a portion of the line circuit when a connection was made with it. Furthermore, the test circuits were entirely local to the central office and were not likely to be affected by outside conditions on the line. This switchboard also added the feature of the automatic restoration of the drops, thus relieving the operator of the burden of doing that manually, and also permitting the drops to be mounted on a portion of the switchboard that was not available for the mounting of jacks, and thus permitting a greater capacity in jack equipment.

Each jack has five contacts, and the answering and multiple jacks are alike, both in respect to their construction and their connection with the line. The drops are the electrically self-restoring type shown in Fig. 263. The line circuits extended permanently from the subscriber's station to the line winding of the drop and the

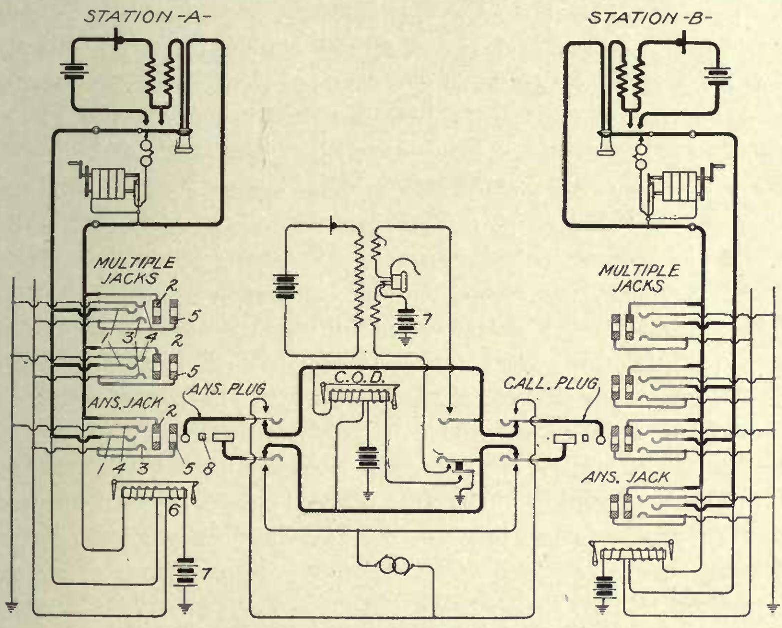


Fig. 338. Branch-Terminal Magneto Multiple Switchboard

two limbs of the line branched off to the tip and sleeve contacts *1* and *2* respectively of each jack. Another pair of wires extended through the multiple parallel to the line wires and these branched off respectively to the contact springs *3* and *4* of each of the jacks. This pair of wires formed portions of the drop-restoring circuit, including the restoring coil *6* and the battery *7*, as indicated. The test thimble *5* of each of the jacks is connected permanently with the spring *3* of the corresponding jack and, therefore, with the wire which connects through the restoring coil *6* of the corresponding drop to ground through the battery *7*.

The plugs were each provided with three contacts. Two of these were the usual tip and sleeve contacts connected with the two strands of the cord circuit. The third contact *8* was not connected with any portion of the cord circuit, being merely an insulated contact on the plug adapted, when the plug was fully inserted, to connect together the springs *3* and *4*. The cord circuit itself is readily understood from the drawing, having two features, however, which merit attention. One is the establishing of a grounded battery connection to the center portion of the winding of the receiver for the purposes of the busy test, and the other is the provision of a restoring coil and restoring circuit for the clearing-out drop, this circuit being closed by an additional contact on the listening key so as to restore the clearing-out drop whenever the listening key was operated.

Operation. An understanding of the operation of this system is easy. The turning of the subscriber's generator, when the line was in its normal condition, caused the display of the line signal. The insertion of the answering plug, in response to this call, did three things: (1) It extended the line circuit to the tip and sleeve strand of the cord circuit. (2) It energized the restoring coil *6* of the drop by establishing the circuit from the contact spring *3* through the plug contact *8* to the other contact spring *4*, thus completing the circuit between the two normally open auxiliary wires. (3) The connecting of the springs *3* and *4* established a connection from ground to the test thimbles of all the jacks on a line, the spring *4* being always grounded and the spring *3* being always connected to the test thimble *5*.

It is to be noted that on idle lines the test rings are always at the same potential as the ungrounded pole of the battery *7*, being connected thereto through the winding *6* of the restoring coil. On all busy lines, however, the test rings are dead grounded through the contact *8* of the plug that is connected with the line.

The tip of the testing plug at the time of making a test will also be at the same potential as that of the ungrounded pole of the battery *7*, since this pole of the battery *7* is always connected to the center portion of the operator's receiver winding, and when the listening key is thrown the tip of the calling plug is connected therewith and is at the same potential. When, therefore, the operator touches the tip of the calling plug to the test thimble of an idle line, she will get no click, since the tip of the plug and the test thimble will be at the same potential. If, however, the line has already been switched at another section of the board, there will be a difference of potential, because the test thimble will be grounded, and the circuit, through which the current which causes the click flows, may be traced from the ungrounded pole of the battery *7* to the center portion of the operator's receiver, thence through one-half of the winding to the tip of the calling plug, thence to the test thimble of the jack under test, thence to the spring *3* of the jack on another section at which the connection exists, through the contact *8* on the plug of that jack to the spring *4*, and thence to ground and back to the other terminal of the battery *7*.

Magnet Windings. Coils of the line and clearing-out drops by which these drops are thrown, are wound to such high resistance and impedance as to make it proper to leave them permanently bridged across the talking circuit. The necessity for cutting them out is, therefore, done away with, with a consequent avoidance, in the case of the line drops, of the provision of series contacts in the jacks.

Arrangement of Apparatus. In boards of this type the line and clearing-out drops were mounted in the extreme upper portion of the switchboard face so as to be within the range of vision of the operator, but yet out of her reach. Therefore, the whole face of the board that was within the limit of the operator's reach was available for the answering and multiple jacks. A front view of a little over one of the sections of the switchboard, involving three complete operator's positions, is shown in Fig. 339, which is a portion of the switchboard installed by the Western Electric Company in one of the large exchanges in Paris, France. (This has recently been replaced by a common-battery multiple board.) In this the line drops may be seen at the extreme top of the face of the switchboard, and immediately beneath these the clearing-out drops. Beneath these are the multiple jacks arranged in banks of one hundred, each hundred consisting of five strips of twenty. At the extreme lower portion of the jack space are shown the answering jacks and beneath these on the horizontal shelf, the plugs and keys. These jacks were mounted on $\frac{1}{2}$-inch centers, both vertically and horizontally, and each section had in multiple 90 banks of 100 each, making 9,000 in all. Subsequent practice has shown that this involves too large a reach for the operators and that, therefore, 9,000 is too large a num-

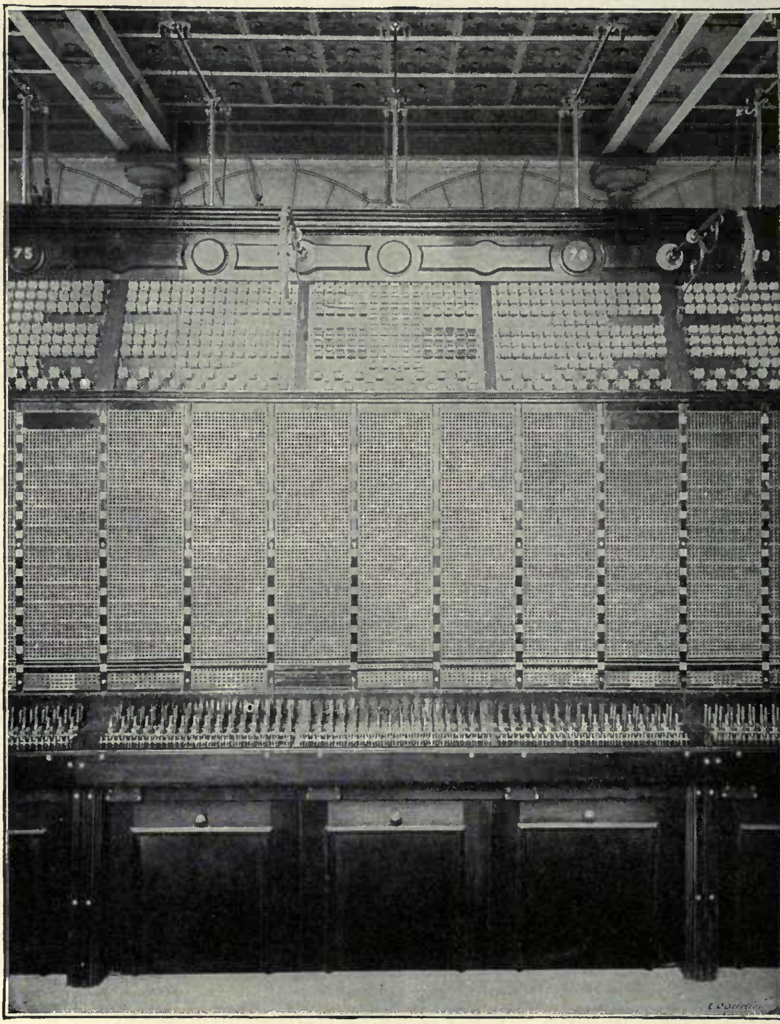


Fig. 339. Face of Magneto Multiple Switchboard

ber of jacks to place on one section if the jacks are not spaced closer than on $\frac{1}{2}$-inch centers. With the jack involving as many parts as that required by this branch terminal system, it was hardly feasible to make them smaller than this without sacrificing their durability, and one of the important features of the common-battery multiple system which has supplanted this branch-terminal magneto system is that the jacks are of such a simple nature as to lend themselves to mounting on $\frac{3}{8}$-inch centers, and in some cases on $\frac{3}{10}$-inch centers.

Modern Magneto Multiple Board. Coming now to a consideration of modern magneto multiple switchboards, and bearing in mind that such boards are to be found in modern practice only in comparatively small installations and then only under rather peculiar conditions, as already set forth, we will consider the switchboard of the Monarch Telephone Manufacturing Company as typical of good practice in this respect.

Line Circuit. The line and cord circuits of the Monarch sys-

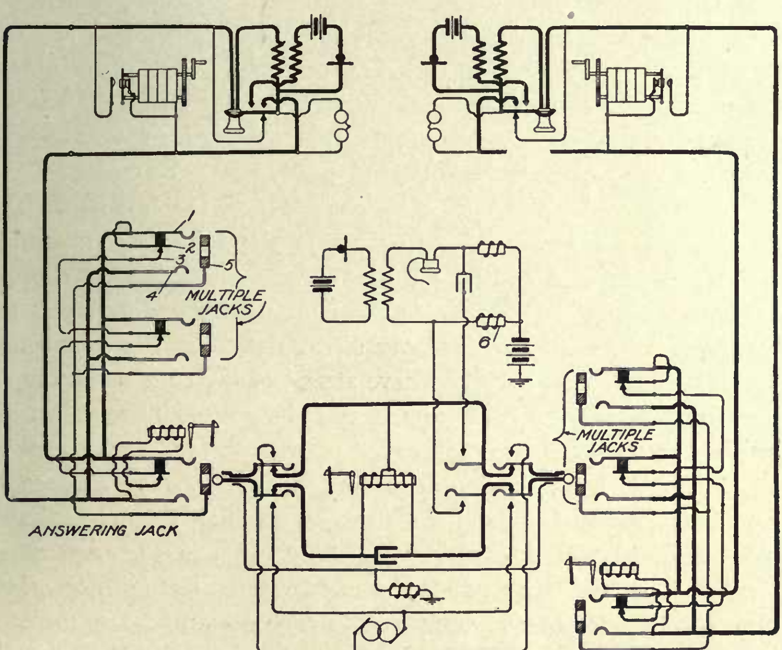


Fig. 340. Monarch Magneto Multiple Switchboard Circuits

tem are shown in Fig. 340. It will be seen that each jack has in all five contacts, numbered from *1* to *5* respectively, of which *1* and *4* are the springs which register with the tip and ring contacts of the plug and through which the talking circuit is continued, while *2* and *3* are series contacts for cutting off the line drop when a plug is inserted, and *5* is the test contact or thimble adapted to register with the sleeve contact on the plug when the plug is fully inserted. The line circuit through the drop may be traced normally from one side of the line through the drop coil, thence through all of the pairs of springs *2* and *3* in the jacks of that line, and thence to spring *1* of the last jack, this spring always being strapped to the spring *2* in the last jack, and thence to the other side of the line. All the ring springs *1* are permanently tapped on to one side of the line, and all of the tip springs *4* are permanently tapped to the other side of the line. This system may, therefore, properly be called a branch-terminal system. It is seen that as soon as a plug is inserted into any of the jacks, the circuit through the drop will be broken by the opening of the springs *2* and *3* in that jack. The drop shown immediately above the answering jack is so associated mechanically with that jack as to be mechanically self-restored when the answering plug is inserted into the answering jack in response to a call. The arrangement in this respect is the same as that shown in Fig. 259, illustrating the Monarch combined drop and jack.

Cord Circuit. The cord circuit needs little explanation. The tip and ring strands are the ones which carry the talking current and across these is bridged the double-wound clearing-out drop, a condenser being included in series in the tip strand between the two drop windings in the manner already explained in connection with Fig. 284. The third or sleeve strand of the cord is continuous from plug to plug, and between it and the ground there is permanently connected a retardation coil.

Test. The test is dependent on the presence or absence of a path to ground from the test thimbles through some retardation coil associated with a cord circuit. Obviously, in the case of an idle line there will be no path to ground from the test thimbles, since normally they are merely connected to each other and are insulated from everything else. When, however, a plug is inserted into a multiple or answering jack, the test thimbles of that line are connected to ground through the retardation coil associated with the third strand of the plug used in making the connection. When the operator applies the tip of the calling plug to a test contact of a multiple jack there will be no path to ground afforded if the line is idle, while if it is busy the potential of the tip of the test plug will cause a current to flow to ground through the impedance coil associated with the plug used in making the connection. This will be made clearer by tracing the test circuit. With the listening key thrown this may be traced from the live side of the battery through the retardation coil *6*, which is common to an operator's position, thence through the tip side of the listening key to the tip conductor of the calling cord, and thence to the tip of the calling plug and the thimble of the jack under test. If the line is idle there will be no path to ground from

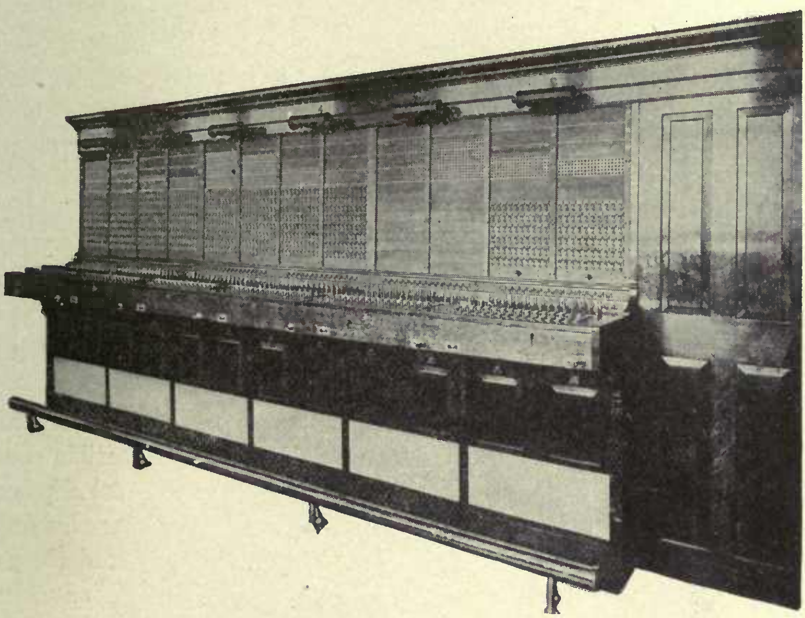


Fig. 341. Magneto Multiple Switchboard

this point and no click will result, but if the line is busy, current will flow from the tip of the test plug to the thimble of the jack tested, thence by the test wire in the multiple to the thimble of the jack at which a connection already exists, and thence to ground through the third strand of the cord used in making that connection and the impedance coil associated therewith. The current which flows in this test circuit changes momentarily the potential of the tip side of the operator's telephone circuit, thus unbalancing her talking circuit and causing a click.

If this test system were used in a very large board where the multiple would extend through a great many sections, there would be some liability of a false test due to the static capacity of the test contacts and the test wire running through the multiple. For small boards, however, where the multiple is short, this system has proven reliable. A multiple magneto switchboard employing the form of circuits just described is shown in Fig. 341. This switchboard consists of three sections of two positions each. The combined answering jacks and drops may be seen at the lower part of the face of the switchboard and occupying somewhat over one-half of the jack and drop space. The multiple jacks are above the answering jacks and drops and it may be noted that the same arrangement and number of these jacks is repeated in each section. This switchboard may be extended by adding more sections and increasing the multiple in those already installed to serve 1,600 lines.

Assembly. In connection with the assembly of these magneto multiple switchboards, as installed by the Monarch Company, Fig. 342 shows the details of the cord rack at the back of the board. It shows how the ends of the switchboard cords opposite to the ends that are fastened to the plugs are connected permanently to terminals on the cord rack, at which point the flexible conductors are brought out to terminal clips or binding posts, to which the wires leading from the other portions of the cord circuit are led. In order to relieve the conductors in the cords from strain, the outer braiding of the cord at the rack end is usually extended to form what is called a *strain cord*, and this attached to an eyelet under the cord rack, so that the weight of the cord and the cord weights will be borne by the braiding rather than by the conductors. This leaves the insulated conductors extending from the ends of the cords free to hang loose without strain and be connected to the terminals as shown. This method of connecting cords, with variations in form and detail, is practically universal in all types of switchboards.

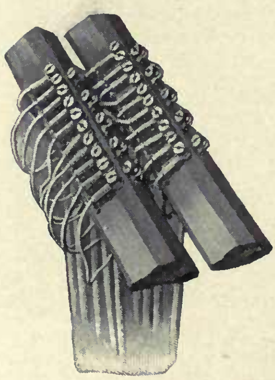


Fig. 342. Cord-Rack Connectors

A detail of the assembly of the drops and jacks in such a switchboard is shown in Fig. 343. The single pair of clearing-out drops is mounted in the lower part of the vertical face of the switchboard just above the space occupied by the plug shelf. Vertical stile strips extend above the clearing-out drop space for supporting the drops

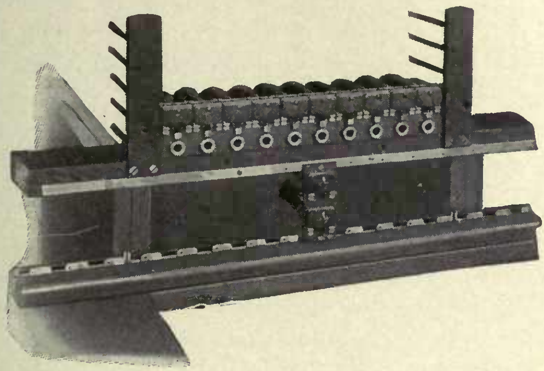


Fig. 343. Drop and Jack Mounting

and jacks. A single row of 10 answering jacks and the corresponding line drops are shown in place. Above these there would be placed, in the completely assembled board, the other answering jacks and line signals that were to occupy this panel, and above these the

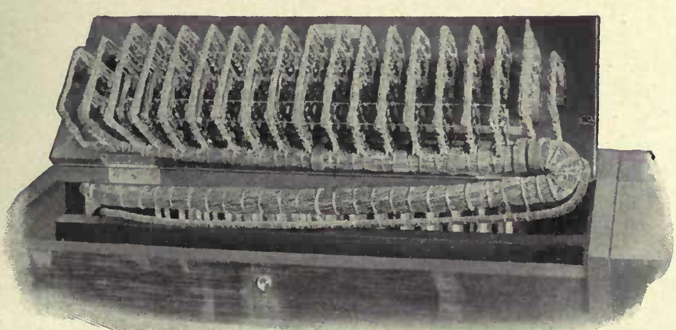


Fig. 344. Keyboard Wiring

strips of multiple jacks. The rearwardly projecting pins from the stile strips are for the support of the multiple jack strips, these pins supporting the strips horizontally by suitable multiple clips at the ends of the jack strips; the jack strips being fastened from the rear by means of nuts engaging the screw threads on these pins. This method of supporting drops and jacks is one that is equally adaptable for use in other forms of boards, such as the simple magneto switchboard.

In Fig. 344 is shown a detail photograph of the key shelf wiring in one of these Monarch magneto switchboards. In this the under side of the keys is shown, the key shelf being raised on its hinge for that purpose. The cable, containing all of the insulated wires leading to these keys, enters the space under the key shelf at the extreme left and from the rear. It then passes to the right of this space where a "knee" is formed, after which the cable is securely strapped to the under side of the key shelf. By this construction sufficient flexibility is provided for in the cable to permit the raising and lowering of the key shelf, the long reach of the cable between the "knee" and the point of entry at the left serving as a torsion member, so that the raising of the shelf will give the cable a slight twist rather than bend it at a sharp angle.

CHAPTER XXVI

THE COMMON-BATTERY MULTIPLE SWITCHBOARD

Western Electric No. 1 Relay Board. The common-battery multiple switchboard differs from the simple or non-multiple common-battery switchboard mainly in the provision of multiple jacks and in the added features which are involved in the provision for a busy test. The principles of signaling and of supplying current to the subscribers for talking are the same as in the non-multiple common-battery board. For purposes of illustrating the practical workings of the common-battery multiple switchboard, we will take the standard form of the Western Electric Company, choosing this only because it is the standard with nearly all the Bell operating companies throughout the United States.

Line Circuit. We will first consider the line circuit in simplified form, as shown in Fig. 345. At the left in this figure the com-

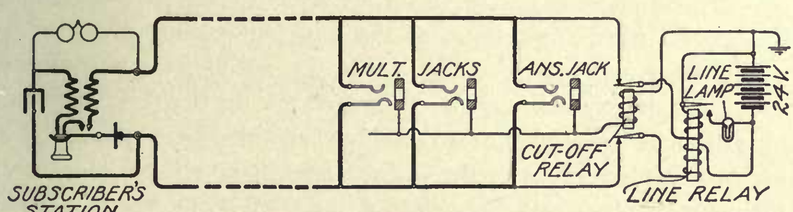


Fig. 345. Line Circuit Western Electric No. 1. Board

mon-battery circuit is shown at the subscriber's station, and at the right the central-office apparatus is indicated so far as equipment of a single line is concerned. In this simplified diagram no attempt has been made to show the relative positions of the various parts, these having been grouped in this figure in such a way as to give as clear and simple an idea as possible of the circuit arrangements. It is seen at a glance that this is a branch terminal board, the three contacts of each jack being connected by separate taps or legs to three wires running throughout the length of the board, these three wires being individual to the jacks of one line. On this account this line circuit is commonly referred to as a three-wire circuit. By the same considerations it will be seen that the switchboard line circuit of the branch-terminal multiple magneto system, shown in Fig. 338, would be called a four-wire circuit. It will be shown later that other multiple switchboards in wide use have a still further reduction in the number of wires running through the jacks, or through the multiple as it is called, such being referred to as two-wire switchboards.

The two limbs of the line which extend from the subscriber's circuit, beside being connected by taps to the tip and sleeve contacts of the jack respectively, connect with the two back contacts of a cut-off relay, and when this relay is in its normal or unenergized condition, these two limbs of the line are continued through the windings of the line relay and thence one to the ungrounded or negative side of the common-battery and the other to the grounded side. The subscriber's station circuit being normally open, no current flows through the line, but when the subscriber removes his receiver for the purpose of making a call the line circuit is completed and current flows through the coil of the line relay, thus energizing that relay and causing it to complete the circuit of the line lamp. The cut-off relay plays no part in the operation of the subscriber's calling, but merely leaves the circuit of the line connected through to the calling relay and battery. The coil of the cut-off relay is connected to ground on one side and on the other side to the third wire running through the switchboard multiple and which is tapped off to each of the test rings on the jacks. As will be shown later, when the operator plugs into the jack of a line, such a connection is established that the test ring of that jack will be connected to the live or negative pole of the common battery, which will cause current to flow through the coil of the cut-off relay, which will then operate to *cut off* both of the limbs of the line from their normal connection with ground and the battery and the line relay. Hence the name *cut-off relay*.

The use of the cut-off relay to sever the calling apparatus from the line at all times when the line is switched serves to make possible a very much simpler jack than would otherwise be required, as will be obvious to anyone who tries to design a common-battery multiple system without a cut-off relay. The additional complication introduced by the cut-off relay is more than offset by the saving in complexity of the jacks. It is desirable, on account of the great number of jacks necessarily employed in a multiple switchboard, that the jacks be of the simplest possible construction, thus reducing to a minimum their first cost and making them much less likely to get out of order.

Cord Circuit. The cord circuit of the Western Electric standard multiple common-battery switchboard is shown in Fig. 346. This cord circuit involves the use of three strands in the flexible cords of both the calling and the answering plugs. Two of these are the ordinary tip and ring conductors over which speech is transmitted to the connected subscriber's wire. The third, the sleeve strand, carries the supervisory lamps and has associated with it other apparatus for the control of these lamps and of the test circuit.

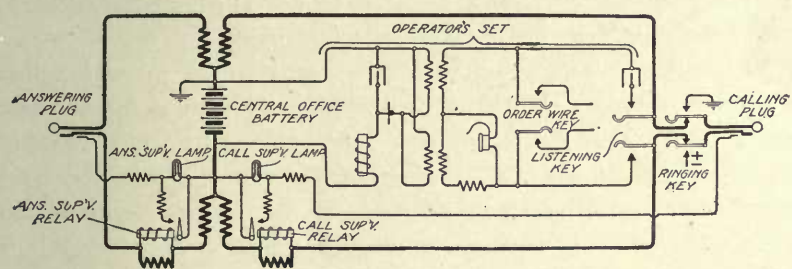


Fig. 346. Cord Circuit Western Electric No. 1 Board

The system of battery feed is the well-known split repeating-coil arrangement already discussed. The tip strand runs straight through to the repeating coil, while the ring strand contains, in each case, the winding of the supervisory relay corresponding to either the calling or the answering plug. In order that the presence in the talking circuit of a magnet winding possessing considerable impedance may not interfere with the talking efficiency, each of these supervisory relay windings is shunted by a non-inductive resistance. In practice the supervisory relay windings have each a resistance of about 20 ohms and the shunt around them each a resistance of about 31 ohms. In the third strand of each cord is placed a 12-volt supervisory lamp, and in series with it a resistance of about 80 ohms. Each supervisory relay is adapted, when energized, to close a 40-ohm shunt about its supervisory lamp. The arrangement and proportion of these resistances is such that when a plug is inserted into the jack of a line the lamp will receive current from a circuit traced from the negative pole of the battery in the center of the cord circuit through the lamp and the 80-ohm series resistance, through the third strand of the cord to the test thimble of the jack, and thence to the positive or grounded pole of the battery through the third conductor in the multiple and the winding of the cut-off relay. This current always flows as long as the plug is inserted, and it is just sufficient to illuminate the lamp when the supervisory relay armature is not attracted. When, however, the supervisory relay armature is attracted, the shunting of the lamp by the 40-ohm resistance cuts down the current to such a degree as to prevent the illumination of the lamp, although some current still flows through it.

The usual ringing and listening key is associated with the calling plug, and in some cases a ring-back key is associated with the answering plug, but this is not standard practice.

Operation. The operation of this cord circuit in conjunction with the line circuit of Fig. 345 may best be understood by reference to Fig. 347. This figure employs a little different arrangement of the line circuit in order more clearly to indicate how the two lines may be connected by a cord; a study of the two line circuits, however, will show that they are identical in actual connections. It is to be remembered that all of the battery symbols shown in this figure represent in reality the same battery, separate symbols being shown for greater simplicity in circuit connections.

We will assume the subscriber at Station *A* calls for the subscriber at Station *B*. The operation of the line relay and the consequent lighting of the line lamp, and also the operation of the pilot relay will be obvious from what has been stated. The response of the operator by inserting the answering plug into the answering jack, and the throwing of her listening key so as to bridge her talking circuit across the cord in order to place herself in communication with the subscriber, is also obvious. The insertion of the answering plug into the answering jack completed the circuit through the third strand of the cord and the winding of the cut-off relay of the calling line, and this accomplishes three desirable results. The circuit so completed may be traced from the negative or ungrounded side of the battery to the center portion of the cord circuit, thence through the supervisory lamp *1*, resistance *2*, to the third conductor on the plug, test thimble on the jack, thence through the winding of the cut-off relay to ground, which forms the other terminal of the battery. The results accomplished by the closing of this circuit are: first, the energizing of the cut-off relay to cut off the signaling portion of the line; second, the flowing of current through the lamp that

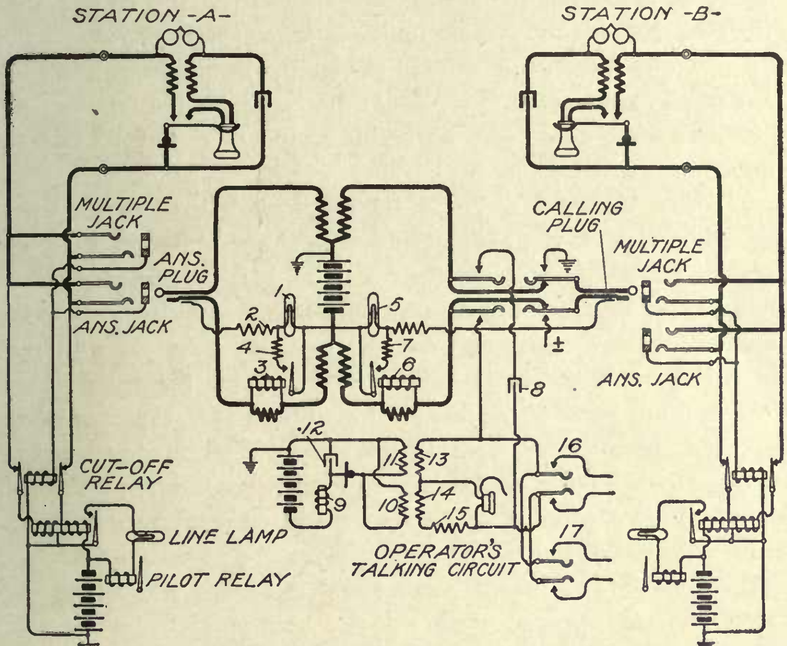


Fig. 347. Western Electric No. 1 Board

is almost sufficient to illuminate it, but not quite so because of the closure of the shunt about it, for the reason that will be described; third, the raising of the potential of all the contact thimbles on the jacks from zero to a potential different from that of the ground and equal in amount to the fall of potential through the winding of the cut-off relay. A condition is thus established at the test rings such that some other operator at some other section in testing the line will find it busy and will not connect with it.

The reason why the lamp *1*, connected with the answering plug, was not lighted was that the supervisory relay *3*, associated with the answering plug, became energized when the operator plugged in, due to the flow of current from the battery through the calling subscriber's talking apparatus, this flow of current being permitted by the removal of the calling subscriber's receiver from its hook. The energizing of this relay magnet by causing the attraction of its armature, closed the shunt about the lamp *1*, which shunt contains the 40-ohm resistance *4*, and thus prevents the lamp from receiving enough current to illuminate it. Obviously, as soon as the calling subscriber replaces his receiver on its hook, the supervisory relay *3* will be de-energized, the shunt around the lamp will be broken, and the lamp will be illuminated to indicate to the operator the fact that the subscriber with whose line her calling plug is connected has replaced his receiver on its hook.

Testing—Called Line Idle. Having now shown how the operator connects with the calling subscriber's line and how that line automatically becomes guarded as soon as it is connected with, so that no other operator will connect with it, we will discuss how the operator tests the called line and subsequently connects with that line, if it is found proper to do so. If, on making the test with one of the multiple jacks of the line leading to Station *B*, that line is idle and free to be connected with, its test rings will all be at zero potential because of the fact that they are connected with ground through the cut-off relay winding with no source of current connected with them. The tip of the calling plug will also be at zero potential in making this test, because it is connected to ground through the tip side of the calling-plug circuit and one winding of the cord-circuit repeating coil. As a result no flow of current will occur, the operator will receive no click, and she will know that she is free to connect with the line. As soon as she does so, by inserting the plug, the third strand of the cord will be connected with the test thimble of the calling line and the resulting flow of current will bring about three results, two of which are the same, and one of which is slightly different from those described as resulting from the insertion of the answering plug into the jack of the calling line. First, the cut-off relay will be operated and cut off the line signaling apparatus from the called line; second, a flow of current will result through the calling supervisory lamp *5*, which in this case will be sufficient to illuminate that lamp for the reason that the called subscriber has not yet responded, the calling supervisory relay *6* has, therefore, not yet been energized, and the lamp has not, therefore, been shunted by its associated resistance *7;* third, the test thimbles of the called line will be raised to a potential above that of the earth, and thus the line will be guarded against connection at another section of the switchboard. As soon as the called subscriber responds to the ringing current sent out by the operator, current will flow over the cord circuit and over his line through his transmitter. This will cause the calling supervisory relay to be energized and the calling lamp to be extinguished. Both lamps *1* and *5* remain extinguished as long as the connected subscribers are in conversation, but as soon as either one of them hangs up his receiver the corresponding lamp will be lighted, due to the de-energization of the supervisory relay and the breaking of the shunt around the lamp. The lighting of both lamps associated with a cord circuit is a signal to the operator for disconnection.

Testing—Called Line Busy. If we now assume that the called line was already busy, by virtue of being connected with at another section, the test rings of that line would accordingly all be raised to a potential above that of the earth. As a result, when the operator applied the tip of her calling plug to a test thimble on that line, current would flow from this test thimble through the tip of the calling plug and tip strand of the cord and through one winding of the cord-circuit repeating coil to ground. This would cause a slight raising of potential of the entire tip side of the cord circuit and a consequent momentary flow of current through the secondary of the operator's circuit bridged across the cord circuit at that time.

Operator's Circuit Details. The details of the operator's talking circuit shown in Fig. 347 deserve some attention. The battery supply to the operator's transmitter is through an impedance coil *9.* The condenser *12* is bridged around the transmitter and the two primary windings *10* and *11,* which windings are in parallel so as to afford a local circuit for the passage of fluctuating currents set up by the transmitter. The two primary windings *10* and *11* are on separate induction coils, the secondary windings *13* and *14* being, therefore, on separate cores. The winding *15,* in circuit with the secondary winding *14* and the receiver, is a non-inductive winding and is supposed to have a resistance about equal to the effective resistance to fluctuating currents of a subscriber's line of average length. Owing to the respective directions of the primary and secondary windings *10* and *11*, *13* and *14*, the result is that the outgoing currents set up by the operator's transmitter are largely neutralized in the operator's receiver. Incoming currents from either of the connected subscribers, however, pass, in the main, through the secondary coil *13* and the operator's receiver, rather than through the shunt path formed by the secondary *14*, and the non-inductive resistance *15*. This is known as an "anti-side tone" arrangement, and its object is to prevent the operator from receiving her own voice transmission so loudly as to make her ear insensitive to the feebler voice currents coming in from the subscribers.

Order-Wire Circuits. The two keys *16* and *17*, shown in connection with the operator's talking circuit in Fig. 347, play no part in the regular operation of connecting two local lines, as described above. They are order-wire keys, and the circuits with which they connect lead to the telephone sets of other operators at distant central offices, and by pressing either one of these keys the operator is enabled to place herself in communication over these so-called order-wire circuits with such other operators. The function and mode of operation of these order-wire circuits will be described in the next chapter, wherein inter-office connections will be discussed.

Wiring of Line Circuit. The line circuits shown in Figs. 345 and 347 are, as stated, simplified to facilitate understanding, although the connections shown are those which actually exist. The more complete wiring of a single line circuit is shown in Fig. 348. The line wires are shown entering at the left. They pass immediately, upon entering the central office, through the main distributing frame, the functions and construction of which will be considered in detail in a subsequent chapter. The dotted portions of the circuit shown in connection with this main distributing frame indicate the path from the terminals on one side of the frame to those on the other through so-called jumper wires. The two limbs of the line then pass to terminals *1* and *2* on one side of the so-called intermediate distributing frame. Here the circuit of each limb of the line divides, passing, on the one hand, to the tip and sleeve springs of all the multiple jacks belonging to that line; and, on the other hand, through the jumper wires indicated by dotted lines on the intermediate distributing frame, and thence to the tip and ring contacts of the answering jack. A consideration of this connection will show that the actual electrical connections so far as already described are exactly those of Figs. 345 and 347, although those figures omitted the main and intermediate distributing frames. Only two limbs of the line are involved in the main frame. In the intermediate frame the test wire running through the multiple is also involved. This test wire, it will be seen, leads from the test thimbles of all the multiple jacks to the terminal *3* on the intermediate frame, thence through the jumper wire to the terminal *6* of this frame, and to the test thimble of the answering jack. Here again the electrical connections are exactly those represented in Figs. 345 and 347, although those figures do not show the intermediate frame.

The two terminals *4* and *5* of the intermediate frame, besides being connected to the tip and sleeve springs of the answering jack, are connected to the contacts of the cut-off relay, and thence through the coils of the line relay to ground on one side and to battery on the other. Thus the line relay and battery are normally included in the circuit of the line. The contact *6* on the intermediate distributing frame, besides being connected to the test thimble of all the jacks, is connected through the coil of the cut-off relay to ground, thus establishing a path by which current is supplied to the cut-off relay when connection is made to the line at any jack. There is another contact *7* on the intermediate distributing frame which merely forms a terminal for joining one side of the line lamp to the back contact of the line relay.

Functions of Distributing Frames. Since the line circuit thus far described in connection with Fig. 348 is exactly the same as that of Fig. 345 in its electrical connections, it becomes obvious that the main and intermediate distributing frames play no part in the operation of the circuit any more than a binding post of a telephone plays a part in its operation. These frames carry terminals for facilitating the connection of the various wires in the line circuit and, as will be shown later, for facilitating certain changes in the line connection.

Remembering that the dotted lines in Fig. 348 indicate jumper wires of the main and intermediate distributing frames, and that these are in the nature of temporary or readily changeable connections, and that the full lines, whether heavy or light, are permanent connections not readily changeable, it will be seen that the wires leading through the multiple jacks of a certain line are permanently associated with each other, and with certain terminals on the main distributing frame and certain other terminals on the intermediate

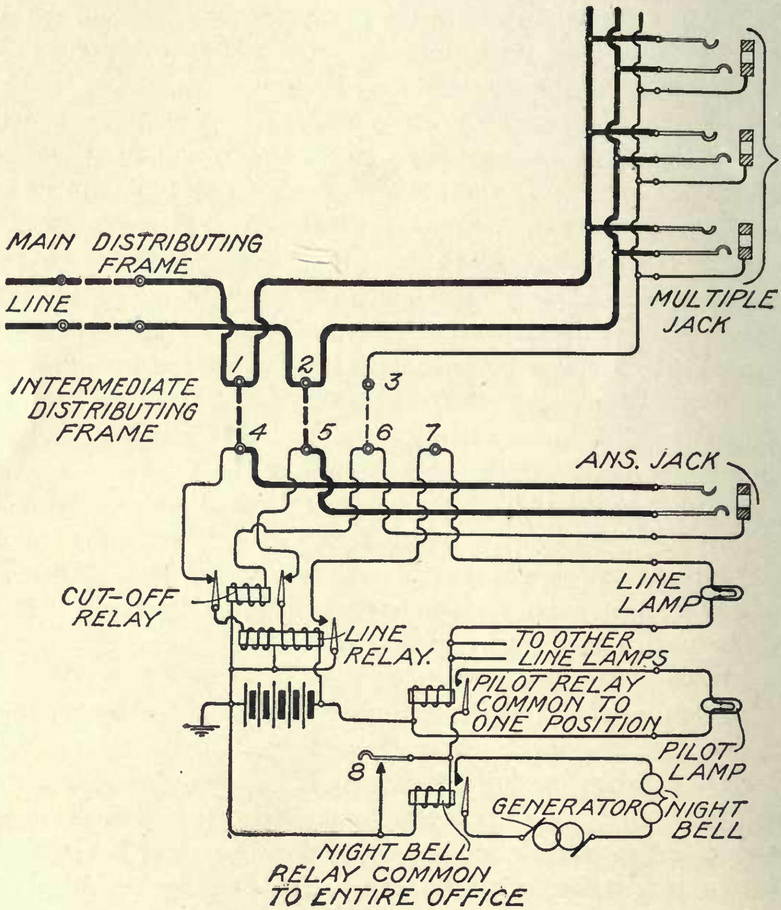


Fig. 348. Line Circuit No. 1 Board

distributing frame. It will also be seen that the line lamp and the answering jack, together with the cut-off relay and line relay, are permanently associated with each other and with another group of terminals *4*, *5*, *6*, and *7* on the intermediate distributing frame. It will also be apparent that by changing the jumper wires on the main frame, any outside line may be connected with any different set of line switchboard equipment, and also that by making changes in the jumper wires on the intermediate frame, any given answering jack and line lamp with its associated line cut-off relay may be associated with any set of multiple jacks.

Pilot Signals. In a portion of the circuit leading from the battery that is common to a group of line lamps is the winding of the pilot relay, which is common to this group of line lamps. This controls, as already described, the circuit of the pilot lamp common to the same group of line lamps. In addition, a night-bell circuit is sometimes provided, this usually being in the form of an ordinary polarized ringer, the circuit of which is controlled by a night-bell relay common to the entire office. Normally, this relay is shunted out of the circuit of the common portion of the lead to the pilot relay contacts by the key *8*, but when the key *8* is opened all current that is fed to the pilot lamps passes through the night-bell relay, and thus, whenever any pilot lamp is lighted, the night-bell relay will attract its armature and thus close the circuit of the calling generator through the night bell.

A study of this figure will make clear to the student how the portions of the circuit that are individual to the line are associated with such things as the battery, that are common to the entire office, and such as the pilot relay and lamp, that are common to a group of lines terminating in one position.

Modified Relay Windings. In some cases, the line relay instead of being double wound, as shown, is made with a single winding, this winding being normally included between the ring side of the cut-off relay and the battery, the tip side of the cut-off relay being run direct to ground. The present practice of the Western Electric Company is towards the double-wound relay, however, and that is considered standard in all of their large No. 1 multiple boards, except where the customer, owing to special reasons, demands a single wound relay on the ring side of the line. The prime reason for the two-winding line relay is the lessened click in the calling-subscriber's receiver which occurs when the operator answers. All line relays prior to 1902 were single-wound, but after that they were made double and used some turns of resistance wire to limit the normal calling current.

Relay Mounting. In the standard No. 1 relay board of the Western Electric Company and, in fact, in nearly all common-battery multiple boards that are manufactured by other companies, the line and cut-off relays are mounted on separate racks outside the switchboard room and adjacent to the main and intermediate distributing frames, the wiring being extended from the relays to the jacks and lamps on the switchboard proper by means of suitable cables. The Western Electric Company has recently instituted a departure from this practice in the case of some of their smaller No. 1 switchboard installations. Where it is thought that the ultimate capacity required by the board will not be above 3,000 lines, the relay rack is dispensed with and all of the line and cut-off relays, as well as the supervisory relays, are mounted in the rear of the switchboard frame. For this purpose the line and cut-off relays are specially made with the view to securing the utmost compactness. In still other cases, in switchboards of relatively small ultimate capacity, they use this small line and cut-off relay mounted on a separate relay rack, in which case the board is the standard No. 1 board except for the type of relays. In all of these modifications of the No. 1 board adapted for the use of the smaller and cheaper relays, the line relay has but a single winding, the small size of the relay winding not lending itself readily to double winding with the added necessary coil terminals.

Capacity Range. The No. 1 Western Electric board is made in standard sizes up to an ultimate capacity of 9,600 lines. For all capacities above 4,900 lines, a $\frac{3}{8}$-inch jack, vertical and horizontal face dimensions, is employed. For this capacity the smaller types of cut-off and line relays are not employed. Up to ultimate capacities of 4,900 lines, $\frac{1}{2}$-inch jacks are employed, and either the small or the large relays mounted on a separate rack are available. Up to 3,000 lines ultimate capacity, the $\frac{1}{2}$-inch jack is employed, and either the small or the large cut-off and line relays are available, but in case the small type is used the purchaser has the option of mounting them on a separate relay rack, as in ordinary practice, or mounting them in the switchboard cabinet and dispensing with the relay rack.

Western Electric No. 10 Board. The No. 1 common-battery multiple switchboard, regardless of its size and type of arrangement of line and cut-off relays, involves two relays for each line, the line relay energized by the taking of the receiver off its hook, and the cut-off relay energized by the act of the operator on plugging in and serving to remove the line relay from the circuit whenever and as long as a plug is inserted into any jack of the line. This seems to involve a considerable expense in relays, but this, as has been stated, is warranted by the greater simplicity in jacks which the use of the cut-off relay makes possible. In addition to this expense of investment in the line and cut-off relays, the amount of current required to hold up the cut-off relays during conversations foots up to a considerable item of expense, particularly as the system of supervisory signals is one in which the supervisory lamp takes current not only while burning, but its circuit takes even more current when the lamp is extinguished during the time of a connection. For all of these reasons, and some other minor ones, it was deemed expedient by the engineers of the Western Electric Company to design a common-battery multiple switchboard for small and medium-sized exchanges in which certain sacrifices might be made to the end of accomplishing certain savings. The result has been a type of switchboard, designated the No. 10, which may be found in a number of Bell exchanges, it being considered particularly adaptable to installations of from 500 to 3,000 lines. Although this board has been subject to a good deal of adverse criticism, and although it seems probable that even for the cheaper boards the No. 1 type with some of the modifications just described will eventually supersede this No. 10 board, yet the present extent of use of the No. 10 board and the instructive features which its type displays warrant its discussion here.

Circuits. The circuits of this switchboard are shown in Fig. 349, this indicating two-line circuits and a connecting cord circuit, together with the auxiliary apparatus employed in connection with the operator's telephone circuit, the pilot and night alarm circuits. The most noticeable feature is that cut-off jacks are employed, the circuit of the line normally extending through the sets of jack springs in the multiple, and answering jacks to the line relay and battery on one side of the line, and to ground on the other side. Obviously, the additional complexity of the jack saves the use of a cut-off relay and the relay equipment of each line consists, therefore, of but a single line relay, which controls the lamp in an obvious manner.

The cord circuit is of the three-conductor type, the two talking strands extending to the usual split repeating-coil arrangement, and battery current for talking purposes being fed through these windings as in the standard No. 1 board. The supervisory relay is included in the ring strand of the cord circuit and is shunted by a non-inductive

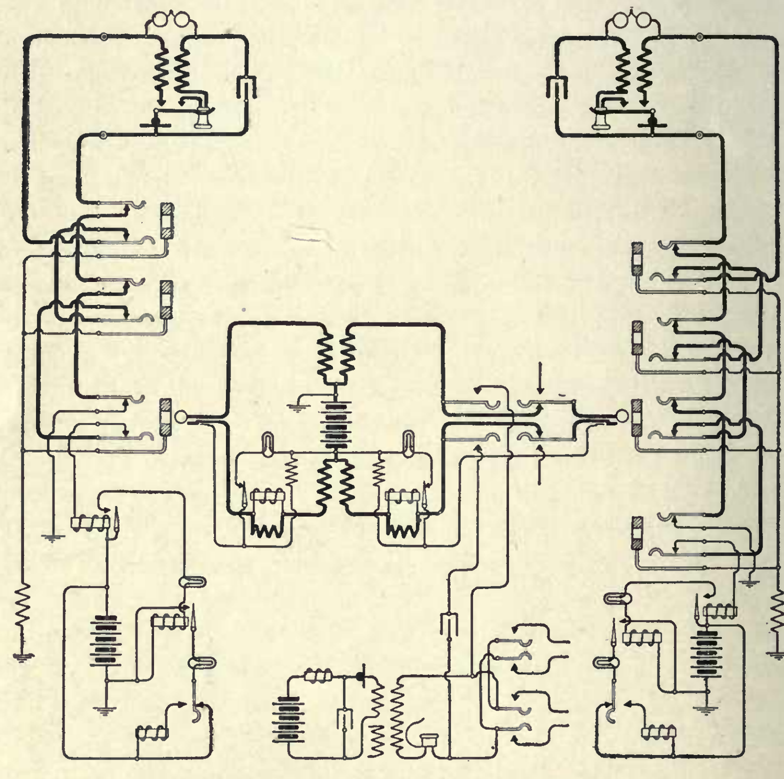


Fig. 349. Western Electric No. 10 Board

resistance, so that its impedance will not interfere with the talking currents. The armature of the supervisory relay closes the lamp contact on its back stroke, so that the lamp is always held extinguished when the relay is energized. The supervisory lamp is included in a connection between the back contact of the supervisory relay and ground, this connection including the central-office battery. As a result, the illumination of the supervisory lamp is impossible until a plug has been inserted into a jack, in which case, assuming the supervisory relay to be de-energized, the lamp circuit is completed through the wire connecting all of the test thimbles and the resistance permanently bridged to ground from that wire.

Test. For purposes of the test it is evident that the test rings of an idle line are always at ground potential, due to their connection to ground through the resistance coil. It is also evident that the tip of an unused calling plug will always be at ground potential and, therefore, that the testing of an idle line will result in no click in the operator's receiver. When a line is switched, however, the potential of all the test rings will be raised due to their being connected with the live pole of the battery through the third strand of the cord. When the operator in testing touches the test contact of the jack of a busy line, a current will, therefore, flow from this test contact to the tip strand of the cord and thence to ground through one of the repeating coil windings. The potential of the tip side of the cord will, therefore, be momentarily altered, and this will result in a click in the operator's receiver bridged across the cord circuit at the time. The details of the operator's cord circuit and of the pilot lamp and night alarm circuits will be clear from the diagram.

Operation. A brief summary of the operation of this system is as follows:

The subscriber removes his receiver from its hook, thus drawing up the armature of the line relay and lighting his line lamp. The operator answers. The line lamp is extinguished by the falling back of the line-relay armature, due to the breaking of the relay circuit at the jack contacts. The subscriber then receives current for his transmitter through the cord-circuit battery connections. The supervisory relay connected with the answering cord is not lighted, because, although the lamp-circuit connection is completed at the jack, the supervisory relay is operated to hold the lamp circuit open. Conversation ensues between the operator and the subscriber, after which the operator tests the line called for with the tip of the calling plug of the pair used in answering. If the called line is not busy, no click will ensue, because both the tested ring and the calling plug are at the same potential. Finding no click, the operator will insert the plug and ring by means of the ringing key. When the operator plugs in, the supervisory lamp, associated with the calling plug, becomes lighted because the circuit is completed at the jack and the supervisory relay remains de-energized, since the line circuit is open at the subscriber's station. When the called subscriber responds, the calling supervisory lamp goes out because of the energization of the supervisory relay. Both lamps remain out during the conversation, but when either subscriber hangs up, the corresponding supervisory lamp will be lighted because of the falling back of the supervisory relay armature.

If the called line is busy, a click will be heard, for the reason described, and the operator will so inform the calling subscriber. It goes without saying that in any multiple-switchboard system a plug may be found in the actual multiple jack that is reached for, in which case, although no test will be made, the busy condition will be reported back to the calling subscriber.

Economy. It has been the belief of the Western Electric engineers that a real economy is accomplished in this type of board by the saving in relay equipment. It is, of course, apparent at a glance that with a switchboard long enough and of sections enough, the cost of extra jack springs and their platinum contacts must become great enough to offset the saving accomplished by omitting the cut-off relay. This makes it apparent that if there is any economy in this type of multiple switchboard, it must be found in the very small boards where there are but few jacks per line and where the extra cost of the cut-off jack is not enough to offset the extra cost of an added relay. It is the growing belief, however, among engineers, that the multiple switchboard must be very small indeed in order that the added complexity of the cut-off jacks and wiring may be able to save anything over the two-relay type of line; and it is believed that where economy is necessary in small boards, it may be best effected by employing cheaper and more compact forms of relays and mounting them, if necessary, directly in the switchboard cabinet.

NOTE. These two standard types of common-battery multiple switchboards of the Western Electric Company represent the development through long years of careful work on the part of the Western Electric and Bell engineers, credit being particularly due to Scribner, McBerty, and McQuarrie of the Western Electric Company, and Hayes of the American Telephone and Telegraph Company.

Kellogg Two-Wire Multiple Board. The simplicity in the jacks permitted by the use of the cut-off relay in the Western Electric common-battery multiple switchboard for larger exchanges was carried a step further by Dunbar and Miller in the development of the so-called two-wire common-battery multiple switchboard, which for many years has been the standard of the Kellogg Switchboard and Supply Company. The particular condition which led to the development of the two-wire system was the demand at that time on the Kellogg Company for certain very large multiple switchboards, involving as many as 18,000 lines in the multiple. Obviously, this necessitated a small jack, and obviously a jack having only two contacts, a tip spring and a sleeve, could be made more easily and with greater durability of this very small size than a jack requiring three or more contacts. Other reasons that were considered were, of course, cheapness in cost of construction and extreme simplicity, which, other things being equal, lends itself to low cost of maintenance.

Line Circuit. Like the standard Western Electric board for large offices, the Kellogg two-wire board employs two relays for each line, the line relay under the control of the subscriber and in turn controlling the lamp, and a cut-off relay under the control of the operator and in turn controlling the connection of the line relay with the line. The line circuit as originally developed and as widely used by the Kellogg Company is shown in Fig. 350. The extreme simplicity of the jacks is apparent, as is also the fact that but two wires lead through the multiple. Another distinguishing feature is, that all of the multiple and answering jacks are normally cut off from the line at the cut-off relay, but when the cut-off relay operates it serves, in addition to cutting off the line relay, to attach the two limbs of the line to the two wires leading through the multiple and answering jacks. The control of the line relay by the subscriber's switch hook is clear from the figure. The control of the cut-off relay is secured by attaching one terminal of the cut-off relay winding permanently to that wire leading through the multiple which connects with the sleeve contacts of the jack, the other terminal of the cut-off relay being grounded. The way in which this relay is operated will be understood when it is stated that the sleeve contacts of both the answering and calling plugs always carry full battery potential and, therefore, whenever any plug is inserted into any jack, current flows from the sleeve of the jack through the sleeve contact of the jack to ground, through the winding of the cut-off relay, which relay becomes energized and performs the functions just stated. It is seen that the wire running through the multiple to which the sleeve jack contacts are attached, is thus made to serve the double purpose of answering as one side of the talking circuit, and also of performing the functions carried out by the separate or third wire in the three-wire system.

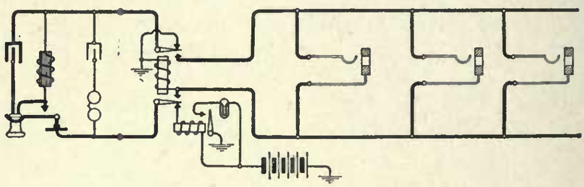


Fig. 350. Two-Wire Line Circuit

It will be shown also that, in addition, this wire is made to lend itself to the purposes of the busy test without any of these functions interfering with each other in any way.

Cord Circuit. The cord circuit in somewhat simplified form is shown in Fig. 351. Here again there are but two conductors to the plugs and two strands to the cords. This greater simplicity is in some measure offset by the fact that four relays are required, two for each plug. This so-called four-relay cord circuit may be most readily understood by considering half of it at a time, since the two relays associated with the answering plug act in exactly the same way as those connected with the calling plug.

Associated with each plug of a pair are two relays *1* and *2*, in the case of the answering cord, and *3* and *4* in the case of the calling cord. The coils of the relays *1* and *2* are connected in series and

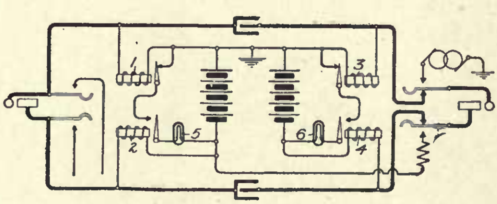


Fig. 351. Two-Wire Cord Circuit

bridged across the answering cord, a battery being included between the coils in this circuit. The coils of the relays *3* and *4* are similarly connected across the calling cord. A peculiar feature of the Kellogg system is that two batteries are used in connection with the cord circuit, one of them being common to all answering cords and the other to all calling cords. The operation of the system would, however, be exactly the same if a single battery were substituted for the two.

Supervisory Signals. Considering the relays associated with the answering cord, it is obvious that these two relays *1* and *2* together control the circuit of the supervisory lamp *5*, the circuit of this lamp being closed only when the relay *1* is de-energized and the relay *2* is energized. We will find in discussing the operation of these that the relay *2* is wholly under the control of the operator, and that the relay *1*, after its plug has been connected with a line, is wholly under the control of the subscriber on that line. It is through the windings of these two relays that current is fed to the line of the subscriber connected with the corresponding cord.

When a plug—the answering plug, for instance—is inserted into a jack, current at once flows from the positive pole of the left-hand battery through the winding of the relay *2* to the sleeve of the plug, thence to the sleeve of the jack and through the cut-off relay to ground. This at once energizes the supervisory relay *2* and the cut-off relay associated with the line. The cut-off relay acts, as stated, to continue the tip and sleeve wires associated with the jacks to the line leading to the subscriber, and also to cut off the line relay. The supervisory relay *2* acts at the same time to attract its armature and thus complete its part in closing the circuit of the supervisory lamp. Whether or not the lamp will be lighted at this time depends on whether the relay *1* is energized or not, and this, it will be seen, depends on whether the subscriber's receiver is off or on its hook. If off its hook, current will flow through the metallic circuit of the line for energizing the subscriber's transmitter, and as whatever current goes to the subscriber's line must flow through the relay *1*, that relay will be energized and prevent the lighting of the supervisory lamp *5*. If, on the other hand, the subscriber's receiver is on its hook, no current will flow through the line, the supervisory relay will not be energized, and the lamp *5* will be lighted.

In a nutshell, the sleeve supervisory relay normally prevents the lighting of the corresponding supervisory lamp, but as soon as the operator inserts a plug into the jack of the line, the relay *2* establishes such a condition as to make possible the lighting of the supervisory lamp, and the lighting of this lamp is then controlled entirely by the relay *1*, which is, in turn, controlled by the position of the subscriber's switch-hook.

Battery Feed. A 2-microfarad condenser is included in each strand of the cord, and battery is fed through the relay windings to the calling and called subscribers on opposite sides of these condensers, in accordance with the combined impedance coil and condenser method described in Chapter XIII. Here the relay windings do double duty, serving as magnets for operating the relays and as retardation coils in the system of battery supply.

Complete Cord and Line Circuits. The complete cord and line circuits of the Kellogg two-wire system are shown in Fig. 352. In the more recent installations of the Kellogg Company the cord and line circuits have been slightly changed from those shown in Figs. 350 and 351, and these changes have been incorporated in Fig. 352. The principles of operation described in connection with the simplified figures remain, however, exactly the same. One of the changes is, that the tip side of the lines is permanently connected to the tips of the jacks instead of being normally cut off by the cut-off relay, as was done in the system as originally developed. Another change is, that the line relay is associated with the tip side of the line, rather than with the sleeve side, as was formerly done. The cord circuit shown in Fig. 352 shows exactly the same arrangement of supervisory relays and exactly the same method of battery feed as in the simplified cord circuit of Fig. 351, but in addition to this the detailed connections of the operator's talking set and of her order-wire keys are indicated, and also the ringing equipment is indicated as being adapted for four-party harmonic work.

In connection with this ringing key it may be stated that the springs *7*, *8*, *9*, and *10* are individually operated by the pressure of one of the ringing key buttons, while the spring *17*, connected with the sleeve side of the calling plug, is always operated simultaneously with the operation of any one of the other springs. As a result the proper ringing circuit is established, it being understood that the upper contacts of the springs *7*, *8*, *9*, and *10* lead to the terminals of their respective ringing generators, the other terminals of which are grounded. The circuit is, therefore, from the generator, through the ringing key, out through the tip side of the line, back over

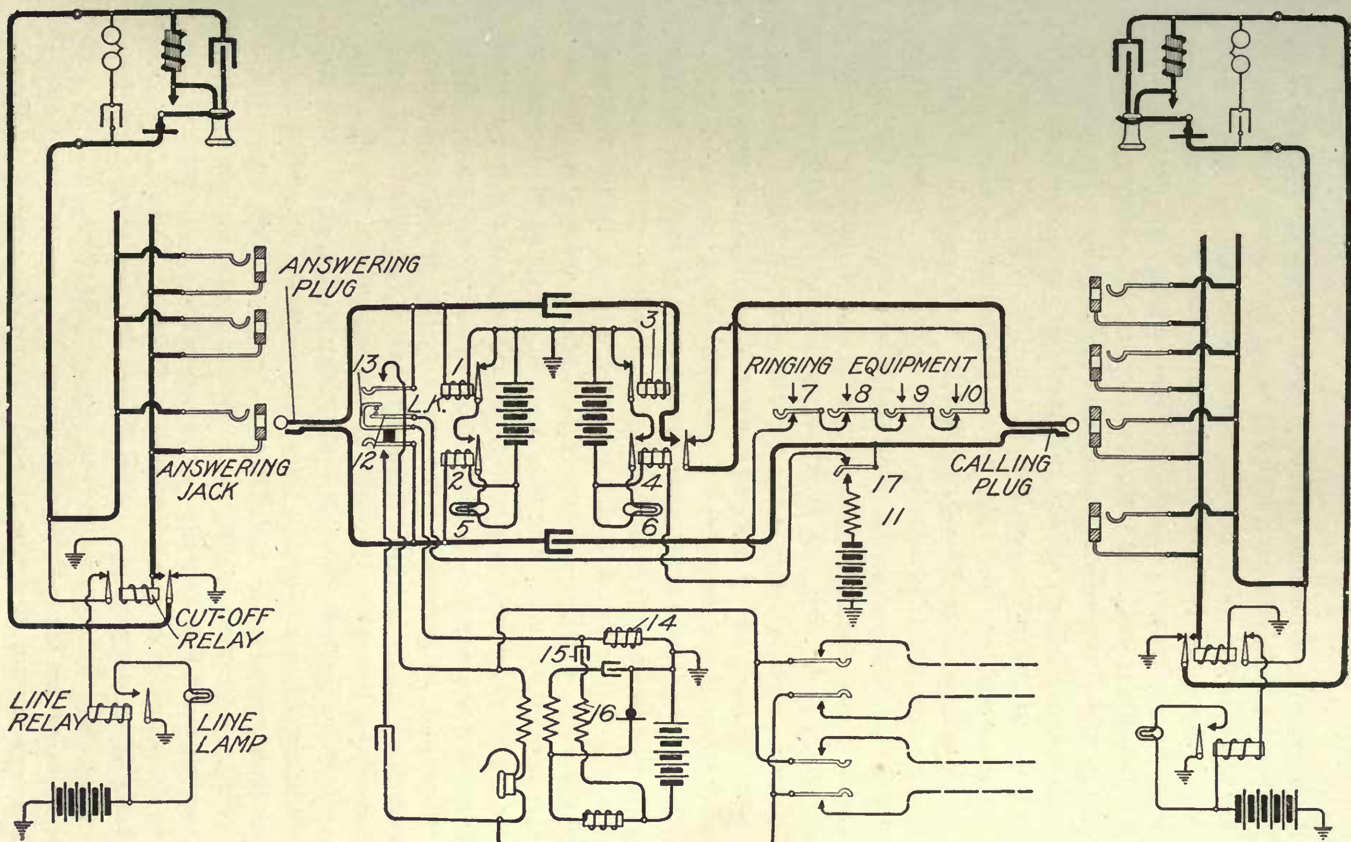


Fig. 352. Kellogg Two-Wire Board

the sleeve side of the line, and to ground through the spring *17*, resistance *11*, and the battery, which is one of the cord-circuit batteries. The object of this coil *11* and the battery connection through it to the ringing-key spring is to prevent the falling back of the cut-off relay when the ringing key is operated. This will be clear when it is remembered that the cut-off relay is energized by battery current fed over the sleeve strand of the cord, and obviously, since it is necessary when the ringing key is operated to cut off the supply wire back of the key, this would de-energize the cut-off relay when the ringing key was depressed, and the falling back of the cut-off relay contacts would make it impossible to ring because the sleeve side of the line would be cut off. The battery supply through the resistance *11* is, therefore, substituted on the sleeve strand of the cord for the battery supply through the normal connection.

Busy Test. The busy test depends on all of the test rings being at zero potential on an idle line and at a higher potential on a busy line. Obviously, when the line is not switched, the test rings are at zero potential on account of a ground through the cut-off relay. When, however, a plug is inserted in either the answering or multiple jacks, the test rings will all be raised in potential due to being connected with the live side of the battery through the sleeve strand of the cord. Conditions on the line external to the central office cannot make an idle line test busy because, owing to the presence of the cut-off relay, the sleeve contacts of all the jacks are disconnected from the line when it is idle. The test circuit from the tip of the calling plug to ground at the operator's set passes through the tip strand of the cord, thence through a pair of normally closed extra contacts on the supervisory relay *4*, thence in series through all the ringing key springs *10*, *9*, *8*, and *7*, thence through an extra pair of springs *12* and *13* on the listening key—closed only when the listening key is operated—and thence to ground through a retardation coil *14*. No battery or other source of potential exists in this circuit between ground and the tip of the calling plug and, therefore, the tip is normally at ground potential. The sleeve ring of the jack being at ground potential if the line is idle, no current will flow and no click will be produced in testing such a line. If, however, the line is busy, the test ring will be at a higher potential and, therefore, current will flow from the tip of the calling plug to ground over the path just traced, and this will cause a rise in potential at the terminal of the condenser *15* and a momentary flow of current through the tertiary winding *16* of the operator's induction coil; hence the click.

Obviously the testing circuit from the tip of the calling plug to ground at the operator's set is only useful during the time when the calling plug is not in a jack, and as the tip strand of the calling plug has to do double duty in testing and in serving as a part of the talking circuit, the arrangement is made that the testing circuit will be automatically broken and the talking circuit through the tip strand automatically completed when the plug is inserted into a jack in establishing a connection. This is accomplished by means of the extra contact on the relay *4*, which relay, it will be remembered, is held energized when its corresponding plug is inserted in a jack. During the time when the plug is not inserted, this relay is not energized and the test circuit is completed through the back contact of its right-hand armature. When connection is made at the jack, this relay becomes energized and the tip strand of the cord circuit is made complete by the right-hand lever being pulled against the front contact of this relay. The keys shown to the right of the operator's set are order-wire keys.

Summary of Operation. We may give a brief summary of the operation of this system as shown in Fig. 352. The left-hand station calls and the line relay pulls up, lighting the lamp. The operator inserts an answering plug in the answering jack, thus energizing the cut-off relay which operates to cut off the line relay and to complete the connection between the jacks and the external line. The act of plugging in by the operator also raises the potential of all the test rings so as to guard the line against intrusion by other callers. The supervisory lamp *5* remains unlighted because, although the relay *2* is operated, the relay *1* is also operated, due to the calling subscriber's receiver being off its hook. The operator throws her listening key, communicates with the subscriber, and, learning that the right-hand station is wanted, proceeds to test that line. If the line is idle, she will get no click, because the tip of her calling plug and the tested ring will be at the same ground potential. She then plugs in and presses the proper ringing-key button to send out the proper frequency to ring the particular subscriber on the line—if there be more than one—the current from the battery through the coil *11* and spring *17* serving during this operation to hold up the cut-off relay.

As soon as the operator plugs in with the calling plug, the supervisory lamp *6* lights, assuming that the called subscriber had not already removed his receiver from its hook, due to the fact that the relay *4* is energized and the relay *3* is not. As soon as the called subscriber responds, the relay *3* becomes energized and the supervisory lamp goes out. If the line called for had been busy by virtue of being plugged at another section, the tip of the operator's plug in testing would have found the test ring raised to a potential above the ground, and, as a consequence, current would have flowed from the tip of this plug through the back contact of the right-hand lever of relay *4*, thence through the ringing key springs and the auxiliary listening-key springs to ground through the retardation coil *14*. This would have produced a click by causing a momentary flow of current through the tertiary winding *16* of the operator's set.

Wiring of Line Circuit. The more complete wiring diagram of a single subscriber's line, Fig. 353, shows the placing in the circuits of the terminals and jumper wires of the main distributing frame and of the intermediate distributing frame, and also shows how the pilot lamps and night-alarm circuits are associated with a group of lines. The main distributing frame occupies the same relative position in this line circuit as in the Western Electric, being located in the main line circuit outside of all the switchboard apparatus. The intermediate distributing frame occupies a different relative position from that in the Western Electric line. It will be recalled by reference to Fig. 348 that the line lamp and the answering jack were permanently associated with the line and cut-off relays, such mutations of arrangement as were possible at the intermediate distributing frame serving only to vary the connection between the multiple of a line and one of the various groups of apparatus consisting of an answering jack and line lamp and associated relays. In the Kellogg arrangement, Fig. 353, the line and cut-off relays, instead of being permanently associated with the answering jack and line lamp, are permanently associated with the multiple jacks, no changes, of which the intermediate or main frames are capable, being able to alter the relation between a group of multiple jacks and its associated line and cut-off relays. In this Kellogg arrangement the intermediate distributing frame may only alter the connection of an answering jack and line lamp with the multiple and its permanently associated relays. The pilot and night alarm arrangements of Fig. 353 should be obvious from the description already given of other similar systems.

Dean Multiple Board. In Fig. 354 are shown the circuits of the multiple switchboard of the Dean Electric Company. The subscrib-

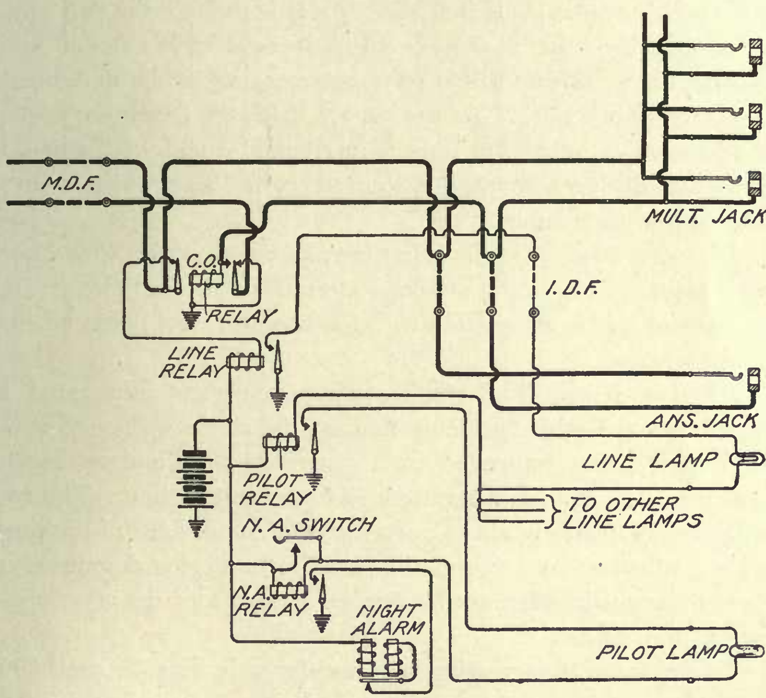


Fig. 353. Kellogg Two-Wire Line Circuit

er's station equipment shown at Station *A* and Station *B* will be recognized as the Wheatstone-bridge circuit of the Dean Company.

Line Circuit. The line circuit is easily understood in view of what has been said concerning the Western Electric line circuit, the line relay *1* being single wound and between the live side of the battery and the ring side of the line. The cut-off relay *2* is operated whenever a plug is inserted in a jack and serves to sever the connection of the line with the normal line signaling apparatus.

Cord Circuit. The cord circuit is of the four-relay type, but employs three conductors instead of two, as in the two-wire system. The relay *3*, being in series between the battery and the sleeve contact on the plug, is energized whenever a plug is inserted in the jack, its winding being placed in series with the cut-off relay of the line with which the plug is connected. This completes the circuit through the associated supervisory lamp unless the relay *4* is energized, the local lamp circuit being controlled by the back contact of relay *4* and the front contact of relay *3*. It is through the two windings of the relay *4* that current is fed to the subscriber's station, and, therefore, the armature of this relay is responsive to the movements of the subscriber's hook. As the relay *3* holds the supervisory lamp circuit closed as long as a plug is inserted in a jack of the line, it follows that during a connection the relay *4* will have entire control of the supervisory lamp.

Listening Key. The listening key, as usual, serves to connect the operator's set across the talking strands of the cord circuit, and the action of this in connection with the operator's set needs no further explanation.

Ringing Keys. The ringing-key arrangement illustrated is adapted for use with harmonic ringing, the single springs *5*, *6*, *7*, and *8* each being controlled by a separate button and serving to select the particular frequency that is to be sent to line. The two springs *9* and *10* always act to open the cord circuit back of the ringing keys, whenever any one of the selective buttons is depressed, in order to prevent interference by ringing current with the other operations of the circuit.

Two views of these ringing keys are shown in Figs. 355 and 356. Fig. 356 is an end view of the entire set. In Fig. 355 the listening key is shown at the extreme right and the four selective buttons at the left. When a button is released it rises far enough to cause the disengagement of the contacts, but remains partially depressed to serve as an indication that it was last used. The group of springs at the extreme left of Fig. 355 are the ones represented at *9* and *10* in Fig. 354 and by the anvils with which those springs co-operate.

Test. The test in this Dean system is simple, and, like the Western Electric and Kellogg systems, it depends on the raising of the potential of the test thimbles of all the line jacks of a line when

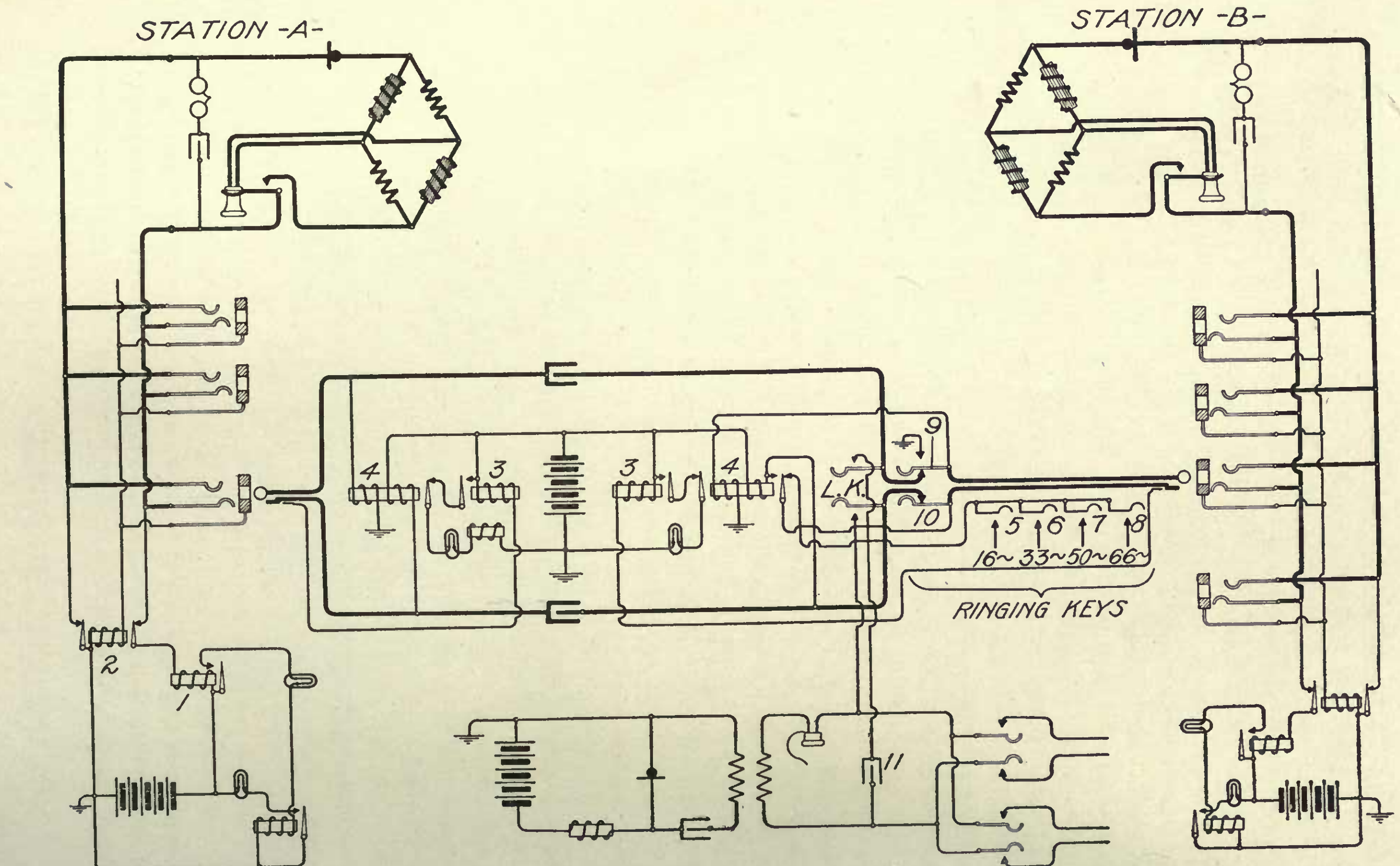


Fig. 354. Dean Multiple Board Circuits

a connection is made with that line by a plug at any position. When an operator makes a test by applying the tip of the calling plug to the test thimble of a busy line, current passes from the test thimble

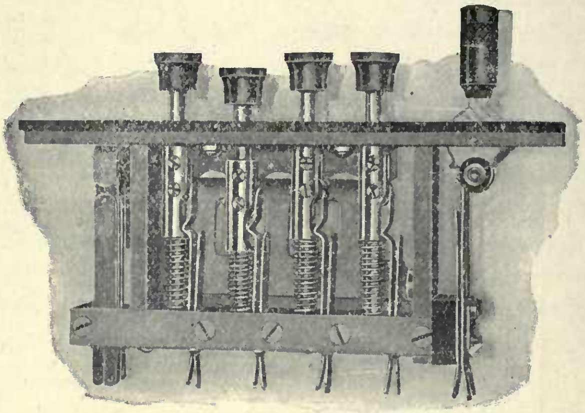


Fig. 355. Dean Party Line R'nging Key

through the tip strand of the cord to ground through the left-hand winding of the calling supervisory relay *4*. The drop of potential through this winding causes the tip strand of the cord to be raised to a higher potential than it was before, and as a result the upper plate of the condenser *11* is thus altered in potential and this change in potential across the condenser results in a click in the operator's ear.

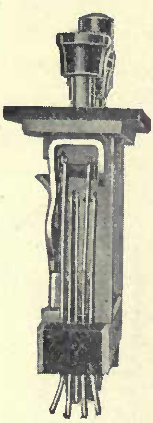


Fig. 356. Dean Party Line Ringing Key

Stromberg-Carlson Multiple Board. *Line Circuit.* In Fig. 357 is shown the multiple common-battery switchboard circuits employed by the Stromberg-Carlson Telephone Manufacturing Company. The subscriber's line circuits shown in this drawing are of the three-wire type and, with the exception of the subscriber's station, are the same as already described for the Western Electric Company's system.

Cord Circuit. The cord circuit employed is of the two-conductor type, the plugs being so constructed as to connect the ring and thimble contacts of the jack when inserted. This cord circuit is somewhat similar to that employed by the Kellogg Switchboard and Supply Company, shown in Fig. 352, except that only one battery is employed, and that certain functions of this circuit are performed mechanically by the inter-action of the armatures of the relays.

Supervisory Signals. When the answering plug is inserted in a jack, in response to a call, the current passing to the subscriber's station and also through the cut-off relay must flow through the relay *1*, thus energizing it. As the calling subscriber's receiver is at this time removed from the hook switch, the path for current will be completed through the tip of the jack, thence through the tip of the plug, through relay *2* to ground, causing relay *2* to be operated and to break the circuit of the answering supervisory lamp. The two relays *1* and *2* are so associated mechanically that the armature of *1* controls the armature of *2* in such a manner as to normally hold the circuit of the answering supervisory lamp open. But, however, when the plug is inserted in a jack, relay *1* is operated and allows the operation of relay *2* to be controlled by the hook switch at the subscriber's station. The supervisory relay *3* associated with the calling cord is operated when the calling plug is placed in a jack, and this relay normally holds the armature of relay *4* in an operated position in a similar manner as the armature of relay *1* controlled that of relay *2*. Supervisory relay *4* is under the control of the hook switch at the called subscriber's station.

Test. In this circuit, as in several previously described, when a plug is inserted in a jack of a line, the thimble contacts of the jacks associated with that line are raised to a higher potential than that which they normally have. The operator in testing a busy line, of course having previously moved the listening key to the listening position, closes a path from the test thimble of the jack, through the tip of the calling plug, through the contacts of the relay *4*, the inside springs of the listening key, thence through a winding of the induction coil associated with her set to ground. The circuit thus established allows current to flow from the test thimble of the jack through the winding of her induction coil to ground, causing a click in her telephone receiver. The arrangement of the ringing circuit does not differ materially from that already described for other systems and, therefore, needs no further explanation.

Multiple Switchboard Apparatus. Coming now to a discussion of the details of apparatus employed in multiple switchboards, it may

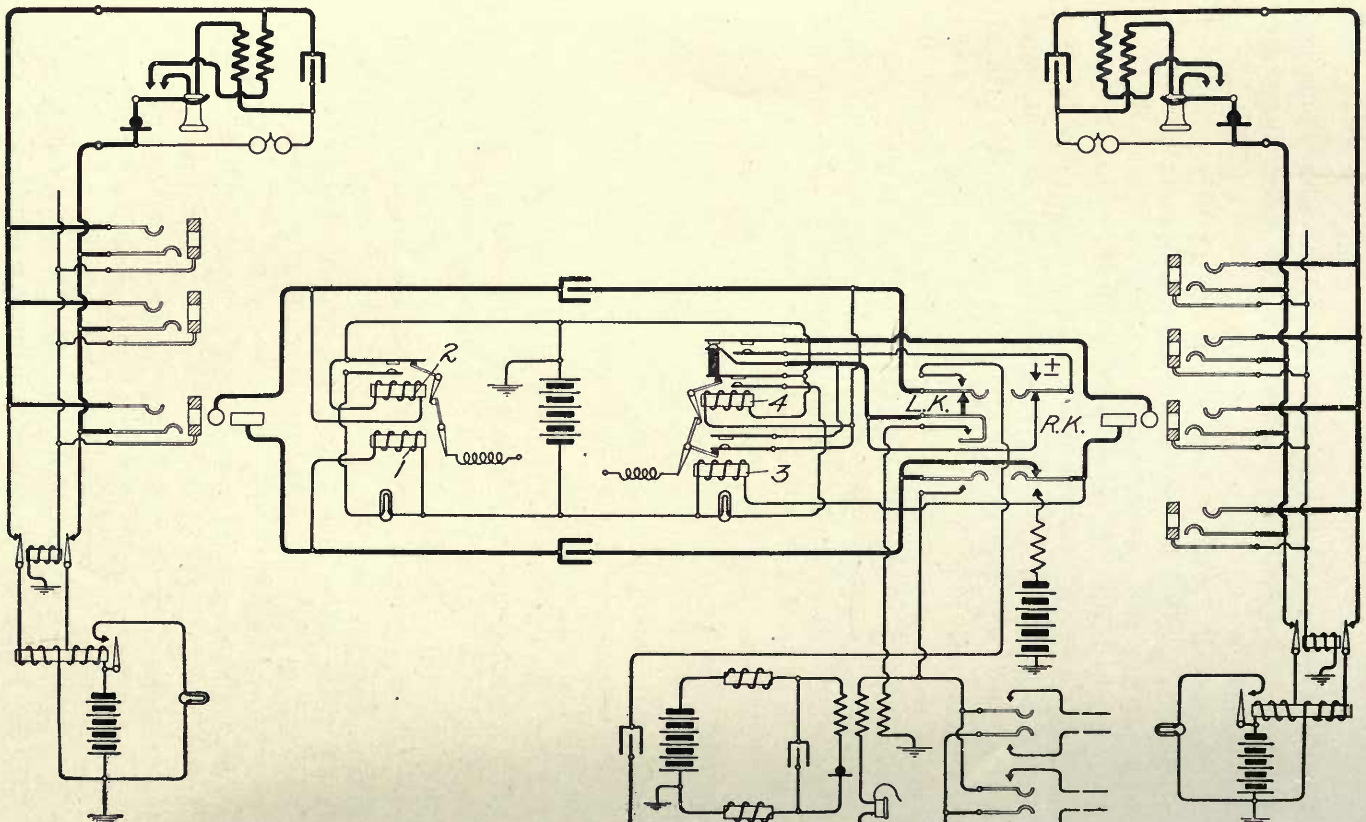


Fig. 357. Stromberg-Carlson Multiple Board Circuits

be stated that much of the apparatus used in the simpler types is capable of doing duty in multiple switchboards, although, of course, modification in detail is often necessary to make the apparatus fit the particular demands of the system in which it is to be used.

Jacks. Probably the most important piece of apparatus in the multiple switchboard is the jack, its importance being increased by the fact that such very large numbers of them are sometimes necessary. Switchboards having hundreds of thousands of jacks are not uncommon. The multiple jacks are nearly always mounted in strips of twenty and the answering jacks usually in strips of ten, the length of the jack strip being the same in each case in the same board and, therefore, giving twice as wide a spacing in the answering as in the multiple jacks. The distance between centers in the multiple jacks varies from a quarter of an inch—which is perhaps the extreme minimum—to half an inch, beyond which larger limit there seems to be no need of going in any case. It is customary that the jack strip shall be made of the same total thickness as the distance between the centers of two of its jacks, and from this it follows that the strips when piled one upon the other give the same vertical distance between jack centers as the horizontal distance.

In Fig. 358 is shown a strip of multiple and a strip of answering jacks of Western Electric make, this being the type employed in the No. 1 standard switchboards for large exchanges. In Fig. 359 are shown the multiple and answering jacks employed in the No. 10 Western Electric switchboard. The multiple jacks in the No. 1 switchboard are mounted on $\frac{3}{8}$-inch centers, the jacks having three branch terminal contacts. The multiple jacks of the No. 10 switchboard indicated in Fig. 359 are mounted on $\frac{1}{2}$-inch centers, each jack having five contacts as indicated by the requirement of the circuits in Fig. 349.

In Fig. 360 are shown the answering and multiple jacks of the Kellogg Switchboard and Supply Company's two-wire system. The extreme simplicity of these is particularly well shown in the cut of the answering jack, and these figures also show clearly the customary method of numbering jacks. In very large multiple boards it has been the practice of the Kellogg Company to space the multiple jacks on $\frac{3}{10}$-inch centers, and in their smaller multiple work, they employ the $\frac{1}{2}$-inch spacing. With the $\frac{3}{10}$-inch spacing that company has been able to build boards having a capacity of 18,000 lines, that many jacks being placed within the reach of each operator.

In all modern multiple switchboards the test thimble or sleeve contacts are drawn up from sheet brass or German silver into tubular form and inserted in properly spaced borings in strips of hard rubber forming the faces of the jacks. These strips sometimes are reinforced by brass strips on their under sides. The springs forming the other terminals of the jack are mounted in milled slots in another

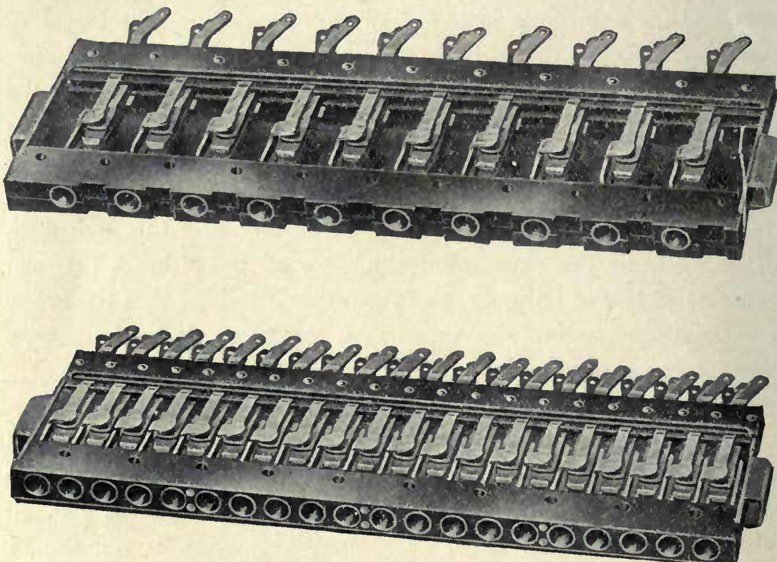


Fig. 358. Answering and Multiple Jacks for No. 1 Board

strip of hard rubber mounted in the rear of and parallel to the front strip and rigidly attached thereto by a suitable metal framework. In this way desired rigidity and high insulation between the various parts is secured.

Lamp Jacks. The lamp jacks employed in multiple work need no further description in view of what has been said in connection with lamp jacks for simple common-battery boards. The lamp jack spacing is always the same as the answering jack spacing, so that the lamps will come in the same vertical alignment as their corresponding answering jacks when the lamp strips and answering jack strips are mounted in alternate layers.

Relays. Next in order of importance in the matter of individual parts for multiple switchboards is the relay. The necessity for reliability of action in these is apparent, and this means that they

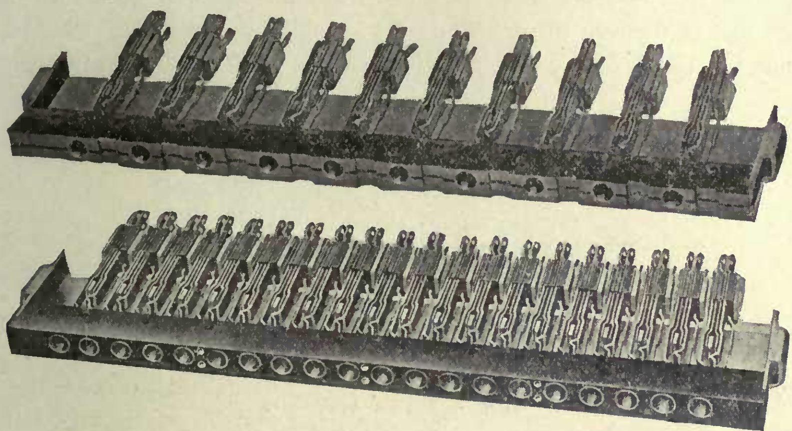


Fig. 359. Answering and Multiple Jacks for No 10 Board

must not only be well constructed, but that they must be protected from dust and moisture and must have contact points of such a nature as not to corrode even in the presence of considerable sparking

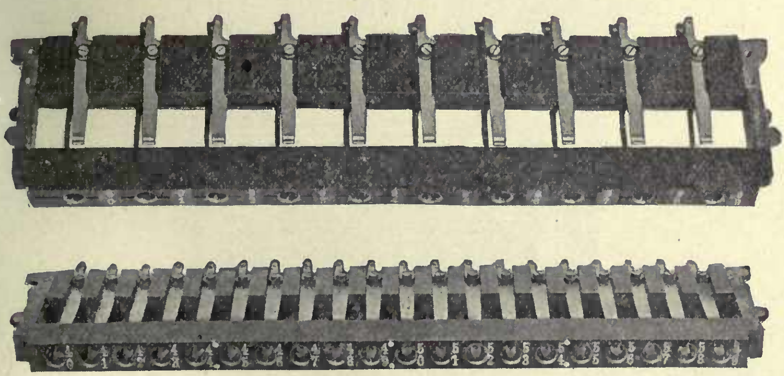


Fig. 360. Answering and Multiple Jacks for Kellogg Two-Wire Board

and of the most adverse atmospheric conditions. Economy of space is also a factor and has led to the almost universal adoption of the single-magnet type of relay for line and cut-off as well as supervisory purposes.

The Western Electric Company employs different types of relays for line, cut-off, and supervisory purposes. This is contrary to the practice of most of the other companies who make the same general type of relay serve for all of these purposes. A good idea of the type of Western Electric line relay, as employed in its No. 1 board, may be had from Fig. 361. As is seen this is of the tilting armature

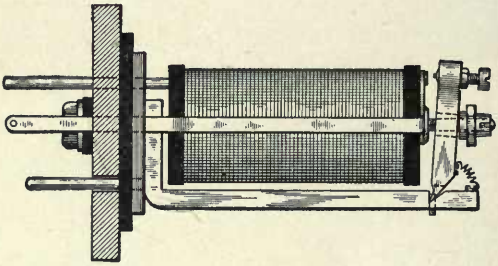


Fig. 361. Type of Line Relay

type, the armature rocking back and forth on a knife-edge contact at its base, the part on which it rests being of iron and of such form as to practically complete, with the armature and core, the magnetic circuit. The cut-off relay, Fig. 362, is of an entirely different type. The armature in this is loosely suspended by means of a flexible

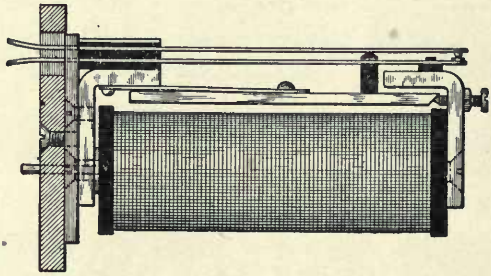


Fig. 362. Type of Cut-Off Relay

spring underneath two L-shaped polar extensions, one extending up from the rear end of the core and the other from the front end. When energized this armature is pulled away from the core by these L-shaped pieces and imparts its motion through a hard-rubber pin to the upper pair of springs so as to effect the necessary changes in the circuit.

Much economy in space and in wiring is secured in the type of switchboards employing cut-off as well as line relays by mounting the two relays together and in making of them, in fact, a unitary

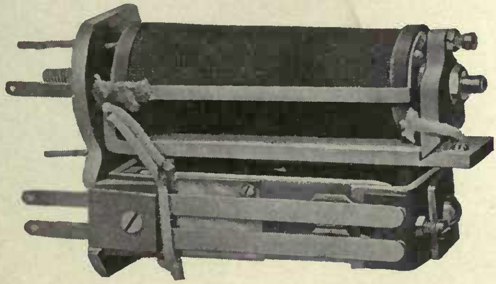


Fig. 363. Western Electric Combined Line and Cut-off Relay

piece of apparatus. Since the line relay is always associated with the cut-off relay of the same line and with no other, it is obvious that this unitary arrangement effects a great saving in wiring and

Fig. 364. Western Electric Supervisory Relay

also secures a great advantage in the matter of convenience of inspection. Such a combined cut-off and line relay, employed in the Western Electric No. 1 relay board, is shown in Fig. 363.

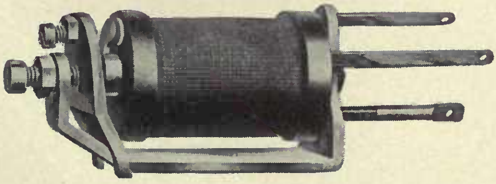


Fig. 365. Line Relay No. 10 Board

These are mounted in banks of ten pairs, a common dust cap of sheet iron covering the entire group.

The Western Electric supervisory relay, Fig. 364, is of the tilting armature type and is copper clad. The dust cap in this case fits on with a bayonet joint as clearly indicated. In Fig. 365 is shown the line relay employed in the Western Electric No. 10 board.

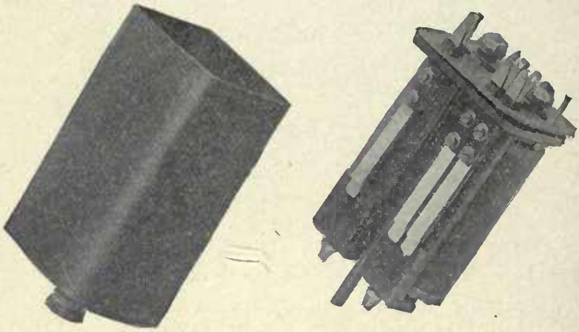


Fig. 366. Kellogg Line and Cut-off Relays

The Kellogg Company employs the type of relay of which the magnetic circuit was illustrated in Fig. 95. In its multiple boards it commonly mounts the line and cut-off relays together, as shown in Fig. 366. A single, soft iron shell is used to cover both of these, thus serving as a dust shield and also as a magnetic shield to prevent cross-talk between adjacent relays—an important feature, since it will be remembered the cut-off relays are left permanently connected with the talking circuit. Fig. 367, which shows a strip of twenty such pairs of relays, from five of which the covers have been

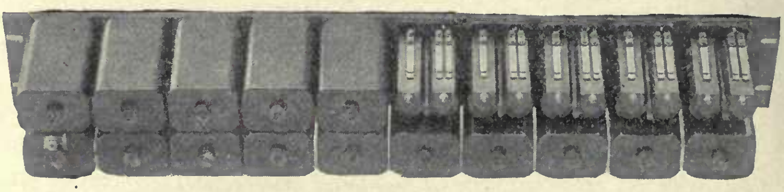


Fig. 367. Strip of Kellogg Line and Cut-Off Relays

removed, is an excellent detail view of the general practice in this respect; obviously, a very large number of such relays may be mounted in a comparatively small space. The mounting strip shown in this cut is of heavy rolled iron and is provided with openings through which the connection terminals—shown more clearly in Fig. 366—project. On the back of this mounting strip all the wiring is done and much of this wiring—that connecting adjacent terminals on the back of the relay strip—is made by means of thin copper wires without insulation, the wires being so short as to support themselves without danger of crossing with other wires. When these wires are adjacent to ground or battery wires they may be protected by sleeving, so as to prevent crosses.

An interesting feature in relay construction is found in the relay of the Monarch Telephone Manufacturing Company shown

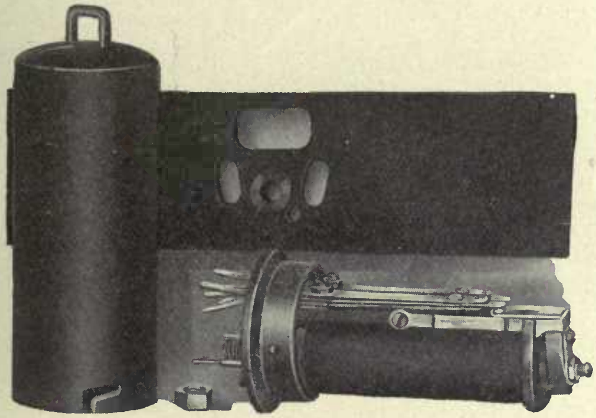


Fig. 368. Monarch Relay

in Figs. 368 and 369. The assembled relay and its mounting strip and cap are shown in Fig. 368. This relay is so constructed that by the lifting of a single latch not only the armature but the coil may be bodily removed, as shown in Fig. 369, in which the latch is shown in its raised position. As seen, the armature has an L-shaped projection which serves to operate the contact springs lying on the iron plate above the coil. The simplicity of this device is attractive, and it is of convenience not only from the standpoint of easy repairs but also from the standpoint of factory assembly, since by manufacturing standard coils with different characters of windings and standard groups of springs, it is possible to produce without special manufacture almost any combination of relay.

Assembly. The arrangement of the key and jack equipment in complete multiple switchboard sections is clearly shown in Fig. 370, which shows a single three-position section of one of the small multiple switchboards of the Kellogg Switchboard and Supply Company. The arrangement of keys and plugs on the key shelf is substantially the same as in simple common-battery boards. As in the simple switchboards the supervisory lamps are usually mounted on the hinged key shelf immediately in the rear of the listening and ringing keys and with such spacing as to lie immediately in front of

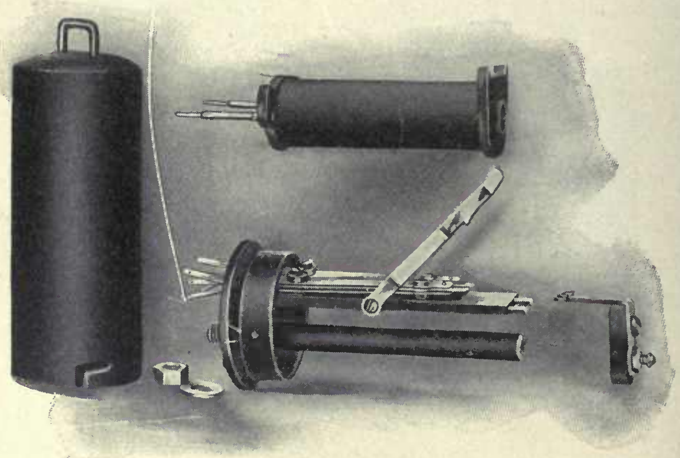


Fig. 369. Monarch Relay

the plugs to which they correspond. The reason for mounting the supervisory lamps on the key shelf is to make them easy of access in case of the necessity of lamp renewals or repairs on the wiring The space at the bottom of the vertical panels, containing the jacks, is left blank, as this space is obstructed by the standing plugs in front of it. Above the plugs, however, are seen the alternate strips of line lamps and answering jacks, the lamps in each case being directly below the corresponding answering jacks. Above the line lamps and answering jacks in the two positions at the right there are blank strips into which additional line lamps and jacks may be placed in case the future needs of the system demand it. The space above these is the multiple jack space, and it is evident from the small number of multiple jacks in this little switchboard that the present equipment of the board is small. It is also evident from the amount of blank space left for future installations of multiple jacks that a considerable growth is expected. Thus, while there are but four banks of 100 multiple jacks, or 400 in all, there is room in the multiple for 300 banks of 100 multiple jacks, or 3,000 in all. The method of grouping the jacks in banks of 100 and of providing for their future growth is clearly indicated in this figure. The next section at the right of the one shown would contain a duplicate set of multiple jacks and also an additional equipment of answering jacks and lamps.

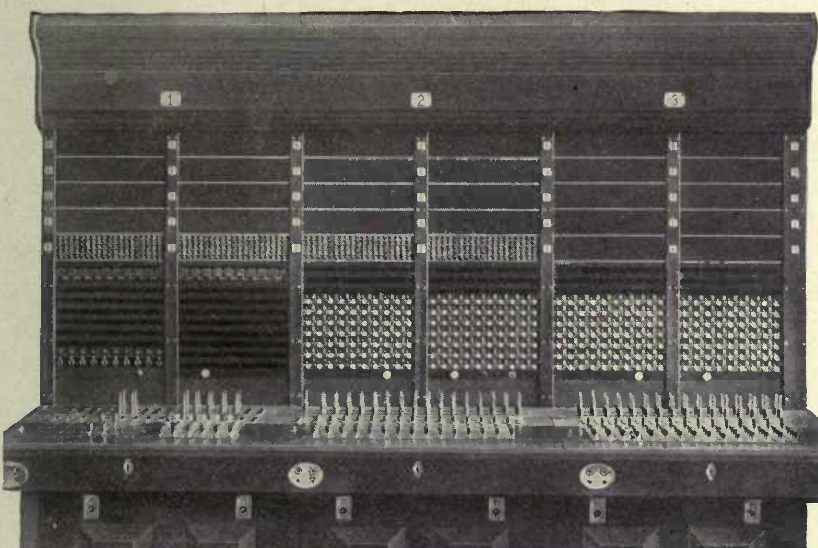


Fig. 370. Small Multiple Board Section

For ordinary local service no operator would sit at the left-hand position of the section shown, that being the end position, since the operator there would not be able easily to reach the extreme right-hand portion of the third position and would have nothing to reach at her left. This end position in this particular board illustrated is provided with toll-line equipment, a practice not uncommon in small multiple boards. To prevent confusion let us assume that the multiple jack space contains its full equipment of 3,000 jacks on each section. The operator in the center position of the section shown could easily reach any one of the jacks on that section. The operator at the third position could reach any jack on the second and third position of her section, but could not well reach multiple jacks in the first position. She would, however, have a duplicate of the multiple jacks in this first position in the section at her right, *i. e.,* in the fourth position, and it makes no difference on what portion of the switchboard she plugs into the multiple so long as she plugs into a jack of the right line.

CHAPTER XXVII

TRUNKING IN MULTI-OFFICE SYSTEMS

It has been stated that a single exchange may involve a number of offices, in which case it is termed a multi-office exchange. In a multi-office exchange, switchboards are necessary at each office in which the subscribers' lines of the corresponding office district terminate. Means for intercommunication between the subscribers in one office and those in any other office are afforded by inter-office trunks extended between each office and each of the other offices.

If the character of the community is such that each of the offices has so few lines as to make the simple switchboard suffice for its local connections, then the trunking between the offices may be carried out in exactly the same way as explained between the various simple switchboards in a transfer system, the only difference being that the trunks are long enough to reach from one office to another instead of being short and entirely local to a single office. Such a condition of affairs would only be found in cases where several small communities were grouped closely enough together to make them operate as a single exchange district, and that is rather unusual.

The subject of inter-office trunking so far as manual switchboards are concerned is, therefore, confined mainly to trunking between a number of offices each equipped with a manual multiple switchboard.

Necessity for Multi-Office Exchanges. Before taking up the details of the methods and circuits employed in trunking in multi-office systems, it may be well to discuss briefly why the multi-office exchange is a necessity, and why it would not be just as well to serve all of the subscribers in a large city from a single huge switchboard in which all of the subscribers' lines would terminate. It cannot be denied, when other things are equal, that it is better to have only one operator involved in any connection which means less labor and less liability of error.

The reasons, however, why this is not feasible in really large exchanges are several. The main one is that of the larger investment required. Considering the investment first from the standpoint of the subscriber's line, it is quite clear that the average length of subscriber's line will be very much greater in a given community if all of the lines are run to a single office, than will be the case if the exchange district is divided into smaller office districts and the lines run merely from the subscribers to the nearest office. There is a direct and very large gain in this respect, in the multi-office system over the single office system in large cities, but this is not a net gain, since there is an offsetting investment necessary in the trunk lines between the offices, which of course are separate from the subscribers' lines.

Approaching the matter from the standpoint of switchboard construction and operation, another strong reason becomes apparent for the employment of more than one office in large exchange districts. Both the difficulties of operation and the expense of construction and maintenance increase very rapidly when switchboards grow beyond a certain rather well-defined limit. Obviously, the limitation of the multiple switchboard as to size involves the number of multiple jacks that it is feasible to place on a section. Multiple switchboards have been constructed in this country in which the sections had a capacity of 18,000 jacks. Schemes have been proposed and put into effect with varying success, for doubling and quadrupling the capacity of multiple switchboards, one of these being the so-called divided multiple board devised by the late Milo G. Kellogg, and once used in Cleveland, Ohio, and St. Louis, Missouri. Each of these boards had an ultimate capacity of 24,000 lines, and each has been replaced by a "straight" multiple board of smaller capacity. In general, the present practice in America does not sanction the building of multiple boards of more than about 10,000 lines capacity, and as an example of this it may be cited that the largest standard section manufactured for the Bell companies has an ultimate capacity of 9,600 lines.

European engineers have shown a tendency towards the opposite practice, and an example of the extreme in this case is the multiple switchboard manufactured by the Ericsson Company, and installed in Stockholm, in which the jacks have been reduced to such small dimensions as to permit an ultimate capacity of 60,000 lines.

The reasons governing the decision of American engineers in establishing the practice of employing no multiple switchboards of greater capacity than about 10,000 lines, briefly outlined, are as follows: The building of switchboards with larger capacity, while perfectly possible, makes necessary either a very small jack or some added complexity, such as that of the divided multiple switchboard, either of which is considered objectionable. Extremely small jacks and large multiples introduce difficulties as to the durability of the jacks and the plugs, and also they tend to slow down the work of operators and to introduce errors. They also introduce the necessity of a smaller gauge of wire through the multiple than it has been found desirable to employ. Considered from the standpoint of expense, it is evident that as a multiple switchboard increases in number of lines, its size increases in two dimensions, *i. e.*, in length of board and height of section, and this element of expense, therefore, is a function of the square of the number of lines.

The matter of insurance, both with respect to the risk as to property loss and the risk as to breakdown of the service, also points distinctly in the direction of a plurality of offices rather than one. Both from the standpoint of risk against fire and other hazards, which might damage the physical property, and of risk against interruption to service due to a breakdown of the switchboard itself, or a failure of its sources of current, or an accident to the cable approaches, the single office practice is like putting all one's eggs in one basket.

Another factor that has contributed to the adoption of smaller switchboard capacities is the fact that in the very large cities even a 40,000 line multiple switchboard would still not remove the necessity of multi-office exchanges with the consequent certainty that a large proportion of the calls would have to be trunked anyway.

Undoubtedly, one of the reasons for the difference between American and European practice is the better results that American operating companies have been able to secure in the handling of calls at the incoming end of trunks. This is due, no doubt, in part to the differences in social and economic conditions under which exchanges are operated in this country and abroad, and also in part to the characteristics of the English tongue when compared to some of the other tongues in the matter of ease with which numbers may be spoken. In America it has been found possible to so perfect the operation of trunking under proper operating conditions and with good equipment as to relieve multi-office practice of many of the disadvantages which have been urged against it.

Classification. Broadly speaking there are two general methods that may be employed in trunking between exchanges. The first and simplest of these methods is to employ so-called *two-way trunks.* These, as their name indicates, may be used for completing connections between offices in either direction, that is, whether the call originates at one end or the other. The other way is by the use of *one-way trunks,* wherein each trunk carries traffic in one direction only. Where such is the case, one end of the trunk is always used for connecting with the calling subscriber's line and is termed the *outgoing* end, and the other end is always used in completing the connection with the called subscriber's line, and is referred to as the *incoming* end. Traffic in the other direction is handled by another set of trunks differing from the first set only in that their outgoing and incoming ends are reversed.

As has already been pointed out, a system of trunks employing two-way trunks is called a *single-track system,* and a system involving two sets of one-way trunks is called a *double-track system.* It is to be noted that the terms outgoing and incoming, as applied to the ends of trunks and also as applied to traffic, always refer to the direction in which the trunk handles traffic or the direction in which the traffic is flowing with respect to the particular office under consideration at the time. Thus an *incoming trunk* at one office is an *outgoing trunk* at the other.

Two-Way Trunks. Two-way trunks are nearly always employed where the traffic is very small and they are nearly always operated by having the *A*-operator plug directly into the jack at her end of the trunk and displaying a signal at the other end by ringing over the trunk as she would over an ordinary subscriber's line. The operator at the distant exchange answers as she would on an ordinary line, by plugging into the jack of that trunk, and receives her orders over the trunk either from the originating operator or from the subscriber, and then completes the connection with the called subscriber. Such trunks are often referred to as "ring-down" trunks, and their equipment consists in a drop and jack at each end. In case there is a multiple board at either or both of the offices, then the equipment at each end of the trunk would consist of a drop and answering jack, together with the full quota of multiple jacks. It is readily seen that this mode of operation is slow, as the work that each operator has to do is the same as that in connecting two local subscribers, plus the time that it takes for the operators to communicate with each other over the trunk.

One-Way Trunks. Where one-way trunks are employed in the double-track system, the trunks, assuming that they connect multiple boards, are provided with multiple jacks only at their outgoing ends, so that any operator may reach them for an outgoing connection, and at their incoming ends they terminate each in a single plug and in suitable signals and ringing keys, the purpose of which will be explained later. Over such trunks there is no verbal communication between the operators, the instructions passing between the operators over separate order-wire circuits. This is done in order that the trunk may be available as much as possible for actual conversation between the subscribers. It may be stated at this point that the duration of the period from the time when a trunk is appropriated by the operators for the making of a certain connection until the time when the trunk is finally released and made available for another connection is called the *holding time*, and this holding time includes not only the period while the subscribers are in actual conversation over it, but also the periods while the operators are making the connection and afterwards while they are taking it down. It may be said, therefore, that the purpose of employing separate order wires for communication between the operators is to make the holding time on the trunks as small as possible and, therefore, for the purpose of enabling a given trunk to take part in as many connections in a given time as possible.

In outline the operation of a one-way trunk between common-battery, manual, multiple switchboards is, with modifications that will be pointed out afterwards, as follows: When a subscriber's line signal is displayed at one office, the operator in attendance at that position answers and finding that the call is for a subscriber in another office, she presses an order-wire key and thereby connects her telephone set directly with that of a *B*-operator at the proper other office. Unless she finds that other operators are talking over the order wire, she merely states the number of the called subscriber, and the *B*-operator whose telephone set is permanently connected with that order wire merely repeats the number of the called subscriber and follows this by designating the number of the trunk which the *A*-operator is to employ in making the connection. The *A*-operator, thereupon, immediately and without testing, inserts the calling plug of the pair used in answering the call into the trunk jack designated by the *B*-operator; the *B*-operator simultaneously tests the multiple jack of the called subscriber and, if she finds it not busy, inserts the plug of the designated trunk into the multiple jack of the called subscriber and rings his bell by pressing the ringing key associated with the trunk cord used. The work on the part of the *A*-operator in connecting with the outgoing end of the trunk and on the part of the *B*-operator in connecting the incoming end of the trunk with the line goes on simultaneously, and it makes no difference which of these operators completes the connection first.

It is the common practice of the Bell operating companies in this country to employ what is called automatic or machine ringing in connection with the *B*-operator's work. When the *B*-operator presses the ringing key associated with the incoming trunk cord, she pays no further attention to it, and she has no supervisory lamp to inform her as to whether or not the subscriber has answered. The ringing key is held down, after its depression by the operator, either by an electromagnet or by a magnet-controlled latch, and the ringing of the subscriber's bell continues at periodic intervals as controlled by the ringing commutator associated with the ringing machine. When the subscriber answers, however, the closure of his line circuit results in such an operation of the magnet associated with the ringing key as to release the ringing key and thus to automatically discontinue the ringing current.

When a connection is established between two subscribers through such a trunk the supervision of the connection falls entirely upon the *A*-operator who established it. This means that the calling supervisory lamp at the *A*-operator's position is controlled over the trunk from the station of the called subscriber, the answering supervisory lamp being, of course, under the control of the calling subscriber as in the case of a local connection. It is, therefore, the *A*-operator who always initiates the taking down of a trunk connection, and when, in response to the lighting of the two lamps, she withdraws her calling plug from the trunk jack, the supervisory lamp associated with the incoming end of the trunk at the other office is lighted, and the *B*-operator obeys it by pulling down the plug.

If, upon testing the multiple jack of the called subscriber's line, the *B*-operator finds the line to be busy, she at once inserts the trunk plug into a so-called "busy-back" jack, which is merely a jack whose terminals are permanently connected to a circuit that is intermittently opened and closed, and which also has impressed upon it an alternating current of such a nature as to produce the familiar "buzz-buzz" in a telephone receiver. The opening and closing of this circuit causes the calling supervisory lamp of the *A*-operator to flash at periodic intervals just as if the called subscriber had raised and lowered his receiver, but more regularly. This is the indication to the *A*-operator that the line called for is busy. The buzzing sound is repeated back through the cord circuit of the *A*-operator to the calling subscriber and is a notification to him that the line is busy.

Sometimes, as is practiced in New York City, for instance, the buzzing feature is omitted, and the only indication that the calling subscriber receives that the called-for line is busy is being told so by the *A*-operator. This may be considered a special feature and it is employed in New York because there the custom exists of telling a calling subscriber, when the line he has called for has been found busy, that the party will be secured for him and that he, the calling subscriber, will be called, if he desires.

A modification of this busy-back feature that has been employed in Boston, and perhaps in other places, is to associate with the busy-back jack at the *B*-operator's position a phonograph which, like a parrot, keeps repeating "Line busy—please call again." Where this is done the calling subscriber, *if he understands what the phonograph says,* is supposed to hang up his receiver, at which time the *A*-operator takes down the connection and the *B*-operator follows in response to the notification of her supervisory lamp. The phonograph busy-back scheme, while ingenious, has not been a success and has generally been abandoned.

As a rule the independent operating companies in this country have not employed automatic ringing, and in this case the *B*-operators have been required to operate their ringing keys and to watch for the response of the called subscriber. In order to arrange for this, another supervisory lamp, termed the *ringing lamp*, is associated with each incoming trunk plug, the going out of this lamp being a notification to the *B*-operator to discontinue ringing.

Western Electric Trunk Circuits. The principles involved in inter-office trunking with automatic ringing, are well illustrated in the trunk circuit employed by the Western Electric Company in connection with its No. 1 relay boards. The dotted dividing line through the center of Fig. 371 represents the separating space between two offices. The calling subscriber's line in the first office is shown at the extreme left and the called subscriber's line in the second office is shown at the extreme right. Both of these lines are standard multiple switchboard lines of the form already discussed. The equipment illustrated in the first office is that of an *A*-board, the cord circuit shown being that of the regular *A*-operator. The outgoing trunk jacks connecting with the trunk leading to the other office are, it will be understood, multipled through the *A*-sections of the board and contain no relay equipment, but the test rings are connected to ground through a resistance coil *1*, which takes the place of the cut-off relay winding of a regular line so far as test conditions and supervisory relay operation are concerned. The equipment illustrated in the second office is that of a *B*-board, it being understood that the called subscriber's line is multipled through both the *A*- and *B*-boards at that office. The part of the equipment that is at this point unfamiliar to the reader is, therefore, the cord circuit at the *B*-operator's board. This includes, broadly speaking, the means: (1) for furnishing battery current to the called subscriber; (2) for accomplishing the ringing of the called subscriber and for automatically stopping the ringing when he shall respond; (3) for performing the ordinary switching functions in connection with the relays of the called subscriber's line in just the same way that an *A*-operator's cord carries out these functions; and (4) for causing the operation of the calling supervisory relay of the *A*-operator's cord circuit in just the same manner, under control of the connected called subscriber, as if that subscriber's line had been connected directly to the *A*-operator's cord circuit.

The operation of these devices in the *B*-operator's cord circuit

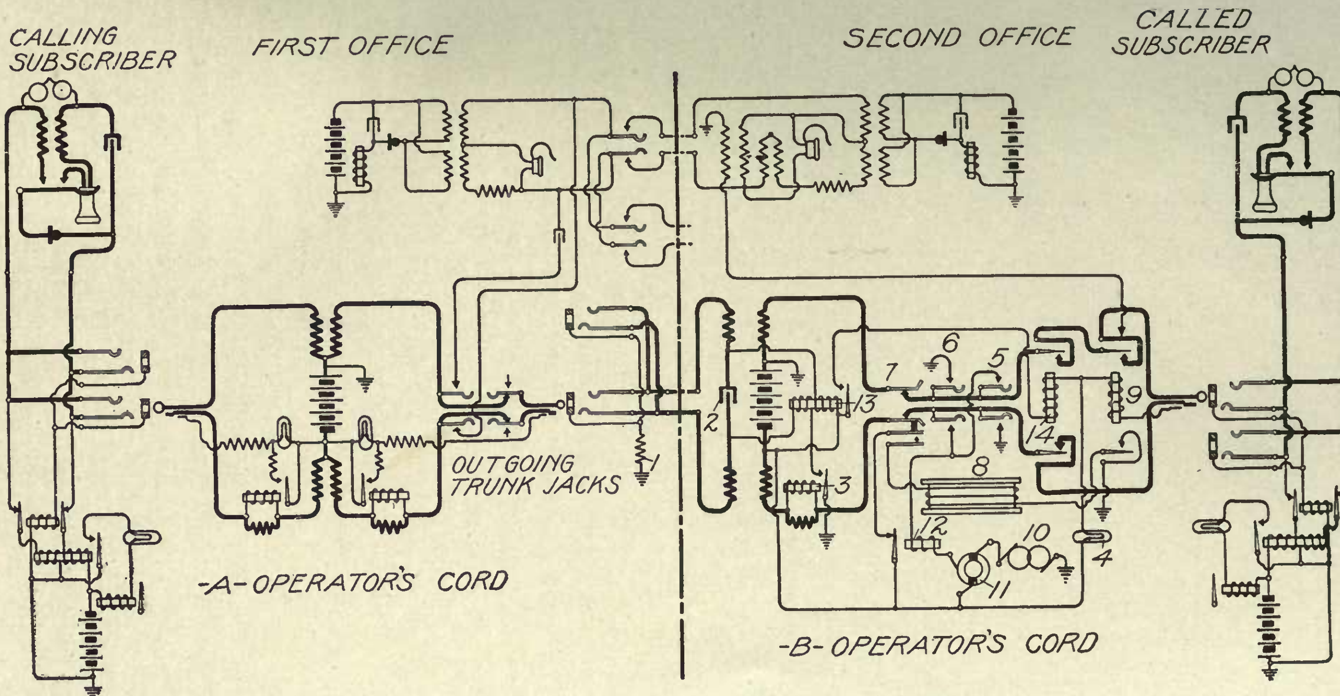


Fig. 371. Inter-Office Connection—Western Electric System

may be best understood by following the establishment of the connection. Assuming that the calling subscriber in the first office desires a connection with the subscriber's line shown in the second office, and that the *A*-operator at the first office has answered the call, she will then communicate by order wire with the *B*-operator at the second office, stating the number of the called subscriber and receiving from that operator in return the number of the trunk to be employed. The two operators will then proceed simultaneously to establish the connection, the *A*-operator inserting the calling plug into the outgoing trunk jack, and the *B*-operator inserting the trunk plug into the multiple jack of the called subscriber's line after testing. We will assume at first that the called subscriber's line is found idle and that both of the operators complete their respective portions of the work at the same time and we will consider first the condition of the calling supervisory relay at the *A*-operator's position.

The circuit of the calling supervisory lamp will have been closed through the resistance coil *1* connected with the outgoing trunk jacks and the lamp will be lighted because, as will be shown, it is not yet shunted out by the operation of its associated supervisory relay. Tracing the circuit of the calling supervisory relay of the *A*-operator's circuit, it will be found to pass from the live side of the battery to the ring side of the trunk circuit through one winding of the repeating coil of the *B*-operator's cord; beyond this the circuit is open, since no path exists through the condenser *2* bridged across the trunk circuit or through the normally open contacts of the relay *3* connected in the talking circuit of the trunk. The association of this relay *3* with the repeating coil and the battery of the trunk is seen to be just the same as that of a supervisory relay in the *A*-operator's cord, and it is clear, therefore, that this relay *3* will not be energized until the called subscriber has responded. When it is energized it will complete the path to ground through the *A*-operator's calling supervisory relay and operate to shunt out the *A*-operator's calling supervisory lamp in just the same manner as if the *A*-operator's calling plug had been connected directly with the line of the calling subscriber. In other words, the called subscriber in the second office controls the relay *3*, which, in turn, controls the calling supervisory relay of the *A*-operator, which, in turn, shunts out its lamp.

The connection being completed between the two subscribers, the *B*-operator depresses one or the other of the ringing keys *5* or *6*, according to which party on the line is called, assuming that it is a two-party line. It will be noticed that the springs of these ringing keys are not serially arranged in the talking circuit, but the cutting off of the trunk circuit back of the ringing keys is accomplished by the set of springs shown just at the left of the ringing keys, which set of springs *7* is operated whenever either one of the ringing keys is depressed. An auxiliary pair of contacts, shown just below the group of springs *7*, is also operated mechanically whenever either one of the ringing keys is depressed, and this serves to close one of two normally open points in the circuit of the ringing-key holding magnet *8*. This holding magnet *8* is so arranged with respect to the contacts of the ringing key that whenever any one of them is depressed by the operator, it will be held depressed as long as the magnet is energized just the same as if the operator kept her finger on the key. The other normally open point in the circuit of the holding magnet *8* is at the lower pair of contacts of the test and holding relay *9*. This relay is operated whenever the trunk plug is inserted in the jack of a called line, regardless of the position of the subscriber's equipment on that line. The circuit may be traced from the live side of the battery through the trunk disconnect lamp *4*, coil *9*, sleeve strand of cord, and to ground through the cut-off relay of the line. The insertion of the trunk plug into the jack thus leaves the completion of the holding-magnet circuit dependent only upon the auxiliary contact on the ringing key, and, therefore, as soon as the operator presses either one of these keys, the clutch magnet is energized and the key is held down, so that ringing current continues to flow at regular intervals to the called subscriber's station.

The ringing current issues from the generator *10*, but the supply circuit from it is periodically interrupted by the commutator *11* geared to the ringing-machine shaft. This periodically interrupted ringing current passes to the ringing-key contacts through the coil of the ringing cut-off relay *12*, and thence to the subscriber's line. The ringing current is, however, insufficient to cause the operation of this relay *12* as long as the high resistance and impedance of the subscriber's bell and condenser are in the circuit. It is, however, sufficiently sensitive to be operated by this ringing current when the subscriber responds and thus substitutes the comparatively low resistance and impedance path of his talking apparatus for the previous path through his bell. The pulling up of the ringing cut-off relay *12* breaks a third normally closed contact in the circuit of the holding coil *8*, de-energizing that coil and releasing the ringing key, thus cutting off ringing current. There is a third brush on the commutator *11* connected with the live side of the central battery, and this is merely for the purpose of assuring the energizing of the ringing cut-off relay *12*, should the subscriber respond during the interval while the commutator *11* held the ringing current cut off. The relay *12* may thus be energized either from the battery, if the subscriber responds during a period of silence of his ringer, or from the generator *10*, if the subscriber responds during a period while his bell is sounding; in either case the ringing current will be promptly cut off by the release of the ringing key.

The trunk operator's "disconnect lamp" is shown at *4*, and it is to be remembered that this lamp is lighted only when the *A*-operator takes down the connection at her end, and also that this lamp is entirely out of the control of the subscribers, the conditions which determine its illumination being dependent on the positions of the operators' plugs at the two ends of the trunk. With both plugs up, the lamp *4* will receive current, but will be shunted to prevent its illumination. The path over which it receives this current may be traced from battery through the lamp *4*, thence through the coil of the relay *9* and the cut-off relay of the called subscriber's line. This current would be sufficient to illuminate the lamp, but the lamp is shunted by a circuit which may be traced from the live side of battery through the contact of the relay *13*, closed at the time, and through the coil of the trunk cut-off relay coil *14*. The resistance of this coil is so proportioned to the other parts of the circuit as to prevent the illumination of the lamp just exactly as in the case of the shunting resistances of the lamps in the *A*-operator's cord. It will be seen, therefore, that the supply of current to the trunk disconnect lamp is dependent on the trunk plug being inserted into the jack of the subscriber's line and that the shunting out of this lamp is dependent on the energization of the relay *13*. This relay *13* is energized as long as the *A*-operator's plug is inserted into the outgoing trunk jack, the path of the energizing circuit being traced from the live side of the battery at the second office through the right-hand winding of this relay, thence over the tip side of the trunk to ground at the first office. From this it follows that as long as both plugs are up, the disconnect lamp will receive current but will be shunted out, and as soon as the *A*-operator pulls down the connection, the relay *13* will be de-energized and will thus remove the shunt from about the lamp, allowing its illumination. The left-hand winding of the relay *13* performs no operating function, but is merely to maintain the balance of the talking circuit, it being bridged during the connection from the ring side of the trunk to ground in order to balance the bridge connection of the right-hand coil from the live side of battery to the tip side of the trunk circuit.

The relay *14*, already referred to as forming a shunt for the trunk disconnect lamp, has for its function the keeping of the talking circuit through the trunk open until such time as the relay *13* operates, this being purely an insurance against unnecessary ringing of a subscriber in case the *A*-operator should by mistake plug into the wrong trunk. It is not, therefore, until the *A*-operator has plugged into the trunk and the relay *13* has been operated to cause the energization of the relay *14* that the ringing of the called subscriber can occur, regardless of what the *B*-operator may have done.

The relay *9* has an additional function to that of helping to control the circuit of the ringing-key holding magnet. This is the holding of the test circuit complete until the operator has tested and made a connection and then automatically opening it. The test circuit of the *B*-operator's trunk may be traced, at the time of testing, from the thimble of the multiple jack under test, through the tip of the cord, thence through the uppermost pair of contacts of the relay *9* to ground through a winding of the *B*-operator's induction coil. After the test has been made and the plug inserted, the relay *9*, which is operated by the insertion of the plug, acts to open this test circuit and at the same time complete the tip side of the cord circuit.

In the upper portion of Fig. 371 the order-wire connections, by which the *A*-operator and the *B*-operator communicate, are indicated. It must be remembered in connection with these that the *A*-operator only has control of this connection, the *B*-operator being compelled necessarily to hear whatever the A-operators have to say when the A-operators come in on the circuit.

The incoming trunk circuit employed by the Western Electric Company for four-party line ringing is shown in Fig. 372, it being

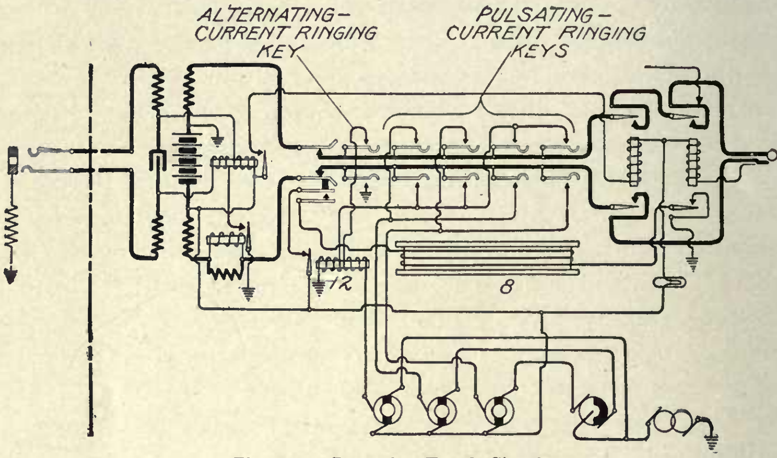


Fig. 372. Incoming Trunk Circuit

necessarily somewhat modified from that shown in Fig. 371, which is adapted for two-party line ringing only. In addition to the provision of the four-party line ringing keys, by which positive or negative pulsating current is received over either limb of the line, and to

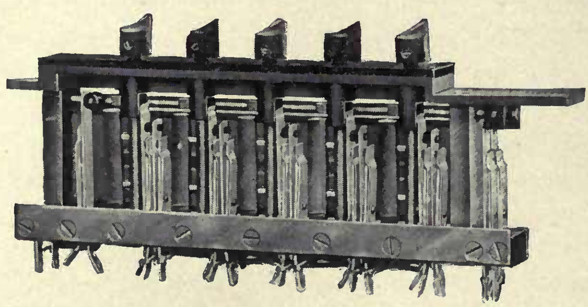


Fig. 373. Western Electric Trunk Ringing Key

the provision of the regular alternating current ringing key for ringing on single party lines, it is necessary in the ringing cut-off relay to provide for keeping the alternating and the pulsating ringing currents entirely separate. For this reason, the ringing cut-off relay *12* is provided with two windings, that at the right being in the path of the alternating ringing currents that are supplied to the alternating current key, and that at the left being in the

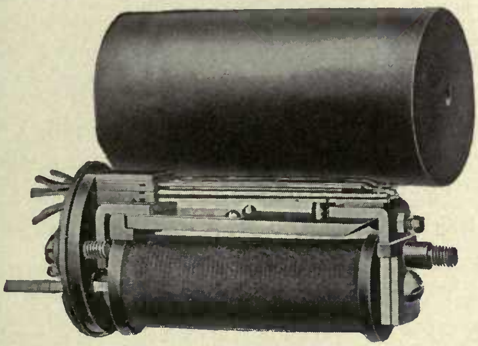


Fig. 374 Trunk Relay

ground return path for all of the pulsating ringing currents supplied to the pulsating keys. With this explanation it is believed that this circuit will be understood from what has been said in connection with Fig. 371. The operation of the holding coil *8* is the same in each case, the holding magnet in Fig. 372 serving to hold depressed any one of the five ringing keys that may have been used in calling the subscriber.

The standard four-party line, trunk ringing key of the Western Electric Company is shown in Fig. 373. In this the various keys

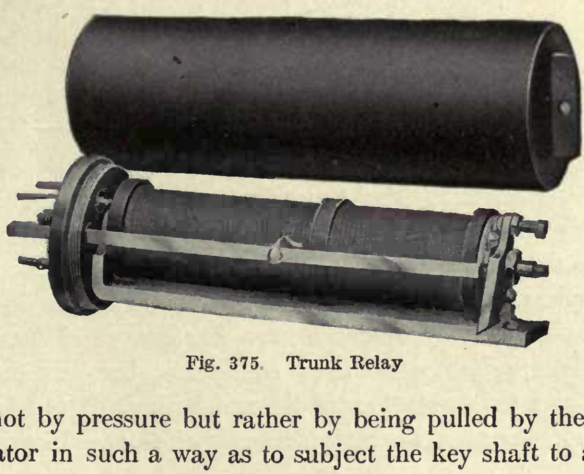


Fig. 375. Trunk Relay

operate not by pressure but rather by being pulled by the finger of the operator in such a way as to subject the key shaft to a twisting movement. The holding magnet lies on the side opposite to that shown in the figure and extends along the full length of the set of keys, each key shaft being provided with an armature which is held by this magnet until the magnet is de-energized by the action of the ringing cut-off relay.

The standard trunk relays employed by the Western Electric Company in connection with the circuits just described are shown in Figs. 374 and 375. In each case the dust-cap or shield is also shown. The relay of Fig. 374 is similar to the regular cut-off relay and is the one used for relays *9* and *14* of Figs. 371 and 372. The relay of Fig. 375 is somewhat similar to the subscriber's line relay in that it has a tilting armature, and is the one used at *13* in Figs. 371 and 372. The trunk relay *3* in Figs. 371 and 372 is the same as the *A*-operator's supervisory relays already discussed.

It has been stated that under certain circumstances *B*-operator's trunk circuits devoid of ringing keys, and consequently of all keys, may be employed. This, so far as the practice of the Bell companies

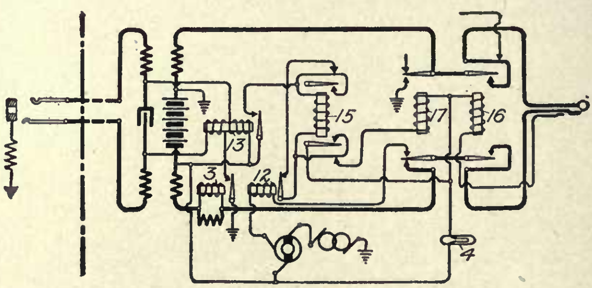


Fig. 376. Keyless Trunk

is concerned, is true only in offices where there are no party lines, or where, as in many of the Chicago offices, the party lines are worked on the "jack per station" basis. In "jack per station" working, the selection of the station on a party line is determined by the jack on which the plug is put, rather than by a ringing key, and hence the keyless trunk may be employed.

A keyless trunk as used in New York is shown in Fig. 376 This has no manually operated keys whatever, and the relay *17*, when it is operated, establishes connection between the ringing generator and the conductors of the trunk plug. The relays *3*, *13*, and *12* operate in a manner identical with those bearing corresponding numbers in Fig. 371. As soon as the trunk operator plugs into the multiple jack of the called subscriber, the relay *16* will operate for the same reason that the relay *9* operated in connection with Fig. 371. The trunk disconnect lamp will receive current, but if the operator has already established connection with the other end of the trunk, this lamp will not be lighted because shunted by the relay *17*, due to the pulling up of the armature of the relay *13*. The relay *15* plays no part in the operation so far described, because of the fact that its winding is short-circuited by its own contacts and those of relay *12*, when the latter is not energized. As a result of the operation of the relay *17*, ringing current is sent to line, the supply circuit including the coil of the relay *12*. As soon as the subscriber responds to this ringing current, the armature of the relay *12* is pulled up, thus breaking the shunt about the relay *15*, which, therefore, starts to operate in series with the relay *17*, but as its armatures assume their attracted position, the relay *17* is cut out of the circuit, the coil of the relay *15* being substituted for that of the relay *17* in the shunt path around the lamp *4*. The relay *17* falls back and cuts off the ringing current. The relay *15* now occupies the place with respect to the shunt around the lamp *4* that the relay *17* formerly did, the continuity of this shunt being determined by the energization of the relay *13*. When the *A*-operator at the distant exchange withdraws the calling plug from the trunk jack, this relay *13* becomes de-energized, breaking the shunt about the lamp *4* and permitting the display of that lamp as a signal to the operator to take down the connection. It may be asked why the falling back of relay *15* will not again energize relay *17* and thus cause a false ring on the called subscriber. This will not occur because both the relays *15* and *17* depend for their energization on the closure of the contacts of the relay *13*, and when this falls back the relay *17* cannot again be energized even though the relay *15* assumes its normal position.

Kellogg Trunk Circuits. The provision for proper working of trunk circuits in connection with the two-wire multiple switchboards is not an altogether easy matter, owing particularly to the smaller number of wires available in the plug circuits. It has been worked out in a highly ingenious way, however, by the Kellogg Company, and a diagram of their incoming trunk circuit, together with the associated circuits involved in an inter-office connection, is shown in Fig. 377.

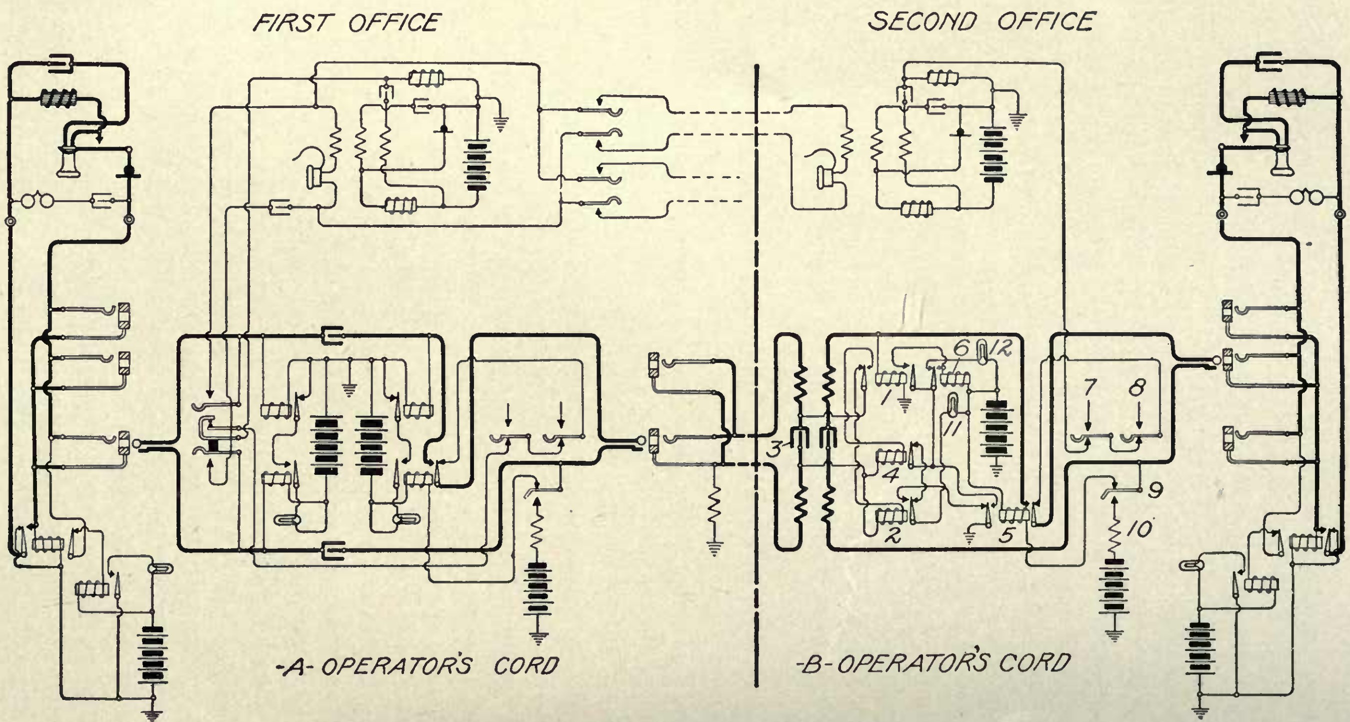


Fig. 377 Inter-Office Connection—Kellogg System

This figure illustrates a connection from a regular two-wire multiple subscriber's line in one office, through an *A*-operator's cord circuit there, to the outgoing trunk jacks at that office, thence through the incoming trunk circuit at the other office to the regular two-wire multiple subscriber's line at that second office. The portion of this diagram to be particularly considered is that of the *B*-operator's cord circuit. The trunk circuit terminates in the multipled outgoing trunk jacks at the first office, the trunk extending between offices consisting, of course, of but two wires. We will first consider the control of the calling supervisory lamp in the *A*-operator's cord circuit, it being remembered that this control must be from the called subscriber's station. It will be noticed that the left-hand armature of the relay *1* serves normally to bridge the winding of relay *2* across the cord circuit around the condenser *3*. When, however, the relay *1* pulls up, the coil of relay *4* is substituted in this bridge connection across the trunk. The relay *2* has a very high resistance winding—about 15,000 ohms—and this resistance is so great that the tip supervisory relay of the *A*-operator's cord will not pull up through it. As a result, when this relay is bridged across the trunk circuit, the tip relay on the calling side of the *A*-operator's cord circuit is de-energized, just as if the trunk circuit were open, and this results in the lighting of the *A*-operator's calling supervisory lamp. The winding of the relay *4*, however, is of low resistance—about 50 ohms—and when this is substituted for the high-resistance winding of the relay *2*, the tip relay on the calling side of the *A*-operator's cord is energized, resulting in the extinguishing of the calling supervisory lamp. The illumination of the *A*-operator's calling supervisory lamp depends, therefore, on whether the high-resistance relay *2*, or the low-resistance relay *4*, is bridged across the trunk, and this depends on whether the relay *1* is energized or not. The relay *1*, being bridged from the tip side of the trunk circuit to ground and serving as the means of supply of battery current to the called subscriber, is operated whenever the called subscriber's receiver is removed from its hook. Therefore, the called subscriber's hook controls the operation of this relay *1*, which, in turn, controls the conditions which cause the illumination or darkness of the calling supervisory lamp at the distant office.

Assuming that the *A*-operator has received and answered a call, and has communicated with the *B*-operator, telling her the number of the called subscriber, and has received, in turn, the number of the trunk to be used, and that both operators have put up the connection, then it will be clear from what has been said that the calling supervisory lamp of the *A*-operator will be lighted until the called subscriber removes his receiver from its hook, because the tip relay in the *A*-operator's cord circuit will not pull up through the 15,000-ohm resistance winding of the relay *2*. As soon as the subscriber responds, however, the relay *1* will be operated by the current which supplies his transmitter. This will substitute the low-resistance winding of the relay *4* for the high-resistance winding of the relay *2*, and this will permit the energizing of the tip supervisory relay of the *A*-operator and put out the calling supervisory lamp at her position. As in the Western Electric circuit, therefore, the control of the *A*-operator's calling supervisory lamp is from the called subscriber's station and is relayed back over the trunk to the originating office.

In this circuit, manual instead of automatic ringing is employed, therefore, unlike the Western Electric circuit, means must be provided for notifying the *B*-operator when the calling subscriber has answered. This is done by placing at the *B*-operator's position a ringing lamp associated with each trunk cord, which is illuminated when the *B*-operator places the plug of the incoming trunk into the multiple jack of the subscriber's line, and remains illuminated until the subscriber has answered This is accomplished in the following manner: when the operator plugs into the jack of the line called, relay *5* is energized but is immediately de-energized by the disconnecting of the circuit of this relay from the sleeve conductor of the cord when the ringing key is depressed, the selection of the ringing key being determined by the particular party on the line desired. These ringing keys have associated with them a set of springs *9*, which springs are operated when any one of the ringing keys is depressed. Thus, with a ringing key depressed and the relay *5* de-energized, the ringing lamp will be illuminated by means of a circuit as follows: from the live side of the battery, through the ringing lamp *12*, through the back contact and armature of the relay *6*, through the armature and contact of relay *4*, then through the armature and front contact of relay *2*—which at this time is the relay bridged across the trunk and, therefore, energized—and thence through the back contact and armature of relay *5* to ground. When the subscriber removes his receiver from the hook, the relay *1* will become energized as previously described, and will, therefore, operate relay *6* to break the circuit of the ringing lamp. The circuit thus established by the operation of relay *1* is as follows: from the live side of battery, through the winding of relay *6*, through the armature and contact of relay *1*, through the armature and contact of relay *4*, through the armature and front contact of relay *2*, thence through the armature and back contact of relay *5* to ground. As soon as the *B*-operator notes that the ringing lamp has gone out, she knows that no further ringing is required on that line, thus allowing the operation of relay *5* and accomplishing the locking out of the ringing lamp during the remainder of that connection. The relay *6*, after having once pulled up, remains locked up through the rear contact of the left-hand armature of relay *5* and ground, until the plug is removed from the jack.

At the end of the conversation, when the *A*-operator has disconnected her cord circuit on the illumination of the supervisory signals, both relays *2* and *4* will be in an unoperated condition and will provide a circuit for illuminating the disconnect lamp associated with the *B*-operator's cord. This circuit may be traced as follows: from battery through the disconnect lamp, through the armatures and contacts of relays *2* and *4*, thence through the front contact and armature of relay *5* to ground, thus illuminating the disconnect lamp. The ringing lamp will not be re-illuminated at this time, due to the fact that it has been previously locked out by relay *6*. The operator then removes the plug from the jack of the line called, and the apparatus in the trunk circuit is restored to normal condition.

In the circuit shown only keys are provided for ringing two parties. This circuit, however, is not confined to the use of two-party lines, but may be extended to four parties by simply duplicating the ringing keys and by connecting them with the proper current for selectively ringing the other stations.

The method of determining as to whether the called line is free or busy is similar to that previously described for the *A*-operator's cord circuit when making a local connection, and differs only in the fact that in the case of the trunk cord the test circuit is controlled through the contacts of a relay, whereas in the case of the *A*-operator's cord, the test circuit was controlled through the contacts of the listening key. The function of the resistance *10* and the battery connected thereto is the same as has been previously described.

The general make-up of trunking switchboard sections is not greatly different from that of the ordinary switchboard sections where no trunking is involved. In small exchanges where ring-down trunks are employed, the trunk line equipment is merely added to the regular jack and drop equipment of the switchboard. In common-battery multiple switchboards the *A*-boards differ in no respect from the standard single office multiple boards, except that immediately above the answering jacks and below the multiple there are arranged in suitable numbers the jacks of the outgoing trunks.

Where the offices are comparatively small, the incoming trunk portions of the *B*-boards are usually merely a continuance of the *A*-boards, the subscriber's multiple being continuous with and differing in no respect from that on the *A*-sections. Instead of the usual pairs of *A*-operators' plugs, cords, and supervisory equipment, there are on the key and plug shelves of these *B*-sections the incoming trunk plugs and their associated equipment.

In large offices it is customary to make the *B*-board entirely separate from the *A*-board, although the general characteristics of construction remain the same. The reason for separate *A*- and *B*-switchboards in large exchanges is to provide for independent growth of each without the growth of either interfering with the other.

A portion of an incoming trunk, or *B*-board, is shown in Fig. 378. The multiple is as usual, and, of course, there are no outgoing trunk jacks nor regular cord pairs. Instead the key and plug shelves are provided with the incoming-trunk plug equipments, thirty of these being about the usual quota assigned to each operator's position.

In multi-office exchanges, employing many central offices, such, for instance, as those in New York or Chicago, it is frequently found that nearly all of the calls that originate in one office are for subscribers whose lines terminate in some other office. In other words, the number of calls that have to be trunked to other offices is greatly in excess of the number of calls that may be handled through the multiple of the *A*-board in which they originate. It is

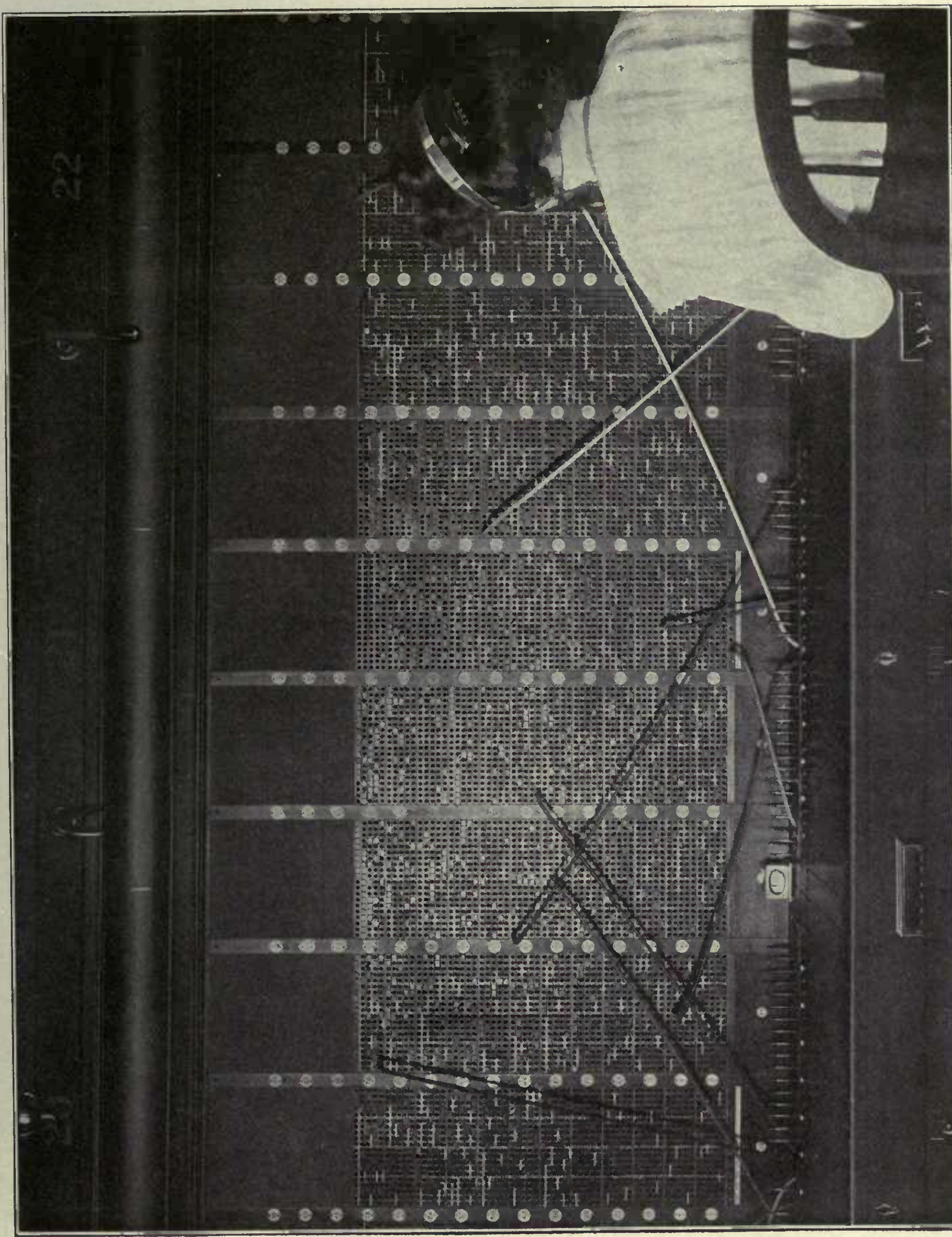


Fig. 378. Section of Trunk Switchboard

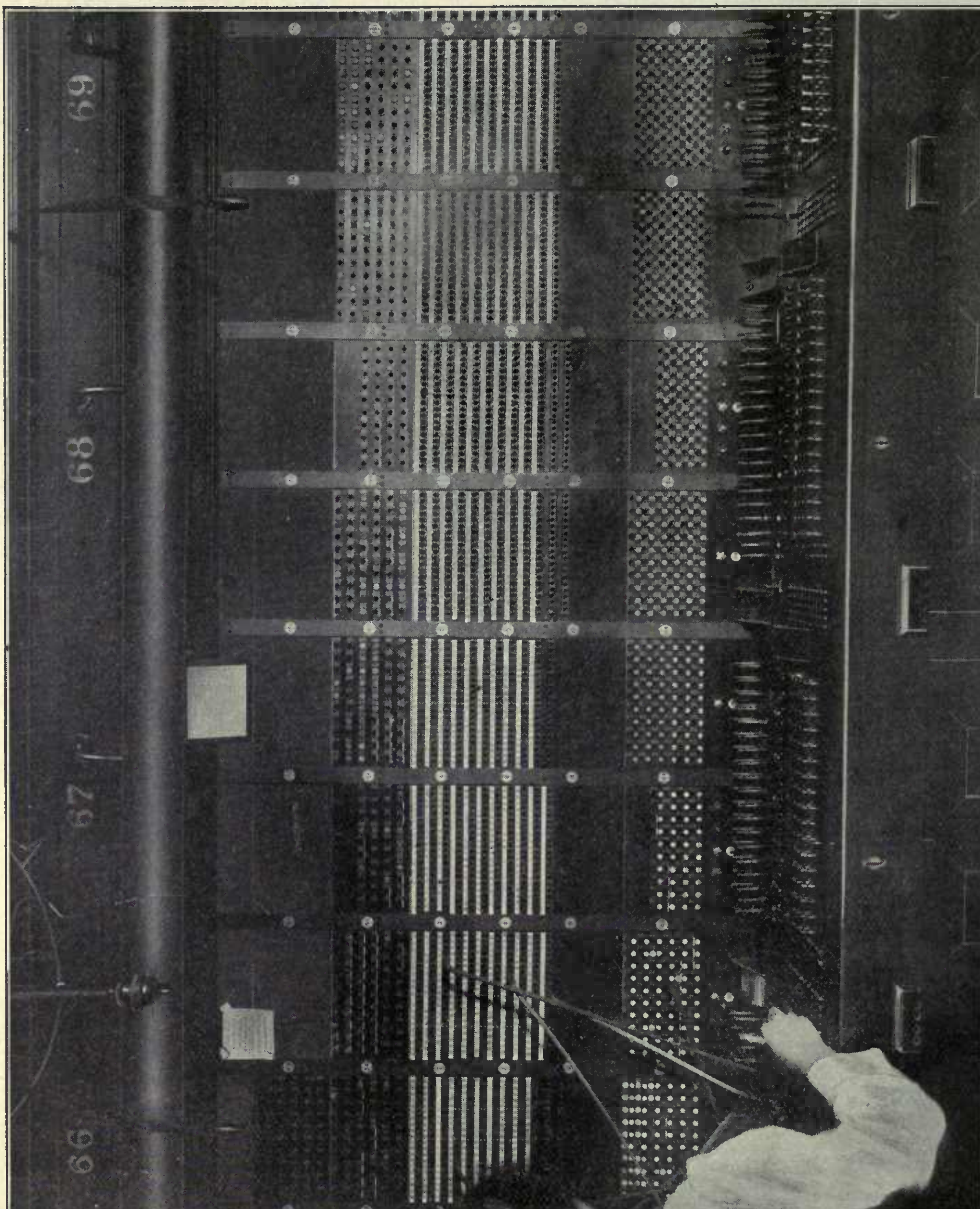


Fig. 379. Section of Partial Multiple Switchboard

not infrequent to have the percentage of trunked calls run as high as 75 per cent of the total number of calls originating in any one office, and in some of the offices in the larger cities this percentage runs higher than 90 per cent.

This fact has brought up for consideration the problem as to whether, when the nature of the traffic is such that only a very small portion of the calls can be handled in the office where they originate, it is worth while to employ the multiple terminals for the subscribers' lines on the *A*-boards. In other words. if so great a proportion as 90 per cent of the calls have to be trunked any way, is it worth while to provide the great expense of a full multiple on all the sections of the *A*-board in order to make it possible to handle the remaining 10 per cent of the calls directly by the *A*-operators?

As a result of this consideration it has been generally conceded that where such a very great percentage of trunking was necessary, the full multiple of the subscribers' lines on each section was not warranted, and what is known as the partial multiple board has come into existence in large manual exchanges. In these the regular subscribers' multiple is entirely omitted from the *A*-board, all subscribers' calls being handled through outgoing trunk jacks connected by trunks to *B*-boards in the same as well as other offices. In these partial multiple *A*-boards, the answering jacks are multipled a few times, usually twice, so that calls on each line may be answered from more than one position. This multipling of answering jacks does not in any way take the place of the regular multipling in full multiple boards, since in no case are the calls completed through the multiple jacks. It is done merely for the purpose of contributing to team work between the operators.

A portion of such a partial multiple *A*-board is shown in Fig. 379. This view shows slightly more than one section, and the regular answering jacks and lamps may be seen at the bottom of the jack space just above the plugs. Above these are placed the outgoing trunk jacks, those that are in use being indicated with white designation strips. Above the outgoing trunk jacks are placed the multiples of the answering jacks, these not being provided with lamps.

The partial multiple *A*-section of Fig. 379 is a portion of the switchboard equipment of the same office to which the trunking section shown in Fig. 378 belongs. That this is a large multiple board may be gathered from the number of multiple jacks in the trunking section, 8,400 being installed with room for 10,500. That the board is a portion of an equipment belonging to an exchange of enormous proportions may be gathered from the number of outgoing trunk jacks shown in the *A*-board, and in the great number of order-wire keys shown between each of the sets of regular cord-circuit keys. The switchboards illustrated in these two figures are those of one of the large offices of the New York Telephone Company on Manhattan Island, and the photographs were taken especially for this work by the Western Electric Company.

Cable Color Code. A great part of the wiring of switchboards requires to be done with insulated wires grouped into cables. In the wiring of manual switchboards as described in the seven preceding chapters, and of automatic and automanual systems and of private branch-exchange and intercommunicating systems described in succeeding chapters, cables formed as follows are widely used:

Tinned soft copper wires, usually of No. 22 or No. 24 B. & S. gauge, are insulated, first with two coverings of silk, then with one covering of cotton. The outer (cotton) insulation of each wire is made of white or of dyed threads. If dyed, the color either is solid red, black, blue, orange, green, brown, or slate, or it is striped, by combining one of those colors with white or a remaining color. The object of coloring the wires is to enable them to be identified by sight instead of by electrical testing.

Wires so insulated are twisted into pairs, choosing the colors of the "line" and "mate" according to a predetermined plan. An assortment of these pairs then is laid up spirally to form the cable core, over which are placed certain wrappings and an outer braid. A widely used form of switchboard cable has paper and lead foil wrappings over the core, and the outer cotton braid finally is treated with a fire-resisting paint.

STANDARD COLOR CODE FOR CABLES

Line Wire	Mate				
	White	Red	Black	Red-White	Black-White
Blue	1	21	41	61	81
Orange	2	22	42	62	82
Green	3	23	43	63	83
Brown	4	24	44	64	84
Slate	5	25	45	65	85
Blue-White	6	26	46	66	86
Blue-Orange	7	27	47	67	87
Blue-Green	8	28	48	68	88
Blue-Brown	9	29	49	69	89
Blue-Slate	10	30	50	70	90
Orange-White	11	31	51	71	91
Orange-Green	12	32	52	72	92
Orange-Brown	13	33	53	73	93
Orange-Slate	14	34	54	74	94
Green-White	15	35	55	75	95
Green-Brown	16	36	56	76	96
Green-Slate	17	37	57	77	97
Brown-White	18	38	58	78	98
Brown-Slate	19	39	59	79	99
Slate-White	20	40	60	80	100

The numerals represent the pair numbers in the cable.

The wires of spare pairs usually are designated by solid red with white mate for first spare pair, and solid black with white mate for second spare pair. Individual spare wires usually are colored red-white for first individual spare, and black-white for second individual spare.

CHAPTER XXVIII

FUNDAMENTAL CONSIDERATIONS OF AUTOMATIC SYSTEMS

Definition. The term automatic, as applied to telephone systems, has come to refer to those systems in which machines at the central office, under the guidance of the subscribers, do the work that is done by operators in manual systems. In all automatic telephone systems, the work of connecting and disconnecting the lines, of ringing the called subscriber, even though he must be selected from among those on a party line, of refusing to connect with a line that is already in use, and informing the calling subscriber that such line is busy, of making connections to trunk lines and through them to lines in other offices and doing the same sort of things there, of counting and recording the successful calls made by a subscriber, rejecting the unsuccessful, and nearly all the thousand and one other acts necessary in telephone service, are performed without the presence of any guiding intelligence at the central office.

The fundamental object of the automatic system is to do away with the central-office operator. In order that each subscriber may control the making of his own connections there is added to his station equipment a call transmitting device by the manipulation of which he causes the central-office mechanisms to establish the connections he desires.

We think that the automatic system is one of the most astonishing developments of human ingenuity. The workers in this development are worthy of particular notice. From occupying a position in popular regard in common with long-haired men and short-haired women they have recently appeared as sane, reasonable men with the courage of their convictions and, better yet, with the ability to make their convictions come true. The scoffers have remained to pray.

Arguments Against Automatic Idea. Naturally there has been a bitter fight against the automatic. Those who have opposed it have contended:

First: that it is too complicated and, therefore, could be neither reliable or economical.

Second: that it is too expensive, and that the necessary first cost could not be justified.

Third: that it is too inflexible and could not adapt itself to special kinds of service.

Fourth: that it is all wrong from the subscribers' point of view as the public will not tolerate "doing its own operating."

Complexity. This first objection as to complexity, and consequent alleged unreliability and lack of economy should be carefully analyzed. It too often happens that a new invention is cast into outer darkness by those whose opinions carry weight by such words as "it cannot work; it is too complicated." Fortunately for the world, the patience and fortitude which men must possess before they can produce meritorious, though intricate inventions, are usually sufficient to prevent their being crushed by any such offhand condemnation, and the test of time and service is allowed to become the real criterion.

It would be difficult to find an art that has gone forward as rapidly as telephony. Within its short life of a little over thirty years it has grown from the phase of trifling with a mere toy to an affair of momentous importance to civilization. There has been a tendency, particularly marked during recent years, toward greater complexity; and probably every complicated new system or piece of apparatus has been roundly condemned, by those versed in the art as it was, as being unable to survive on account of its complication.

To illustrate: A prominent telephone man, in arguing against the nickel-in-the-slot method of charging for telephone service once said, partly in jest, "The Lord never intended telephone service to be given in that way." This, while a little off the point, is akin to the sweeping aside of new telephone systems on the sole ground that they are complicated. These are not real reasons, but rather convenient ways of disposing of vexing problems with a minimum amount of labor. Important questions lying at the very root of the development of a great industry may not be put aside permanently in this offhand way. The Lord has never, so far as we know, indicated just what his intentions were in the matter of nickel service; and no one has ever shown yet just what degree of complexity will prevent a telephone system from working.

It is safe to say that, if other things are equal, the simpler a machine is, the better; but simplicity, though desirable, is not all-important. Complexity is warranted if it can show enough advantages.

If one takes a narrow view of the development of things mechanical and electrical, he will say that the trend is toward simplicity. The mechanic in designing a machine to perform certain functions tries to make it as simple as possible. He designs and re-designs, making one part do the work of two and contriving schemes for reducing the complexity of action and form of each remaining part. His whole trend is away from complication, and this is as it should be. Other things being equal, the simpler the better. A broad view, however, will show that the arts are becoming more and more complicated. Take the implements of the art of writing: The typewriter is vastly more complicated than the pen, whether of steel or quill, yet most of the writing of today is done on the typewriter, and is done better and more economically. The art of printing affords even more striking examples.

In telephony, while every effort has been made to simplify the component parts of the system, the system itself has ever developed from the simple toward the complex. The adoption of the multiple switchboard, of automatic ringing, of selective ringing on party lines, of measured-service appliances, and of automatic systems have all constituted steps in this direction. The adoption of more complicated devices and systems in telephony has nearly always followed a demand for the performance by the machinery of the system of additional or different functions. As in animal and plant life, so in mechanics—the higher the organism functionally the more complex it becomes physically.

Greater intricacy in apparatus and in methods is warranted when it is found desirable to make the machine perform added functions. Once the functions are determined upon, then the whole trend of the development of the machine for carrying them out should be toward simplicity. When the machine has reached its highest stage of development some one proposes that it be required to do something that has hitherto been done manually, or by a separate machine, or not at all. With this added function a vast added complication may come. after which, if it develops that the new function may with economy be performed by the machine, the process of simplification again begins, the whole design finally taking on an indefinable elegance which appears only when each part is so made as to be best adapted in composition, form, and strength to the work it is to perform.

Achievements in the past teach us that a machine may be made to do almost anything automatically if only the time, patience, skill, and money be brought to bear. This is also true of a telephone system. The primal question to decide is, what functions the system is to perform within itself, automatically, and what is to be done manually or with manual aid. Sometimes great complications are brought into the system in an attempt to do something which may very easily and cheaply be done by hand. Cases might be pointed out in which fortunes and life-works have been wasted in perfecting machines for which there was no real economic need. It is needless to cite cases where the reverse is true. The matter of wisely choosing the functions of the system is of fundamental importance. In choosing these the question of complication is only one of many factors to be considered.

One of the strongest arguments against intricacy in telephone apparatus is its greater initial cost, its greater cost of maintenance, and its liability to get out of order. Greater complexity of apparatus usually means greater first cost, but it does not necessarily mean greater cost of up-keep or lessened reliability. A dollar watch is more simple than an expensive one. The one, however, does its work passably and is thrown away in a year or so; the other does its work marvelously well and may last generations, being handed down from father to son. Merely reducing the number of parts in a machine does not necessarily mean greater reliability. Frequently the attempt to make one part do several diverse things results in such a sacrifice in the simplicity of action of that part as to cause undue strain, or wear, or unreliable action. Better results may be attained by adding parts, so that each may have a comparatively simple thing to do.

The stage of development of an art is a factor in determining the degree of complexity that may be allowed in the machinery of that art. A linotype machine, if constructed by miracle several hundred years ago, would have been of no value to the printer's art then. The skill was not available to operate and maintain it, nor was the need of the public sufficiently developed to make it of use. Similarly the automatic telephone exchange would have been of little value thirty years ago. The knowledge of telephone men was not sufficiently developed to maintain it, telephone users were not sufficiently numerous to warrant it, and the public was not sufficiently trained to use it. Industries, like human beings, must learn to creep before they can walk.

Another factor which must be considered in determining the allowable degree of complexity in a telephone system is the character of the labor available to care for and manage it. Usually the conditions which make for unskilled labor also lend themselves to the use of comparatively simple systems. Thus in a small village remote from large cities the complexity inherent in a common-battery multiple switchboard would be objectionable. The village would probably not afford a man adequately skilled to care for it, and the size of the exchange would not warrant the expense of keeping such a man. Fortunately no such switchboard is needed. A far simpler device, the plain magneto switchboard—so simple that the girl who manipulates it may also often care for its troubles—is admirably adapted to the purpose. So it is with the automatic telephone system; even its most enthusiastic advocate would be foolish indeed to contend that for all places and purposes it was superior to the manual.

These remarks are far from being intended as a plea for complex telephone apparatus and systems; every device, every machine, and every system should be of the simplest possible nature consistent with the functions it has to perform. They are rather a protest against the broadcast condemnation of complex apparatus and systems just because they are complicated, and without regard to other factors. Such condemnation is detrimental to the progress of telephony. Where would the printing art be today if the linotype, the cylinder press, and other modern printing machinery of marvelous intricacy had been put aside on account of the fact that they were more complicated than the printing machinery of our forefathers?

That the automatic telephone system is complex, exceedingly complex, cannot be denied, but experience has amply proven that its complexity does not prevent it from giving reliable service, nor from being maintained at a reasonable cost.

Expense. The second argument against the automatic—that it is too expensive—is one that must be analyzed before it means anything. It is true that for small and medium-sized exchanges the total first cost of the central office and subscribers' station equipment, is greater than that for manual exchanges of corresponding sizes. The prices at which various sizes of automatic exchange equipments may be purchased vary, however, almost in direct proportion to the number of lines, whereas in manual equipment the price per line increases very rapidly as the number of lines increases. From this it follows that for very large exchanges the cost of automatic apparatus becomes as low, and may be even lower than for manual. Roughly speaking the cost of telephones and central-office equipment for small exchanges is about twice as great for automatic as for manual, and for very large exchanges, of about 10,000 lines, the cost of the two for switchboards and telephones is about equal.

For all except the largest exchanges, therefore, the greater first cost of automatic apparatus must be put down as one of the factors to be weighed in making the choice between automatic and manual, this factor being less and less objectionable as the size of the equipment increases and finally disappearing altogether for very large equipments. Greater first cost is, of course, warranted if the fixed charges on the greater investment are more than offset by the economy resulting. The automatic screw machine, for instance, costs many times more than the hand screw machine, but it has largely displaced the hand machine nevertheless.

Flexibility. The third argument against the automatic telephone system—its flexibility—is one that only time and experience has been able to answer. Enough time has elapsed and enough experience has been gained, however, to disprove the validity of this argument. In fact, the great flexibility of the automatic system has been one of its surprising developments. No sooner has the statement been made that the automatic system could not do a certain thing than forthwith it has done it. It was once quite clear that the automatic system was not practicable for party-line selective ringing; yet today many automatic systems are working successfully with this feature; the selection between the parties on a line being accomplished with just as great certainty as in manual systems. Again it has seemed quite obvious that the automatic system could not hope to cope with the reverting call problem, *i. e.*, enabling a subscriber on a party line to call back to reach another subscriber on the same line; yet today the automatic system may do this in a way that is perhaps even more satisfactory than the way in which it is done in multiple manual switchboards. It is true that the automatic system has not done away with the toll operator and it probably never will be advantageous to require it to do so for the simple reason that the work of the toll operator in recording the connections and in bringing together the subscribers is a matter that requires not only accuracy but judgment, and the latter, of course, no machine can supply. It is probable also that the private branch-exchange operator will survive in automatic systems. This is not because the automatic system cannot readily perform the switching duties, but the private branch-exchange operator has other duties than the mere building up and taking down of connections. She is, as it were, a door-keeper guarding the telephone door of a business establishment; like the toll operator she must be possessed of judgment and of courtesy in large degree, neither of which can be supplied by machinery.

In respect to toll service and private branch-exchange service where, as just stated, operators are required on account of the nature of the service, the automatic system has again shown its adaptability and flexibility. It has shown its capability of working in harmony with manual switchboards, of whatever nature, and there is a growing tendency to apply automatic devices and automatic principles of operation to manual switchboards, whether toll or private branch or other kinds, even though the services of an operator are required, the idea being to do by machinery that portion of the work which a machine is able to do better or more economically than a human being.

Attitude of Public. The attitude of the public toward the automatic is one that is still open to discussion; at least there is still much discussion on it. A few years ago it did seem reasonable to suppose that the general telephone user would prefer to get his connection by merely asking for it rather than to make it himself by "spelling" it out on the dial of his telephone instrument. We have studied this point carefully in a good many different communities and it is our opinion that the public finds no fault with being required to make its own connections. To our minds it is proven beyond question that either the method employed in the automatic or that in the manual system is satisfactory to the public as long as good service results, and it is beyond question that the public may get this with either.

Subscriber's Station Equipment. The added complexity of the mechanism at the subscriber's station is in our opinion the most valid objection that can be urged against the automatic system as it exists today. This objection has, however, been much reduced by the greater simplicity and greater excellence of material and workmanship that is employed in the controlling devices in modern automatic systems. However, the automatic system must always suffer in comparison with the manual in respect of simplicity of the subscriber's equipment. The simplest conceivable thing to meet all of the requirements of telephone service at a subscriber's station is the modern common-battery manual telephone. The automatic telephone differs from this only in the addition of the mechanism for enabling the subscriber to control the central-office apparatus in the making of calls. From the standpoint of maintenance, simplicity at the subscriber's station is, of course, to be striven for since the proper care of complex devices scattered all over a community is a much more serious matter than where the devices are centered at one point, as in the central office. Nevertheless, as pointed out, complexity is not fatal, and it is possible, as has been proven, to so design and construct the required apparatus in connection with the subscribers' telephones as to make them subject to an amount of trouble that is not serious.

Comparative Costs. A comparison of the total costs of owning, operating, and maintaining manual and automatic systems usually results in favor of the automatic, except in small exchanges. This seems to be the consensus of opinion among those who have studied the matter deeply. Although the automatic usually requires a larger investment, and consequently a larger annual charge for interest and depreciation, assuming the same rates for each case, and although the automatic requires a somewhat higher degree of skill to maintain it and to keep it working properly than the manual, the elimination of operators or the reduction in their number and the consequent saving of salaries and contributory expenses together with other items of saving that will be mentioned serves to throw the balance in favor of the automatic.

The ease with which the automatic system lends itself to inter-office trunking makes feasible a greater subdivision of exchange districts into office districts and particularly makes it economical, where such would not be warranted in manual working. All this tends toward a reduction in average length of subscribers' lines and it seems probable that this possibility will be worked upon in the future, more than it has been in the past, to effect a considerable saving in the cost of the wire plant, which is the part of a telephone plant that shows least and costs most.

Automatic vs. Manual. Taking it all in all the question of automatic versus manual may not and can not be disposed of by a consideration of any single one of the alleged features of superiority or inferiority of either. Each must be looked at as a practical way of giving telephone service, and a decision can be reached only by a careful weighing of all the factors which contribute to economy, reliability, and general desirability from the standpoint of the public. Public sentiment must neither be overlooked nor taken lightly, since, in the final analysis, it is the public that must be satisfied.

Methods of Operation. In all of the automatic telephone systems that have achieved any success whatever, the selection of the desired subscriber's line by the calling subscriber is accomplished by means of step-by-step mechanism at the central office, controlled by impulses sent or caused to be sent by the acts of the subscriber.

Strowger System. In the so-called Strowger system, manufactured by the Automatic Electric Company of Chicago, the subscriber, in calling, manipulates a dial by which the central-office switching mechanism is made to build up the connection he wants. The dial is moved as many times as there are digits in the called subscriber's number and each movement sends a series of impulses to the central office corresponding in number respectively to the digits in the called subscriber's number. During each pause, except the last one, between these series of impulses, the central-office mechanism operates to shift the control of the calling subscriber's line from one set of switching apparatus at the central office to another.

In case a four-digit number is being selected first, the movement of the dial by the calling subscriber will correspond to the thousands digit of the number being called, and the resulting movement of the central-office apparatus will continue the calling subscriber's line through a trunk to a piece of apparatus capable of further extending his line toward the line terminals of the thousand subscribers whose numbers begin with the digit chosen. The next movement of the dial corresponding to the hundreds digit of the called number will operate this piece of apparatus to again extend the calling subscriber's line through another trunk to apparatus representing the particular hundred in which the called subscriber's number is. The third movement of the dial corresponding to the tens digit will pick out the group of ten containing the called subscriber's line, and the fourth movement corresponding to the units digit will pick out and connect with the particular line called.

Lorimer System. In the Lorimer automatic system invented by the Lorimer Brothers, and now being manufactured by the Canadian Machine Telephone Company of Toronto, Canada, the subscriber sets up the number he desires complete by moving four levers on his telephone so that the desired number appears visibly before him. He then turns a handle and the central-office apparatus, under the control of the electrical conditions thus set up by the subscriber, establishes the connection. In this system, unlike the Strowger system, the controlling impulses are not caused by the movement of the subscriber's apparatus in returning to its normal position after being set by the subscriber. Instead, the conditions established at the subscriber's station by the subscriber in setting up the desired number, merely determine the point in the series of impulses corresponding to each digit at which the stepping impulses local to the central office shall cease, and in this way the proper number of impulses in the series corresponding to each digit is determined.

Magnet- vs. Power-Driven Switches. These two systems differ radically in another respect. In the Strowger system it is the electrical impulses initiated at the subscriber's apparatus that actually cause the movement of the switching parts at the central office, these impulses energizing electromagnets which move the central-office switching devices a step at a time the desired number of steps. In the Lorimer system the switches are all power-driven and the impulses under the control of the subscriber's instrument merely serve to control the application of this power to the various switching mechanisms. These details will be more fully dealt with in subsequent chapters.

Multiple vs. Trunking. It has been shown in the preceding portion of this work that the tendency in manual switchboard practice has been away from trunking between the various sections or positions of a board, and toward the multiple idea of operating, wherein each operator is able to complete the connection with any line in the same office without resorting to trunks or to the aid of other operators. Strangely enough the reverse has been true in the development of the automatic system. As long as the inventors tried to follow the most successful practice in manual working, failure resulted. The automatic systems of today are essentially trunking systems and while they all involve multiple connections in greater or less degree, all of them depend fundamentally upon the extending of the calling line by separate lengths until it finally reaches and connects with the called line.

Grouping of Subscribers. In this connection we wish to point out here two very essential features without which, so far as we are aware, no automatic telephone system has been able to operate successfully. The first of these is the division of the total number of lines in any office of the exchange into comparatively small groups and the employment of correspondingly small switch units for each group. Many of the early automatic systems that were proposed involved the idea of having each switch capable in itself of making connection with any line in the entire office. As long as the number of lines was small—one hundred or thereabouts—this might be all right, but where the lines number in the thousands, it is readily seen that the switches would be of prohibitive size and cost.

Trunking between Groups. This feature made necessary the employment of trunk connections between groups. By means of these the lines are extended a step at a time, first entering a large group of groups, containing the desired subscriber; then entering the smaller group containing that subscriber; and lastly entering into connection with the line itself. The carrying out of this idea was greatly complicated by the necessity of providing for many simultaneous connections through the switchboard. It was comparatively easy to accomplish the extension of one line through a series of links or trunks to another line, but it was not so easy to do this and still leave it possible for any other line to pick out and connect with any other idle line without interference with the first connection. A number of parallel paths must be provided for each possible connection. Groups of trunks are, therefore, provided instead of single trunks between common points to be connected. The subscriber who operates his instrument in making a call knows nothing of this and it is, of course, impossible for him to give any thought to the matter as to which one of the possible paths he shall choose. It was by a realization of these facts that the failures of the past were turned into the successes of the present. The subscriber by setting his signal transmitter was made to govern the action of the central-office apparatus in the selection of the proper *group* of trunks. The group being selected, the central-office apparatus was made to act at once *automatically* to pick out and connect with *the first idle trunk of such group.* Thus, we may say *that the subscriber by the act performed on his signal transmitter, voluntarily chooses the group of trunks, and immediately thereafter the central-office apparatus without the volition of the subscriber picks out the first idle one of this group of trunks so chosen.* This fundamental idea, so far as we are aware, underlies all of the successful automatic telephone-exchange systems. It provides for the possibility of many simultaneous connections through the switchboard, and it provides against the simultaneous appropriation of the same path by two or more calling subscribers and thus assures against interference in the choice of the paths.

Outline of Action. In order to illustrate this point we may briefly outline the action of the Strowger automatic system in the making of a connection. Assume that the calling subscriber desires a connection with a subscriber whose line bears the number 9,567. The subscriber in making the call will, by the first movement of his dial, transmit nine impulses over his line. This will cause the selective apparatus at the central office, that is at the time associated with the calling subscriber's line, to move its selecting fingers opposite a group of terminals representing the ends of a group of trunk lines leading to apparatus employed in connecting with the ninth thousand of the subscribers' lines.

While the calling subscriber is getting ready to transmit the next digit, the automatic apparatus, without his volition, starts to pick out the first idle one of the group of trunks so chosen. Having found this it connects with it and the calling subscriber's line is thus extended to another selective apparatus capable of performing the same sort of function in choosing the proper hundreds group.

In the next movement of his dial the calling subscriber will send five impulses. This will cause the last chosen selective switch to move its selective fingers opposite a group of terminals representing the ends of a group of trunks each leading to a switch that is capable of making connection with any one of the lines in the fifth hundred of the ninth thousand. Again during the pause by the subscriber, the switch that chose this group of trunks will start automatically to pick out and connect with the first idle one of them, and will thus extend the line to a selective switch that is capable of reaching the desired line, since it has access to all of the lines in the chosen hundred. The third movement of the dial sends six impulses and this causes this last chosen switch to move opposite the sixth group of ten terminals, so that there has now been chosen the nine hundred and fifty-sixth group of ten lines. The final movement of the dial sends seven impulses and the last mentioned switch connects with the seventh line terminal in the group of ten previously chosen and the connection is complete, assuming that the called line was not already engaged. If it had been found busy, the final switch would have been prevented from connecting with it by the electrical condition of certain of its contacts and the busy signal would have been transmitted back to the calling subscriber.

Fundamental Idea. This idea of subdividing the subscribers' lines in an automatic exchange, of providing different groups of trunks so arranged as to afford by combination a number of possible parallel paths between any two lines, of having the calling subscriber select, by the manipulation of his instrument, the proper group of trunks any one of which might be used to establish the connection he desires, and of having the central-office apparatus act automatically to choose and connect with an idle one in this chosen group, should be firmly grasped. It appears, as we have said, in every successful automatic system capable of serving more than one small group of lines, and until it was evolved automatic telephony was not a success.

Testing. As each trunk is chosen and connected with, conditions are established, by means not unlike the busy test in multiple manual switchboards, which will guard that trunk and its associated apparatus against appropriation by any other line or apparatus as long as it is held in use. Likewise, as soon as any subscriber's line is put into use, either by virtue of a call being originated on it, or by virtue of its being connected with as a called line, conditions are automatically established which guard it against being connected with any other line as long as it is busy. These guarding conditions of both trunks and lines, as in the manual board, are established by making certain contacts, associated with the trunks or lines, assume a certain electrical condition when busy that is different from their electrical condition when idle; but unlike the manual switchboard this different electrical condition does not act to cause a click in any one's ear, but rather to energize or de-energize certain electromagnets which will establish or fail to establish the connection according to whether it is proper or improper to do so.

Local and Inter-Office Trunks. The groups of trunks that are used in building up connections between subscribers' lines may be local to the central office, or they may extend between different offices. The action of the two kinds of trunks, local or inter-office, is broadly the same.

CHAPTER XXIX

THE AUTOMATIC ELECTRIC COMPANY'S SYSTEM

Almost wherever automatic telephony is to be found—and its use is extensive and rapidly growing—the so-called Strowger system is employed. It is so named because it is the outgrowth of the work of Almon B. Strowger, an early inventor in the automatic telephone art. That the system should bear the name of Strowger, however, gives too great prominence to his work and too little to that of the engineers of the Automatic Electric Company under the leadership of Alexander E. Keith.

Principles of Selecting Switch. The underlying features of this automatic system have already been referred to in the abstract. A better grasp of its principles may, however, be had by considering a concrete example of its most important piece of apparatus—the selecting switch. The bare skeleton of such a switch, sufficient only to illustrate the salient point in its mode of operation, is shown in Fig. 380. The essential elements of this are a vertical shaft capable of both longitudinal and rotary motion; a pawl and ratchet mechanism actuated by a magnet for moving the shaft vertically a step at a time; another pawl and ratchet mechanism actuated by another magnet for rotating the shaft a step at a time; an arm carrying wiper contacts on its outer end, mounted on and moving with the shaft; and a bank of contacts arranged on the inner surface of a section of a cylinder adapted to be engaged by the wiper contacts on this movable arm.

These various elements are indicated in the merest outline and with much distortion in Fig. 380, which is intended to illustrate the principles of operation rather than the details as they actually are in the system. In the upper left-hand corner of this figure, the magnet shown will, if energized by impulses of current, attract and release its armature and, in doing so, cause the pawl controlled by this magnet to move the vertical shaft of the switch up a step at a time, as many steps as there are impulses of current. The vertical movement of this shaft will carry the wiper arm, attached to the lower end of the shaft, up the same number of steps and, in doing so, will bring the contacts of this wiper arm opposite, but not engaging, the corresponding row of stationary contacts in the semi-cylindrical bank. Likewise, through the ratchet cylinder on the intermediate portion of the shaft, the magnet shown at the right-hand portion of this figure will, when energized by a succession of electrical impulses, ro-

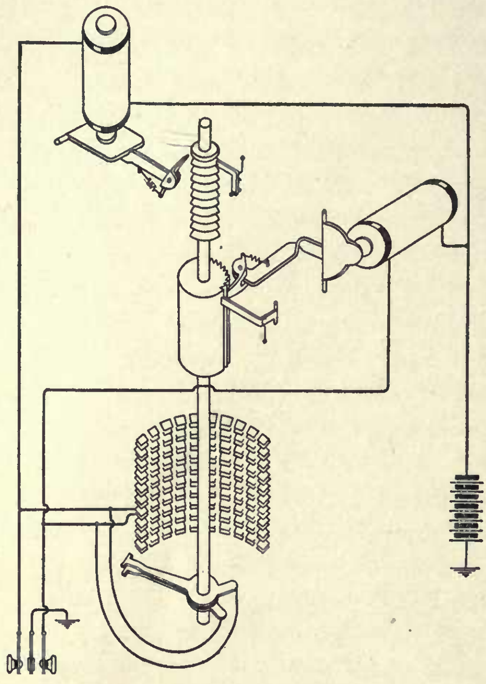


Fig. 380. Principles of Automatic Switch

tate the shaft a step at a time, as many steps as there are impulses. This will thus cause the contacts of the wiper arm to move over the successive contacts in the row opposite to which the wiper had been carried in its vertical movement.

At the lower left-hand corner of this figure, there is shown a pair of keys either one of which, when operated, will complete the circuit of the magnet to which it is connected, this circuit including a common battery. In a certain rough way this pair of key switches in the lower left-hand corner of the drawing may be taken as representing the call-transmitting apparatus at the subscriber's station, and the two wires extending therefrom may be taken as representing the line wires connecting that subscriber's station to the central office; but the student must avoid interpreting them as actual representations of the subscriber's station calling apparatus or the subscriber's line since their counterparts are not to be found in the system as it really exists. Here again accuracy has been sacrificed for ease in setting forth a feature of operation.

Still referring to Fig. 380, it will be seen that the bank contacts consist of ten rows, each having ten pairs of contacts. Assume again, for the sake of simplicity, that the exchange under consideration has one hundred subscribers and that each pair of bank contacts represents the terminals of one subscriber's line. Assume further that the key switches in the lower left-hand corner of the figure are being manipulated by a subscriber at that station and that he wishes to obtain a connection with line No. 67. By pressing and releasing the left-hand key six times, he will cause six separate impulses of current to flow through the upper left-hand magnet and this will cause the switch shaft to move up six steps and bring the wiper arm opposite the sixth row of bank contacts. If he now presses and releases his right-hand key seven times, he will, through the action of the right-hand magnet, rotate the shaft seven steps, thus bringing the wipers into contact with the seventh contact of the sixth row and thus into contact with the desired line. As the wiper contacts on the switch arm form the terminals of the calling subscriber's line, it will be apparent that the calling subscriber is now connected through his switch with the line of subscriber No. 67.

As stated, each of the pairs of bank contacts are connected with the line of a subscriber; the line, Fig. 380, is shown so connected to the forty-first pair of contacts, that is to the first contact in the fourth row. The selecting switch shown in Fig. 380 would be for the sole use of the subscriber on the line No. 41. Each of the other subscribers would have a similar switch for his own exclusive use. Since any of the switches must be capable of reaching line No. 67. for instance, when moved *up* six rows and *around* seven, it follows that the sixty-seventh pair of contacts in each bank of the entire one hundred switches must also be connected together and to line No. 67. The same is.

of course, true of all the contacts corresponding to any other number. Multiple connections are thus involved between the corresponding contacts of the banks, in much the same way as in the corresponding jacks in the multiple of a manual switchboard. As a result of this multiple connection of the bank contacts, any subscriber may move the wiper arm of his selecting switch into connection with the line of any other subscriber.

The "Up-and-Around" Movement. The elemental idea to be grasped by the discussion so far, is the so-called "up-and-around" method of action of the selecting switches employed in this system. This preliminary discussion may be carried a step further by saying that the arrangement is such that when a subscriber presses both his keys and grounds both of the limbs of his line, such a condition is brought about as will cause all holding pawls to be withdrawn from the shaft, and thus allow it to return to its normal position with respect to both its vertical and rotary movements. No attempt has been made in Fig. 380 to show how this is accomplished.

Function of Line Switch. Such a system as has been briefly outlined in the foregoing would require a separate selecting switch for each subscriber's line and would be limited to use in exchanges having not more than one hundred lines. In the modern system of the Automatic Electric Company, the requirement that each subscriber shall have a selective switch, individual to his own line, has been eliminated by introducing what is called an *individual line switch* by means of which any one of a group of subscribers' lines, making a call, automatically appropriates one of a smaller group of selecting switches and makes it its own only while the connection exists.

Subdivision of Subscribers' Lines. The limitation as to the size of the exchange has been overcome, without increasing the number of bank contacts in any selecting switch, by dividing the subscribers' lines into groups of one hundred and causing selecting switches automatically to extend the calling subscriber's line first into a group of groups corresponding, for instance, to the thousand containing the called subscriber's line, and then into the particular group containing the line, and lastly, to connect with the individual line in that group.

Underlying Feature of Trunking System. It will be remembered that in the chapter on fundamental principles of automatic systems, it was stated that the subscriber, by means of the signal transmitter at his station, was made to govern the action of the central-office apparatus in the selection of a proper group of trunks; and the group being selected, the central-office apparatus was made to act automatically to pick out and connect with the first idle trunk of such group. This selection by the subscriber of a group followed by the automatic selection from among that group forms the basis of the trunking system. It is impossible, by means of any simple diagram, to show a complete scheme of trunking employed, but Fig. 381 will give a fundamental conception of it. This figure shows how a single calling line, indicated at the bottom, may find access into any particular line in an office having a capacity for ten thousand.

Names of Selecting Switches. Selecting switches of the "up-and-around" type are the means by which the calling line selects and connects with the trunk lines required in building up the connection, and finally selects and connects with the line of the called subscriber. Where such a switch is employed for the purpose of selecting a *trunk,* it is called a selector switch. It is a *first selector* when it serves to pick out a major group of lines, *i. e.,* a group containing a particular thousand lines or, in a multi-office system, a group represented by a complete central office. It is a *second selector* when it serves to make the next subdivision of groups; a *third selector* if further subdivision of groups is necessary; and finally it is *a connector* when it is employed to pick out and connect with the *particular line in the final group of one hundred lines* to which the connection has been brought by the selectors. In a single office of 10,000-line capacity, therefore, we would have first and second selectors and connectors, the first selectors picking out the thousands, the second selectors the hundreds, and the connectors the individual line. In a multi-office system we may have first, second, and third selectors and connectors, the first selector picking out the office, the second selector the thousands in that office, the third selector the hundreds, and the connector the individual lines.

The Line Switch. In addition to the selectors and connectors there are line switches, which are comparatively simple, one individual to each line. Each of these has the function, purely automatic, of always connecting a line, as soon as a call is originated on it, to some one of a smaller group of first selectors available to that line. This idea may be better grasped when it is understood that, in the earlier systems of the Automatic Electric Company, there was a first selector permanently associated with each line. By the addition of the comparatively simple line switch, a saving of about ninety per cent of the first selectors was effected, since the number of first selectors was thereby reduced from a number equal to the number of lines in a group to a number equal to the number of simultaneous connections resulting from calls originating in that group. In other words, by the line switch, the number of first selectors is determined by the traffic rather than by the number of lines.

Scheme of Trunking. With this understanding as to the names and broader functions of the things involved, Fig. 381 may now be understood. The line switch of the single line, as indicated here, has only the power of selection among three trunks, but it is to be understood that in actual practice, it would have access to a greater number, usually ten. So, also, throughout this diagram we have shown the apparatus and trunks arranged in groups of three instead of in groups of ten, only the first three thousands groups being indicated and the first three hundreds groups in each thousand. Again only three levels instead of ten are indicated for each selecting switch, it being understood that in the diagram the various levels are represented by concentric arcs of circles, and the trunk contacts by dots on these arcs.

Line-Switch Action. When the subscriber, whose line is shown at the bottom of the figure, begins to make a call, the line switch acts to connect his line with one of the first selector trunks available to it. This selection is entirely preliminary and, except to start it, is in no way under the control of the calling subscriber. The calling line now has under its control a first selector which, for the time being, becomes individual to it. Let it be assumed that the line switch found the first of the first selector trunks already appropriated by some other switch, but that the second one of these trunks was found idle. This trunk being appropriated by the line switch places the center one of the first selectors shown under the control of the subscriber's line. This first selector then acts in re-

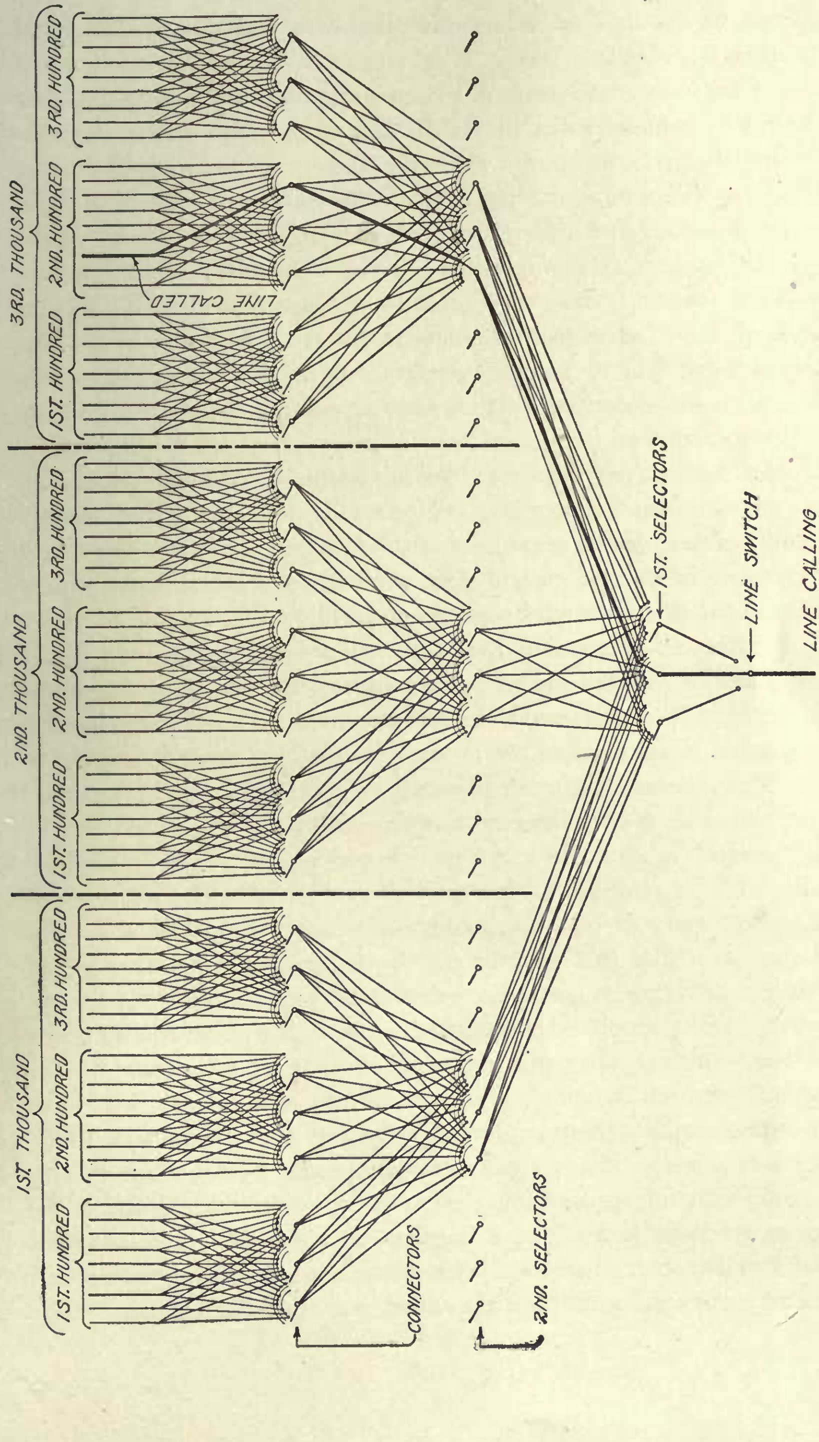


Fig. 381. Scheme of Trunking

sponse to the first set of selective impulses sent out by his signal transmitter.

First Selector Action. We will assume that the calling subscriber desires to connect with No. 3213. The first movement of the subscriber's signal transmitter will send, therefore, three impulses over the line. These impulses will act on the vertical magnet of the first selector switch to move it up three steps. On this "level" of the contact bank of this switch all of the contacts will represent second selector trunks leading to the *third* thousand group. The other ends of these trunks will terminate in the wipers and also in the controlling magnets of second selectors serving this thousand. This function on the part of the first selector controlled by the act of the subscriber will have thus selected a *group* of trunks leading to the *third* thousand, but the subscriber has nothing to do with which one of the trunks of this group will actually be used. Immediately following the vertical movement of the first selector switch the rotary movement of this switch will start and will continue until the wipers of that switch have found contacts of an idle trunk leading to a second selector. Assuming that the first trunk was the one found idle, the first selector wipers would pause on the first pair of contacts in the third level of its bank, and the trunk chosen may be seen leading from that contact off to the group of second selectors belonging to the third thousand For clearness, the chosen trunks in this assumed connection are shown heavier than the others.

Second Selector Action. The next movement of the dial by the subscriber in establishing his desired connection will send two impulses, it being desired to choose the *second* hundred in the *third* thousand. The first selector will have become inoperative before this second series of impulses is sent and, therefore, only the second selector will respond. Its vertical magnet acting under the influence of these two impulses will step up its wiper contacts opposite the second row of bank contacts, and the subscriber will thus have chosen the *group* of trunks leading to the *second* hundred in the *third* thousand. Here, again, the automatic operation of picking out the first idle one of this chosen group of trunks will take place without the volition of the subscriber, and it will be assumed that the first two trunks on this level of the second selector were found already engaged and that the third was therefore chosen. The connection continues, as indicated by heavy lines in Fig. 381, to the third one of the connectors in the *second* hundred of the *third* thousand. Any one of these connectors would have accomplished the purpose but this is assumed to be the first one found idle by the second selector.

Connector Action. The third movement of the subscriber's dial will send but one impulse, this corresponding to the *first* group of ten in the *second* hundred in the *third* thousand. This impulse will move the connector shaft up to the first level of bank contacts; and from now on the action of the connector differs radically from that of the selectors. The connector is not searching for an idle trunk in the group but for a particular line and, therefore, having chosen the group of ten lines in the desired hundred, the connector switch waits for further guidance from the subscriber. This comes in the form of the final set of impulses sent by the subscriber's signal transmitter which, in this case, will be three in number, corresponding to the final digit in the number of the called subscriber. This series of impulses will control the rotary movement of the connector wipers which will move along the first level and stop on the third one. The process is seen to be one of successive selection, first of a large group, then of a smaller, again of a smaller, and finally of an individual.

If the line is found not busy, the connection between the two subscribers is complete and the called subscriber's bell will be rung. If it is found busy, however, the connector will refuse to connect and will drop back to its normal position, sending a busy signal back to the calling subscriber. The details of ringing and the busy-back operation may only be understood by a discussion of drawings, subsequently to be referred to.

Two-Wire and Three-Wire Systems. In most of the systems of the Automatic Electric Company in use today the impulses by which the subscriber controls the central-office apparatus flow over one side of the line or the other and return by ground. The metallic circuit is used for talking and for ringing the called subscriber's bell, while ground return circuits, on one side of the line or the other, are used for sending all the switch controlling impulses.

Recently this company has perfected a system wherein no ground is required at the subscriber's station and no ground return path is used for any purpose between the subscriber and the central office. This later system is known as the "two-wire" system, and in contra-distinction to it, the earlier and most used system has been referred to as the "three-wire." It is not meant by this that the line circuits actually have three wires but that each line employs three conductors, the two wires of the line and the earth. The three-wire system will be referred to and described in detail, and from it the principles of the two-wire system will be readily understood.

Subscriber's Station Apparatus. The detailed operation of the three-wire system may be best understood by considering the subscriber's station apparatus first. The general appearance of the

Fig. 382. Automatic Wall Set

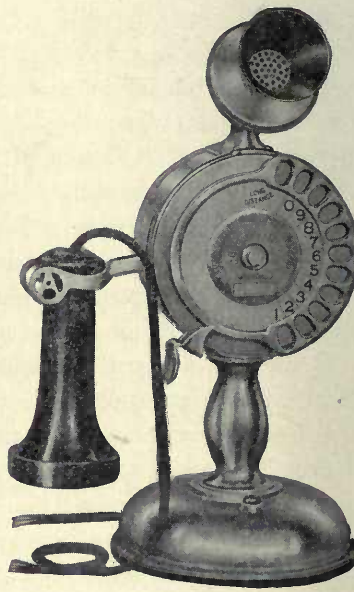


Fig. 383. Automatic Desk Stand

wall set is shown in Fig. 382, and of the desk set in Fig. 383. These instruments embody the usual talking and call-receiving apparatus of a common-battery telephone and in addition to this, the signal transmitter, which is the thing especially to be considered now. The diagrammatic illustration of the signal transmitter and of the relation that its parts bear to the other elements of the telephone set is shown in Fig. 384. It has already been stated that the subscriber manipulates the signal transmitter by rotating the dial on the face of the instrument. A clearer idea of this dial and of the finger stop for it may be obtained from Figs. 382 and 383.

Operation. To make a call for a given number the subscriber removes his receiver from its hook, then places his forefinger in the hole opposite the number corresponding to the first digit of the desired number. By means of the grip thus secured, he rotates the

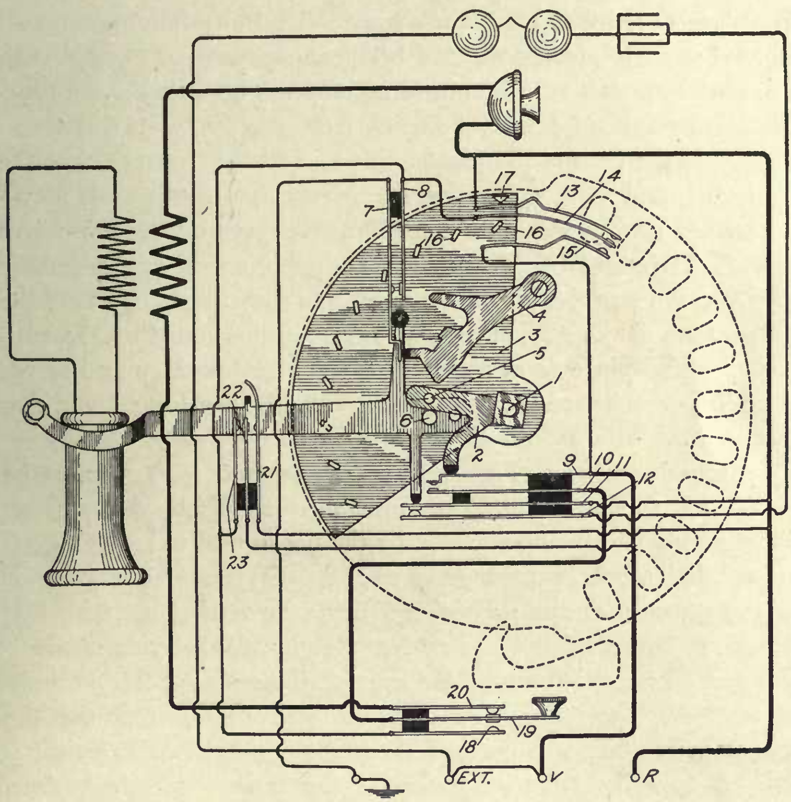


Fig. 384. Circuits of Telephone Set

dial until its movement is stopped by the impact of the finger against the stop. The dial is then released and in its return movement it sends the number of impulses corresponding to the first digit in the called number. A similar movement is made for each digit.

In Fig. 384 is given a phantom view of the dial, in order to show more clearly the relation of the mechanical parts and contacts controlled by it. For a correct idea of its mechanical action it must be understood that the shaft *1*, the lever *2*, and the interrupter segment *3* are all rigidly fastened to the dial and move with it. A coiled spring always tends to move the dial and these associated parts back to their normal positions when released by the subscriber, and a centrifugal governor, not shown, limits the speed of the return movement.

The subscriber's hook switch is mechanically interlocked with the dial so as to prevent the dial being moved from its normal position until the hook is in its raised position. This interlocking function involves also the pivoted dog *4*. Normally the lower end of this dog lies in the path of the pin *5* carried on the lever *2*, and thus the shaft, dial, and segment are prevented from any considerable movement when the receiver is on the hook. However, when the receiver is removed from its hook, the upwardly projecting arm from the hook engages a projection on the dog *4* and moves the dog out of the path of the pin *5*. Thus the dial is free to be rotated by the subscriber. The pin *6* is mounted in a stationary position and serves to limit the backward movement of the dial by the lever *2* striking against it.

Ground Springs:—Five groups of contact springs must be considered, some of which are controlled wholly by the position of the switch hook, others jointly by the position of the switch hook and the dial, others by the movement of the dial itself, and still others by the pressure of the subscriber's finger on a button. The first of these groups consists of the springs *7* and *8*, the function of which is to control the continuity of the ground connection at the subscriber's station. The arrangement of these two springs is such that the ground connection will be broken until the subscriber's receiver is removed from its hook. As soon as the receiver is raised, these springs come together in an obvious manner, the dog *4* being lifted out of the way by the action of the hook. The ledge on the lower portion of the spring *7* serves as a rest for the insulated arm of the dog *4* to prevent this dog, which is spring actuated, from returning and locking the dial until after the receiver has been hung up.

Bell and Transmitter Springs:—The second group is that embracing the springs *9*, *10*, *11*, and *12*. The springs *10* and *11* are controlled by the lower projection from the switch hook, the spring *11* engaging the spring *12* only when the hook is down. The spring *10* engages the spring *9* only when the hook lever is up and not then unless the dial is in its normal position. While the hook is raised, therefore, the springs *9* and *10* break contact whenever the dial is moved and make contact again when it returns to its normal position. The springs *11* and *12* control the circuit through the subscriber's bell while the springs *9* and *10* control the continuity of the circuit from one side of the line to the other so as to isolate the limbs from each other while the signal transmitter is sending its impulses to the central office.

Impulse Springs:—The third group embraces springs *13, 14,* and *15* and these are the ones by which the central-office switches are controlled in building up a connection.

Something of the prevailing nomenclature which has grown up about the automatic system may be introduced at this point. The movements of the selecting switches at the central office are referred to as *vertical* and *rotary* for obvious reasons. On account of this the magnet which causes the vertical movement is referred to as the *vertical magnet* and that which accomplishes the *rotary* movement as the *rotary magnet.* It happens that in all cases the selecting impulses sent by the subscriber's station, corresponding respectively to the number of digits in the called subscriber's number, are sent over one side of the line and in nearly all cases these selecting impulses actuate the vertical movements of the selecting switches. For this reason the particular limb of the line over which the selecting impulses are sent is called the *vertical limb.* The other limb of the line is the one over which the single impulse is sent after each group of selecting impulses, and it is this impulse in every case which causes the selector switch to start rotating in its hunt for an idle trunk. This side of the line is, therefore, called *rotary.* For the same reasons the impulses over the vertical side of the line are called *vertical impulses* and those over the rotary side, *rotary impulses.* The naming of the limbs of the line and of the current impulses *vertical* and *rotary* may appear odd but it is, to say the least, convenient and expressive.

Coming back to the functions of the third group of springs, *13, 14,* and *15, 15* may be called the *vertical spring* since it sends vertical impulses; *13,* the *rotary spring* since it sends rotary impulses;

and *14*, the *ground spring* since, when the hook is up, it is connected with the ground.

On the segment *3* there are ten projections or cams *16* which, when the dial is moved, engage a projection of the spring *15*. When the dial is being pulled by the subscriber's finger, these cams engage the spring *15* in such a way as to move it away from the ground spring and no electrical contact is made. On the return of the dial, however, these cams engage the projection on the spring *15* in the opposite way and the passing of each cam forces this vertical spring into engagement with the ground spring. It will readily be seen, therefore, by a consideration of the spacing of these cams on the segment and the finger holes in the dial that the number of cams which pass the vertical spring *15* will correspond to the number on the hole used by the subscriber in moving the dial.

Near the upper right-hand corner of the segment *3*, as shown in Fig. 384, there is another projection or cam *17*, the function of which is to engage the rotary spring *13* and press it into contact with the ground spring. Thus, the first thing that happens in the movement of the dial is for the projection *17* to ride over the hump on the rotary spring and press the contact once into engagement with the ground spring; and likewise, the last thing that happens on the return movement of the dial is for the rotary spring to be connected once to the ground spring after the last vertical impulse has been sent.

If both the rotary and vertical sides of the line are connected with the live side of the central-office battery, it follows that every contact between the vertical and the ground spring or between the rotary and the ground spring will allow an impulse of current to flow over the vertical or the rotary side of the line.

We may summarize the action of these impulse springs by saying that whenever the dial is moved from its normal position, there is, at the beginning of this movement, a single rotary impulse over the rotary side of the line; and that while the dial returns, there is a series of vertical impulses over the vertical side of the line; and just before the dial reaches its normal position, after the sending of the last vertical impulse, there is another impulse over the rotary side of the line.

The mechanical arrangements of the interrupter segment *3* and its associated parts have been greatly distorted in Fig. 384 in order to make clear their mode of operation. This drawing has been worked out with great care, with this in mind, at a sacrifice of accuracy in regard to the actual structural details.

Ringing Springs:—The fourth group of springs in the subscriber's telephone is the ringing group and embraces the springs *18*, *19*, and *20*. The springs *19* and *20* are normally closed and maintain the continuity of the talking circuit. When, however, the button attached to the spring *19*—which button may be seen projecting from the instrument shown in Fig. 382, and from the base of the one shown in Fig. 383—is pressed, the continuity of the talking circuit is interrupted and the vertical side of the line is connected with the ground. It is by this operation, after the connection has been made with the desired subscriber's line, that the central-office apparatus acts to send ringing current out on that line.

Release Springs:—The fifth set of springs is the one shown at the left-hand side of Fig. 384, embracing springs *21*, *22*, and *23*. The long curved spring *21* is engaged by the projecting lug on the switch hook when it rises so as to press this spring away from the other two. On the return movement of the hook, however, this spring is pressed to the left so as to bring all three of them into contact, and this, it will be seen, grounds both limbs of the line at the subscriber's station. This combination cannot be effected by any of the other springs at any stage of their operation, and it is the one which results in the energization of such a combination of relays and magnets at the central office as will release all parts involved in the connection and allow them to return to their normal positions ready for another call.

Salient Points. If the following things are borne in mind about the operation of the subscriber's station apparatus, an understanding of the central-office operations will be facilitated. First, the selective impulses always flow over the vertical side of the line; they are always preceded and always followed by a single impulse over the rotary side of the line. The ringing button grounds the vertical side of the line and the release springs ground both sides of the line simultaneously.

The Line Switch. The first thing to be considered in connection with the central-office apparatus is the line switch. This, it will be remembered, is the device introduced into each subscriber's line at the central office for the purpose of effecting a reduction of the number of first selectors required at the central office, and also for bringing about certain important functional results in connection with trunking between central and sub-offices. The function of the line switch in connection with the subscriber's line, however, is purely that of reducing the number of first selectors.

The line switches of one hundred lines are all associated to form a single unit of apparatus, which, besides the individual line switches, includes certain other apparatus common to those lines. Such a group of one hundred line switches and associated common apparatus is called a *line-switch unit,* or frequently, a *Keith unit.* Confusion is likely to arise in the mind of the reader between the individual line switch and the line-switch unit, and to avoid this we will refer to the piece of apparatus individual to the line as the line switch, and to the complete unit formed of one hundred of these devices as a line-switch unit.

Line and Trunk Contacts. Each line switch has its own bank of contacts arranged in the arc of a circle, and in this same arc are also placed the contacts of each of the ten individual trunks which it is possible for that line to appropriate. The contacts individual to the subscriber's line in the line switch are all multipled together, the arrangement being such that if a wedge or plunger is inserted at any point, the line contacts will be squeezed out of their normal position so as to engage the contacts of the trunk corresponding to the particular position in the arc at which the wedge or plunger is inserted. A small plunger individual to each line is so arranged that it may be thrust in between the contact springs in the line-switch bank in such manner as to connect any one of the trunks with the line terminals represented in that row, the particular trunk so connected depending on the portion of the arc toward which the plunger is pointed at the time it is thrust in the contacts.

These banks of lines and trunk contacts are horizontally arranged, and piled in vertical columns of twenty-five line switches each. The ten trunk contacts are multipled vertically through the line-switch banks, so that the same ten trunks are available to each of the twenty-five lines. We thus have, in effect, an old style, Western Union, cross-bar switchboard, the line contacts being represented in horizontal rows and the trunk contacts in vertical rows, the connection between any line and any trunk being completed by inserting a plunger at the point of intersection of the horizontal and the vertical rows corresponding to that line and trunk.

Trunk Selection. The plungers by which the lines and trunks are connected are, as has been said, individual to the line, and all of the twenty-five plungers in a vertical row are mounted in such manner as to be normally held in the same vertical plane, and this vertical plane is made to oscillate back and forth by an oscillating shaft so as always *to point the plungers toward a vertical row of trunk contacts that represent a trunk that is not in use at the time.* The to-and-fro movement of this oscillating shaft, called the *master bar,* is controlled by a master switch and the function of this master switch is always to keep the plungers pointed toward the row of contacts of an idle trunk. The thrusting movement of the individual plungers into the contact bank is controlled by magnets individual to the line and under control of the subscriber in initiating a call. As soon as the plunger of a line has been thus thrust into the contact bank so as to connect the terminals of that line with a given trunk, the plunger is no longer controlled by the master bar and remains stationary. The master bar then at once moves all of the other plungers that are not in use so that they will point to the terminals of another trunk that is not in use. The plungers of all the line switches in a group of twenty-five are, therefore, subject to the oscillating movements of the master bar when the line is not connected to a first selector trunk. As soon as a call is originated on a line, the corresponding plunger is forced into the bank and is held stationary in maintaining the connection to a first selector trunk, and all of the other plungers not so engaged, move on so as to be ready to engage another idle trunk.

Trunk Ratio. The assignment of ten trunks to twenty-five lines would be a greater ratio of trunks than ordinary traffic conditions require. This ratio of trunks to lines is, however, readily varied by multipling the trunk contacts of several twenty-five line groups together. Thus, ten trunks may be made available to one hundred subscribers' lines by multipling the trunks of four twenty-five line switch groups together. In this case the four master bars corresponding to the four groups of twenty-five line switches are all mechanically connected together so as to move in unison under the control of a single master switch. If more than ten and less than twenty-one trunks are assigned to one hundred lines, then each set of ten trunks is multipled to the trunk contacts of fifty line switches, the two master bars of these switches being connected together and controlled by a common master switch.

Structure of Line Switch. The details of the parts of a line switch that are individual to the line are shown in Fig. 385, the line and trunk contact bank being shown in the lower portion of this figure and also in a separate view in the detached figure at the right. A detailed group of several such line switches with the oscillating

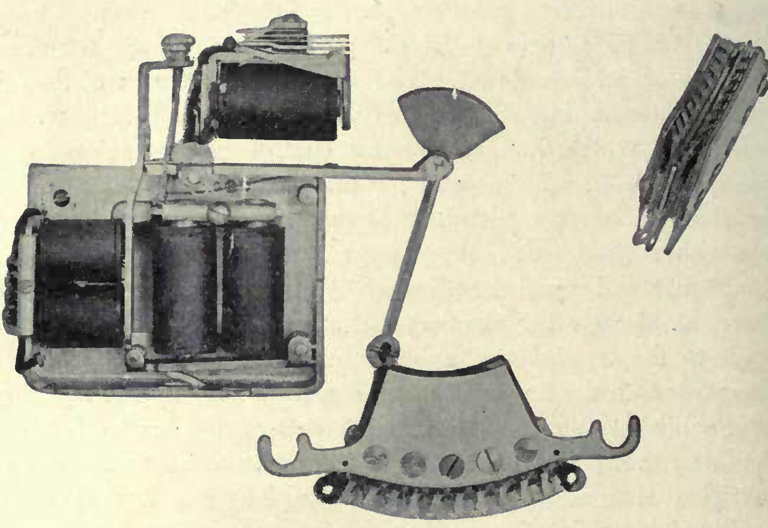


Fig. 385. Line Switch

master bar is shown in Fig. 386. This figure shows quite clearly the relative arrangement of the line and trunk contact banks, the plungers for each bank, and the master bar.

In practice, four groups of twenty-five line switches each are mounted on a single framework and the group of one hundred line switches, together with certain other portions of the apparatus that will be referred to later, form a line-switch unit. A front view of such a unit is shown in Fig. 387. In order to give access to all portions of the wiring and apparatus, the framework supporting each column of fifty line switches is hinged so as to open up the interior of the device as a whole. A line-switch unit thus opened out is shown in Fig. 388.

Circuit Operation. The mode of operation of the line switch may be best understood in connection with Fig. 389, which shows

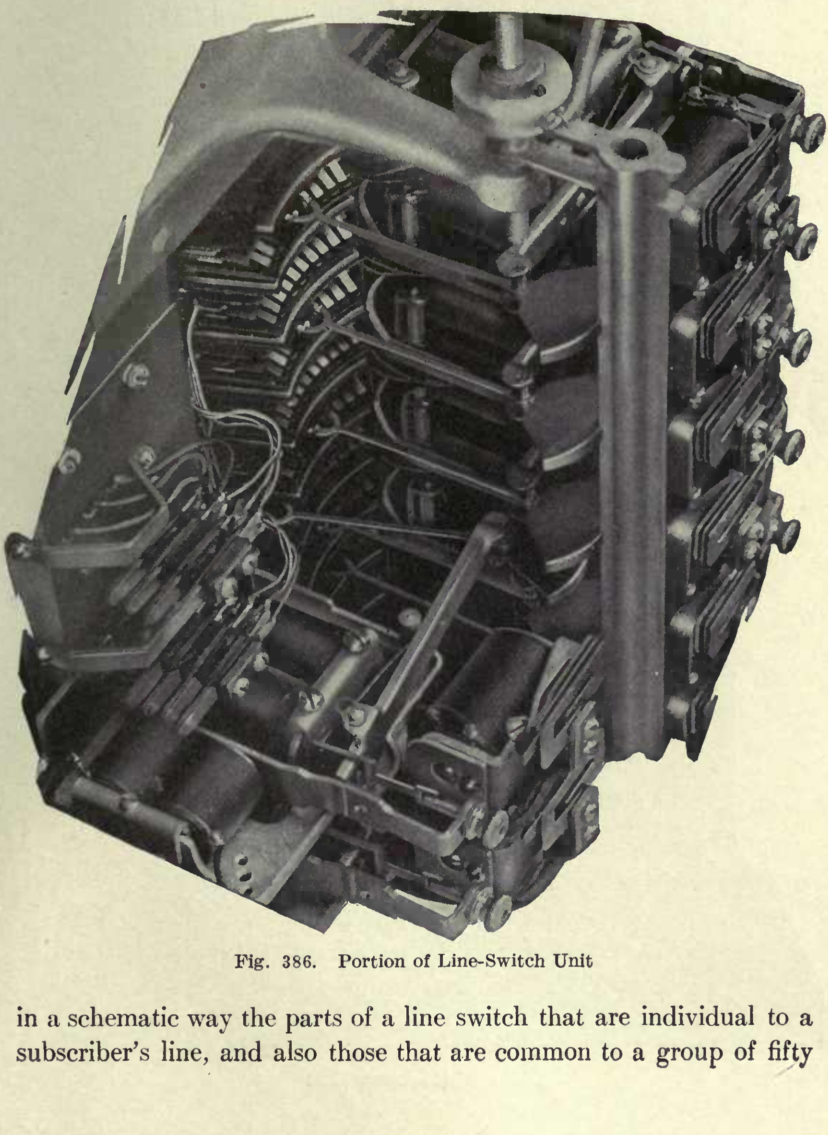


Fig. 386. Portion of Line-Switch Unit

in a schematic way the parts of a line switch that are individual to a subscriber's line, and also those that are common to a group of fifty

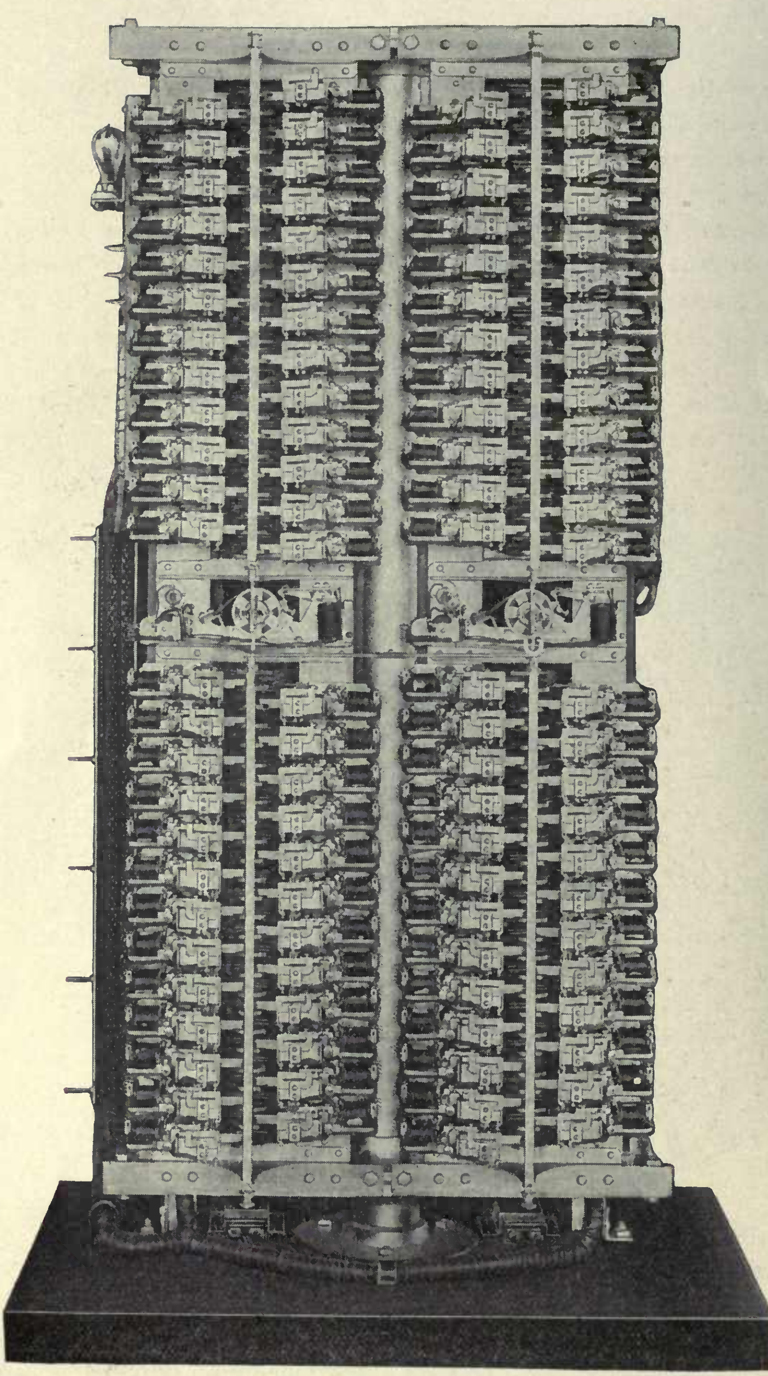


Fig. 387. Line-Switch Unit

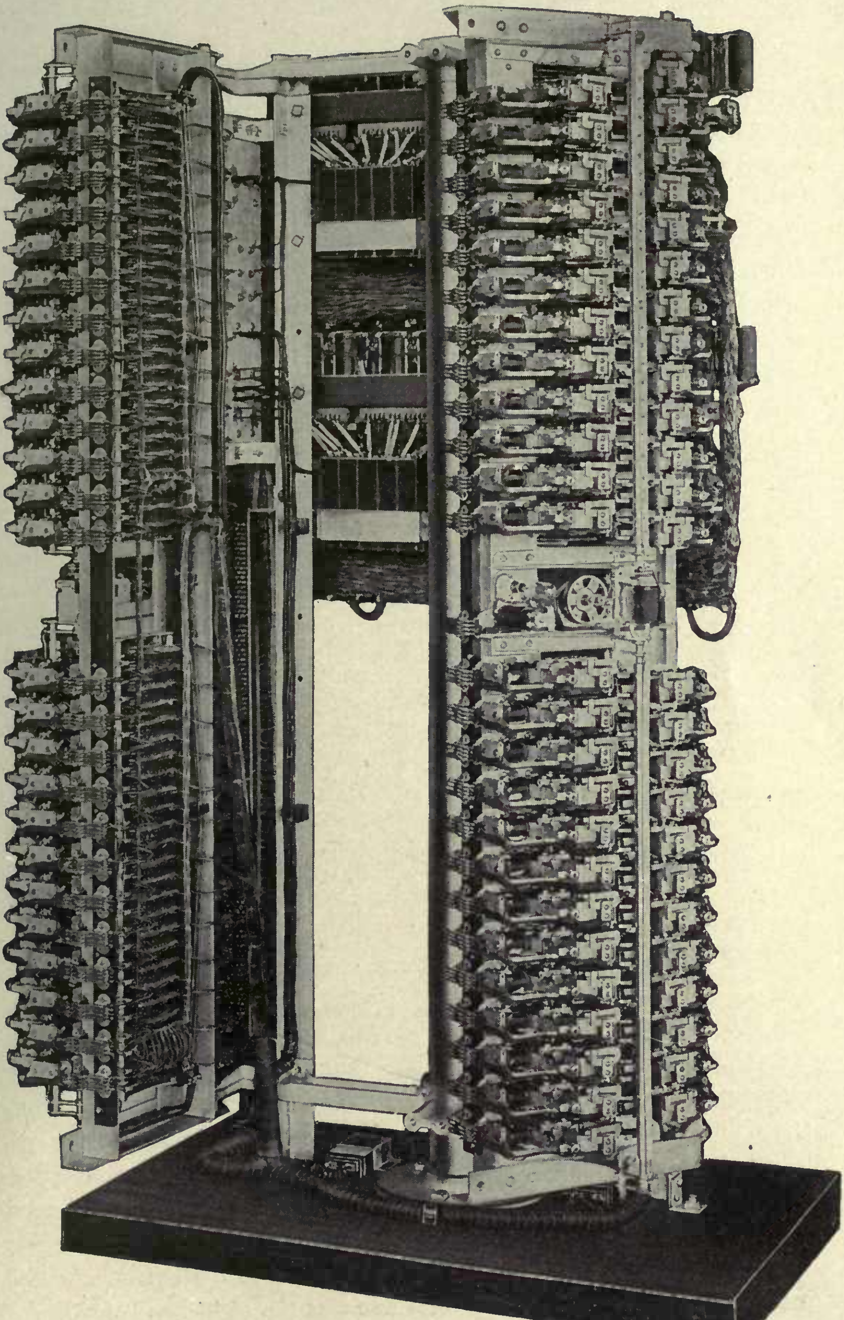


Fig. 388. Line-Switch Unit

or one hundred lines. Those portions of Fig. 389 which are individual to the line are shown below the dotted line extending across the page. The task of understanding the line switch will be made somewhat easier if Figs. 385 and 389 are considered together. The individual parts of the line switch are shown in the same relation to each other in these two figures with the exception that the bank of line and trunk springs in the lower right-hand corner of Fig. 389 have been turned around edgewise so as to make an understanding of their circuit connections possible.

The vertical and rotary sides of the subscriber's line are shown entering at the lower left-hand corner of this figure, and they pass

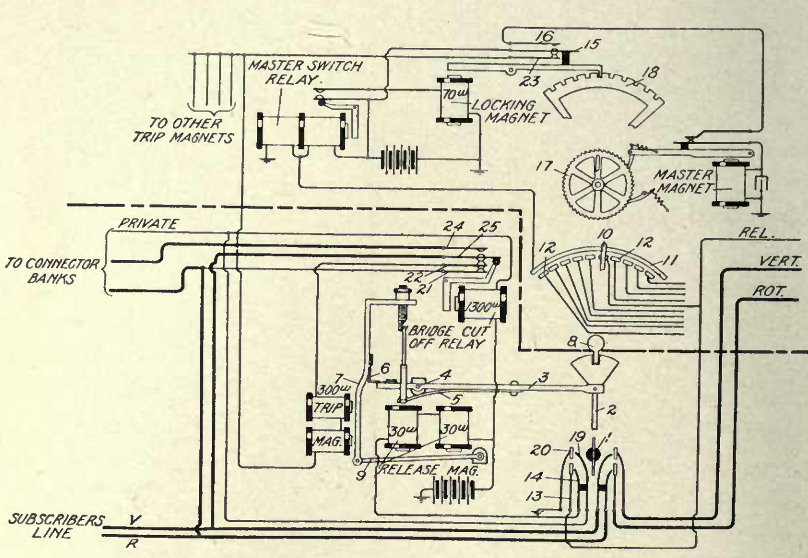


Fig. 389. Circuits of Line-Switch Unit

to the springs of the contact bank. Immediately adjacent to these springs are the trunk contacts from which the vertical and the rotary limbs of the first selector trunk proceed. The plunger is indicated at *1*, it being in the form of a wheel of insulating material. It is carried on the rod *2* pivoted on a lever *3*, which, in turn, is pivoted at *4* in a stationary portion of the framework. A spring *5*, secured to the underside of the lever *3* and projecting to the left beyond the pivot *4* of this lever, serves always to press the right-hand portion of the lever *3* forward in such direction as to tend to thrust it into the contact bank. The plunger is normally held out of the contact bank by means of the latch *6* carried on the armature *7* of the trip magnet. When the trip magnet is energized it pulls the armature *7* to the left and thus releases the plunger and allows it to enter the contact bank.

The master bar is shown at *8*, and a feather on this bar engages a notch in the segment attached to the rear end of the plunger rod *2*. This master bar is common to all of the plunger rods and by its oscillatory movement, under the influence of the master switch, it always keeps all of the idle plunger bars pointed toward the contacts of an idle trunk. As soon, however, as the trip magnet is operated to cause the insertion of a plunger into the contact bank, the feather on the master bar is disengaged by the notch in the segment of the plunger rod, and the plunger rod is, therefore, no longer subject to the oscillating movement of the master bar.

When the release magnet is energized, it attracts its armature *9* and this lifts the armature *7* of the trip magnet so that the latch *6* rides on top of the left-hand end of the lever *3*. Then, when the release magnet is de-energized, the spring *5*, which was put under tension by the latch, moves the entire structure of levers back to its normal position, withdrawing the plunger from the bank of contacts. The notch on the edge of the segment of the plunger rod, when thus released, will probably not strike the feather on the master bar, and the plunger rod will thus not come under the control of the master bar until the master bar has moved, in its oscillation, so that the feather registers with the notch, after which this bar will move with all the others.

If, while the plunger is waiting to be picked up by the master bar, the same subscriber should call again, his line will be connected with the same trunk as before. There is no danger in this, however, that the trunk will be found busy, because the master bar will not have occupied a position which would make it possible for any of the lines to appropriate this trunk during the intervening time.

Master Switch. Associated with each master bar there is a master switch which determines the position in which the master bar shall stop in order that the idle plungers may be pointed always to the contacts of an idle trunk. The arm *10* of this switch is attached to the master bar and oscillates with it and serves to connect the segment *11* successively with the contacts *12*, which are connected respectively to the third, or release wire of each first selector trunk. In the figure the arm *10* is shown resting on the sixth contact of the switch and this sixth contact is connected to a spring *13* in the line-switch contact bank that has not yet been referred to. As soon as the plunger is inserted into the contact bank, the spring *14* will be pressed into engagement with the spring *13*, and this spring *14* is connected with the live side of the battery through the release magnet winding.

The contact strip *11* on the master switch is thus connected through the release magnet to the battery and from this current flows through the left-hand winding of the master-switch relay. This energizes this relay and causes the closure of the circuit of the locking magnet which magnet unlocks the master bar to permit its further rotation. The unlocking of the master bar brings the spring *15* into engagement with *16* and thus energizes the master magnet, the armature of which vibrates back and forth after the manner of an electric-bell armature, and steps the wheel *17* around. The wheel *17* is mechanically connected to the master bar so that each complete revolution of the wheel will cause one complete oscillation of the master bar. The master bar will thus be moved so as to cause all the idle plungers to sweep through an arc and this movement will stop as soon as the master-switch arm *10* connects the arc *11* with one of the contacts *12* that is not connected to the live side of the battery through the springs *13* and *14* of some other line switch. It is by this means that the plungers of the line switches are always kept pointing at the contacts of an idle trunk. The way in which this feature has been worked out must demand admiration and accounts for the marvelous quickness of this line switch. The fact that the plungers are pointed in the right direction before the time comes for their use, leaves only the simple thrusting motion of the plunger to accomplish the desired connection immediately upon the initiation of a call by the subscriber.

Locking Segment. It will be understood that the locking segment *18* and the master-switch contact finger *10* are both rigidly connected with the master bar *8* and move with it, the locking segment *18* serving always to determine accurately the angular position at which the master bar and the master-switch arm are brought to rest.

Bridge Cut-Off. One important feature of automatic switching, particularly as exemplified in the system of the Automatic Electric Company, is the disconnection, after its use, of each operating magnet of each piece of apparatus involved in making a connection. Since these operating magnets are always bridged across the line at the time of their operation and then cut off after they have performed their function, this feature may be referred to as the *bridge cut-off.*

Guarding Functions. Still another feature of importance is the means for guarding a line or a piece of apparatus that has already been appropriated or made busy, so that it will not be appropriated or connected with for use in some other connection. For this latter purpose contacts and wires are associated with each piece of apparatus, which are multipled to similar contacts on other pieces of apparatus in much the same way and for a similar purpose that the test thimbles in a multiple switchboard are multipled together. Such wires and contacts in the Automatic Electric Company's apparatus are called *private wires* and *contacts.*

The bridge cut-off and guarding functions are provided for in the line switch by a bridge cut-off relay shown in Fig 389 and also in Fig. 385, it being the upper one of the individual line relays in each of those figures. This bridge cut-off relay is operated as soon as the plunger of the line is thrust into the bank; the contacts *19* and *20,* closed by the plunger, serving to complete the circuit of this relay. To make clear the bridge cut-off feature it will be noted that the trip magnet of a line switch is connected in a circuit traced from the rotary side of the line through the contacts *21* and *22* of the bridge cut-off relay, thence through the coil of the trip magnet to the common wire leading to the spring *23* of the master-bar locking device and thence to the live side of the battery. Obviously, therefore, as soon as the bridge cut-off relay operates, the trip magnet becomes inoperative and can cause no further action of the line switch because its circuit is broken between the springs *21* and *22.*

The private or guarding feature is taken care of by the action of the plunger in closing contacts *19* and *20,* since the private wire leading to the bridge cut-off relay is, as has already been stated, connected to ground when these contacts are closed. This private wire leads off and is multipled to the private contacts on all the connectors that have the ability to reach this line, and the fact that this wire is grounded by the line switch as soon as it becomes busy, establishes such conditions at all of the connectors that they will refuse to connect with this line as long as it is busy, in a way that will be pointed out later on.

Relation of Line Switch and Connectors. The vertical and rotary wires of the subscriber's line are shown leading off to the connector banks at the left-hand side of Fig. 389, and one side of this connection passes through the contacts *24* and *25* of the bridge cut-off relay on the line switch. It is through this path that a connection from some other line through a connector to this line is established and it is seen that this path is held open until the bridge cut-off relay of the line switch is operated. For such a connection to this line the bridge cut-off relay of the line switch is operated over the private wire leading from the connector, and the operation of the bridge cut-off relay at this time serves to render inoperative the line switch, so that it will not perform its usual functions should the called subscriber start to make a call after his line had been seized.

Summary of Line-Switch Operation. To summarize the operation of a line switch when a call is originated on its line, the first movement of the calling subscriber's dial will ground the rotary side of the line and operate the trip magnet. This will cause the plunger to be inserted into the bank, and thus extend the line to the first selector trunk through the closing of the right-hand set of springs shown in the lower right-hand corner of Fig. 389. The insertion of the plunger will also connect the battery through the left-hand winding of the master-switch relay and, by the sequence of operations which follows, cause the master bar to move all of the idle plungers so as to again point them to an idle trunk. The closure of contacts *19* and *20* by the plunger causes the operation of the bridge cut-off relay which opens the circuit of the trip magnet, rendering it inoperative; and also establishes ground potential on all the private wire contacts of that line in the banks of the connectors, so as to guard the line and its associated apparatus against intrusion by others. The line is cut through, therefore, to a first selector and all of the line-switch apparatus is completely cut off from the talking circuit.

It must be remembered that all of the actions of the line switch, which it has taken so long to describe, occur practically instantaneously and as a result of the first part of the first movement of the subscriber's dial. The line switch has done its work and "gone out of business" before the selective impulses of the first digit begin to take place.

Selecting Switches. The first selector is now in control of the calling subscriber. The circuits and elements of the first selector switch are shown in Fig. 390. The general mechanical structure of the first selectors, second selectors, and connectors, is the same and may be referred to briefly here. Fig. 391 shows a rear view of a first selector; Fig. 392, a side view of a second selector; and Fig. 393, a front view of a connector. The arrangement of the vertical and rotary magnets, of the selector shafts, and of the contact banks are identical in all three of these pieces of apparatus and all these switches work on the "up-and-around principle" referred to in connection with Fig. 380. It is thought that with the general structure shown in Figs. 391, 392, and 393 in mind, the actual operation may be understood much more readily from Fig. 390.

Four magnets—the vertical, the rotary, the private, and the release—produce the switching movements of the machine. These magnets are controlled by various combinations brought upon the circuits by three relays—the vertical, the rotary, and the back release. The fourth relay shown, called the *off-normal,* is purely for signaling purposes, as will be described.

Side Switch. Another important element of the selecting switches is the so-called side switch which might better be called a pilot switch—but we are not responsible for its name. This side switch has for its function the changing of the control of the subscriber's line to successive portions of the selector mechanism, rendering inoperative those portions that have already performed their functions and that, therefore, are no longer needed. This switch may be seen best in Fig. 392 just above the upper bank of contacts. It is shown in Fig. 390 greatly distorted mechanically so as to better illustrate its electrical functions.

The contact levers *1*, *2*, *3*, and *4* of the side switch are carried upon the arm *5* which is pivoted at *6*. All of these contact levers, therefore, move about *6* as an axis. The side switch has three positions and it is shown, in Fig. 390, in the first one of these. When the private magnet armature is attracted and released once, the es-

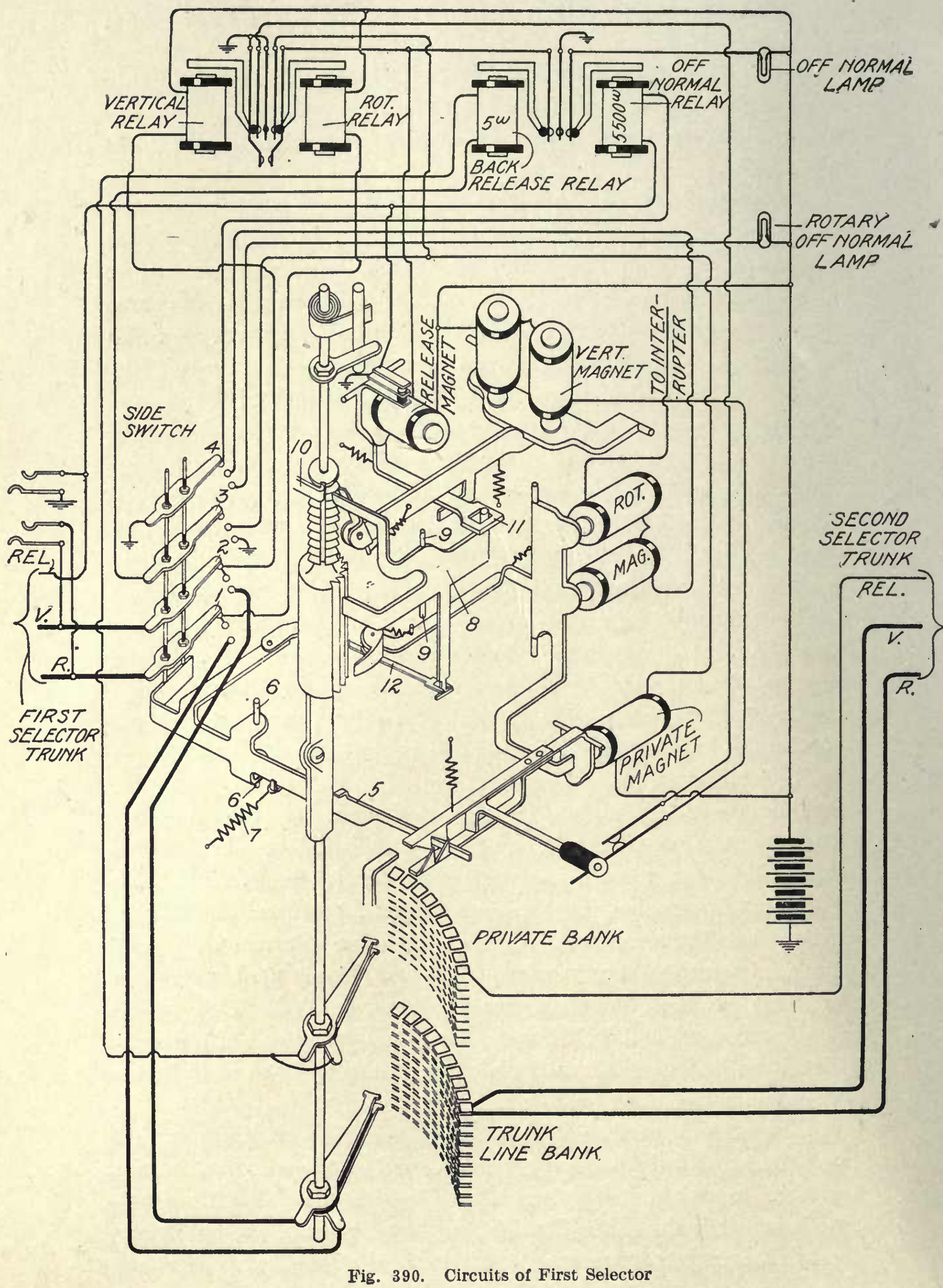


Fig. 390. Circuits of First Selector

capement carried by it permits the spring *7* to move the arm *5* so as to bring the wipers of the side switch into its second position; the second pulling up and release of the private magnet armature will cause the movement of the side switch wipers into the third position. It is to be noted that the escapement which releases the side switch arm may be moved either by the private or by the rotary magnet, since the armature of the latter has a finger which engages the private magnet armature.

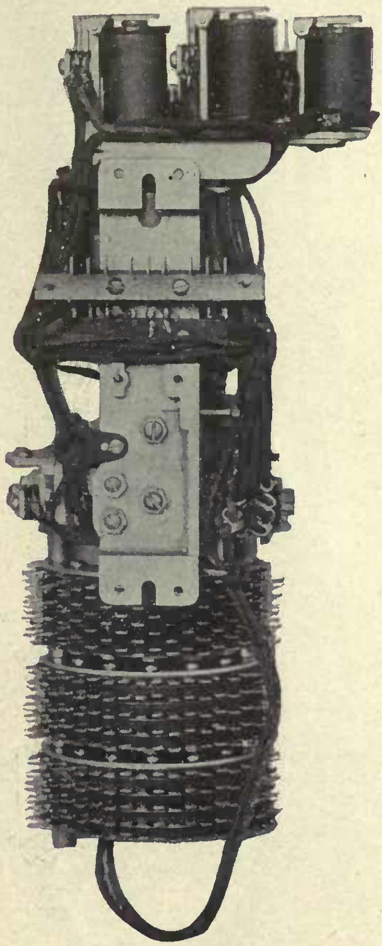


Fig. 391. Rear View of First Selector

Functions of Side Switch. The functions of the side switch may be briefly outlined in connection with the first selector, as an example. In the first position it extends the control of the subscriber's signal transmitter through the first selector trunk and line relays to the vertical and private magnets so that these magnets will be responsive to the selecting impulses corresponding to the first digit. In its second position it brings about such a condition of affairs that the rotary magnet will be brought into play and automatically move the wipers over the bank contacts in search of an idle trunk. In its third position, both the vertical and rotary relays are cut off and the line is cut straight through to the second selector trunk, and only those parts of the first selector apparatus are left in an operative state which have to do with the private or guarding circuits and with the release. Similar functions are performed by the side switch in connection with the other selecting switches.

Release Mechanism. Another one of the features of the switch that needs to be considered before a detailed understanding of its operation may be had, is the mechanical relation of the holding and the release dog. This dog is shown at *8* and, in the language of the art, is called the *double dog.* As will be seen, it has two retaining fingers, one adapted to engage the vertical ratchet and the other, the rotary ratchet on the selector shaft. This double dog is pivoted at *9* and is interlinked in a peculiar way with the armature of the vertical magnet, the armature of the release magnet, and the arm of the side switch. The function of this double dog is to hold the shaft in whatever vertical position it is moved by the vertical magnet and then, when the rotary magnet begins to operate, to hold the shaft in its proper angular position. It will be noted that the fixed dog *10* is ineffective when the shaft is in its normal angular position. But as soon as the shaft is rotated, this fixed dog *10* becomes the real holding pawl so far as the vertical movement is concerned. The double dog *8* is normally held out of engagement with the vertical and the rotary ratchets by virtue of the link connection, shown at *11,* between the release magnet armature and the rear end of the double dog. On the previous release of the switch the attraction of the release magnet armature permitted the link *11* to hook over the end of the dog *8* and thus, on its return movement,

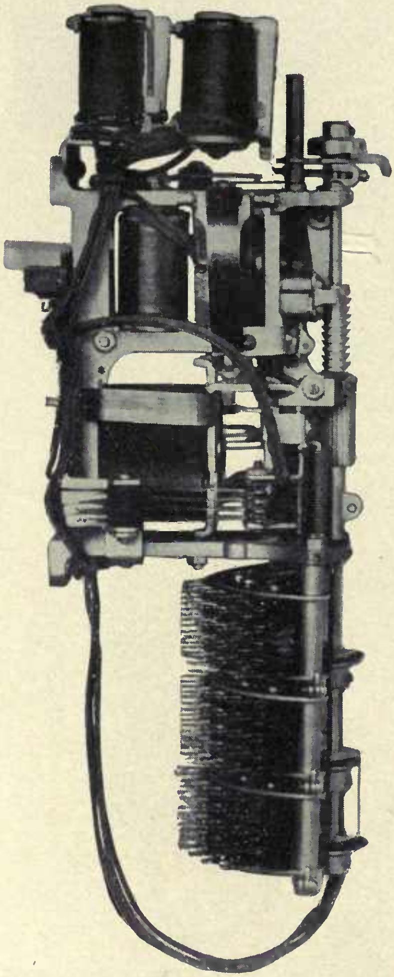


Fig. 392. Side View of Second Selector

to pull this dog out of engagement with its ratchets. This movement also resulted in pushing on the link *12* which is pivoted to the side switch arm *5*, and thus the return movement of the release magnet is made to restore the side switch to its normal position. In order that the double dog may be made effective when it is required, and in order that the side switch may be free to move under the influence of the private magnet, the double dog is released from its connection with the release magnet armature by the first movement of the vertical magnet in a manner which is clear from the drawing.

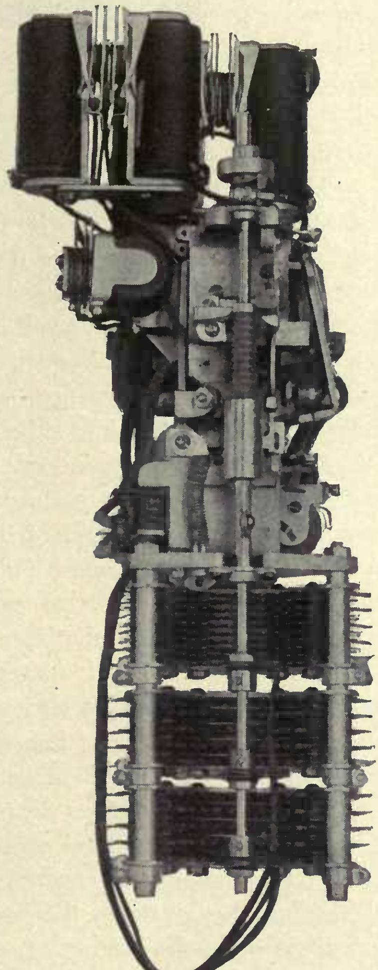


Fig. 393. Front View of Connector

First Selector Operation. In discussing the details of operation of the various selectors it will be found convenient to divide the discussion according to the position of the side switch. This will bring about a logical arrangement because it is really the side switch which determines by its position the sequence of operation.

First Position of Side Switch. This is the position shown in Fig. 390, and is the normal position. The vertical and the rotary lines extending from the calling subscriber are continued by the levers *1* and *2* of the side switch through the vertical and the rotary relay coils, respectively, to the live side of battery. The lever *4* of the side switch in this position connects to ground the circuit leading from the line switch through the release trunk, and the winding of the off-normal relay. This winding is thus put in series with the release magnet of the line switch, but on account of high resistance of the off-normal relay no operation of the release magnet is caused. This will, however, permit such current to flow through the release circuit as will energize the sensitive off-normal relay and cause it to attract its armature and light the off-normal lamp. If this lamp remains lighted more than a brief period of time, it will attract notice and will indicate that the corresponding selector has been appropriated by a line switch and that for some reason the selector has gone no further. This lamp, therefore, is an aid in preventing the continuance of this abnormal condition.

The first thing that happens after the line switch has connected the calling subscriber with the first selector is a succession of impulses over the vertical side of the line, this being the set of impulses corresponding in number to the thousands digit or to the office, if there is more than one. It will be understood that here we are considering a single office of ten-thousand-line capacity or thereabouts, and that, therefore, this first set of impulses corresponds to the thousands digit in the called subscriber's line. Each one of these impulses will flow from the battery through the vertical relay and each movement of this relay armature will close the circuit of the vertical magnet and cause the shaft of the selector to be stepped up to the proper level. Immediately following the first series of selecting impulses from the subscriber's station, a single impulse follows over the rotary side of the line. This gives the rotary relay armature one impulse and this in turn closes the circuit of the private magnet once. The single movement of the private magnet armature allows the escapement finger on the arm *5* to move one step and this brings the side switch contacts into the second position.

Second Position of Side Switch. In this position lever *4* of the side switch places a ground on the wire leading through the rotary magnet to a source of interrupted battery current. The impulses which thus flow through the rotary magnet occur at a frequency dependent upon the battery interrupter and this is at a rate of approximately fifteen impulses per second. The rotary magnet will step the selector shaft rapidly around until something occurs to stop these impulses. This something is the finding by the private wiper of an ungrounded private contact in the bank, since all of the contacts corresponding to busy trunks are grounded, as will be explained.

The action of the private magnet enters into this operation in the following way: A circuit may be traced from the battery through the private magnet to the third side switch wiper when in its second position, thence through the back release relay to the private wiper. If the wiper is at the time on the private bank contact of a busy trunk, it will find that contact grounded and the private magnet will be energized. The energizing of this magnet will not, however, cause the release of the side switch. It must be energized and de-energized. The private magnet armature will, therefore, be operated by the finger of the rotary magnet armature on the first rotary step. The private magnet will be energized and hold its armature operated if the private wiper finds a ground on the first bank contact and will stay energized as long as the private wiper is passing over private contacts of busy trunks. Its armature will not be allowed to fall back during the passage of the wiper from one trunk to another, because during that interval the finger of the rotary magnet will hold it operated. As soon, however, as the private wiper reaches the private bank contact of an idle trunk, no ground will be found and the circuit of the private magnet will be left open. When the impulse through the rotary magnet ceases, the private magnet armature will fall back and the side switch will be released to its third position.

Third Position of Side Switch. The first thing to be noted in this position is that the calling line is cut straight through to the second selector trunk, the connection being clean with no magnets bridged across or tapped off. The third wiper of the side switch, when in its third position, is grounded and this connects the release wire of the second selector trunk, on which the switch wipers rest, through the private wiper, the winding of the back release magnet, and the third wiper of the side switch to ground. This establishes a path for the subsequent release current through the back release magnet; and, of equal importance, it places a ground on the private bank contact of that trunk so that the private wiper of any other switch will be prevented from stopping on the contacts of this trunk in the same manner that the wiper of this switch was prevented from stopping on other trunks that were already in use.

The fourth lever on the side switch, when in its third position, serves merely to close the circuit of the rotary off-normal lamp. This lamp is for the purpose of calling attention to any first selector switch that has been brought into connection with some second selector trunk and which, for some reason, has failed in its release. These off-normal lamps are so arranged that they may be switched off manually to avoid burning them during the hours of heaviest traffic. At night they afford a ready means of testing for switches that have been left off-normal, since the manual switches controlling these lamps may then be closed, and any lamps which burn will show that the switches corresponding to them are off-normal. Simple tests then suffice to show whether they are properly or improperly in their off-normal position.

Release of the First Selector. As will be shown later, the normal way of releasing the switches is from the connector back over the release wire. It is sufficient to say at this point that when the proper time for release comes, an impulse of current will come back over the second selector trunk release wire through the private wiper, to the back release relay magnet, and thence to ground through the third wiper of the side switch which is in its third position. It may be asked why the back release magnet was not energized during the previous operations described, when current passed through it. The reason for this is that in those previous operations the private magnet was always included in series in the circuit and on account of the high resistance of the private magnet, sufficient current did not pass through the back release magnet to energize it.

When the back release relay is energized, it closes the circuit of the release magnet and thus, through the link *11*, draws the double dog away from its engagement with the shaft ratchets and at the same time, through the link *12*, restores the side switch to its normal position. Whenever the release magnet is operated it acts as a relay to close a pair of contacts associated with it and thus to momentarily ground the release wire of the first selector trunk extending back to the line switch. Referring to Fig. 389, it will be seen that this path leads through the contacts *13* and *14* and the release magnet to the battery. It is by this means that the line switch is released, the release impulse being relayed back from the first selector.

Second Selector Operation. For the purpose of considering the action of the second selector, we will go back to the point where the first selector had connected with a second selector trunk and where its side switch had moved into its third position. In this condition, it will be remembered, the trunk line was cut through to a second selector trunk and all first selector apparatus cleared from the talking circuit.

The second selector chosen is one corresponding to the thousands group as determined by the first digit of the called subscriber's number. The circuits of a second selector are shown in Fig. 394 and it must be borne in mind that the mechanical arrangements for producing the vertical and the rotary movement of the shaft and for operating the side switch are practically the same as those of the first selector. As in the first selector, the sequence of operation is controlled by the successive positions of the side switch, the first position permitting the selection of the hundreds corresponding to the vertical impulses, the second position allowing the selector to search for an idle trunk in that hundred, and the third position cutting the trunk through and clearing the circuit of obstructing apparatus.

First Position of Side Switch. The first thing that happens when the subscriber begins to move his dial in the transmission of the second series of selecting impulses is the sending of a preliminary impulse over the rotary side of the line. This, in the case of the second selector, energizes the rotary relay which, in turn, energizes the private magnet; but the private magnet in the case of the second selector can do nothing toward the release of the side switch because the projection 5′, on the side switch arm *5*, meets a projection on the rear of the selector shaft which thus prevents the movement of the side switch arm *5* until the selector shaft has been moved out of its normal position.

Immediately after the establishment of the connection to the selector, the second set of selecting impulses comes in over the vertical wire from the subscriber's station. These impulses, corresponding in number to the hundreds digit, will energize the vertical relay and cause it, in turn, to energize the vertical magnet, stepping up the selector shaft to the level corresponding to the hundred sought. The single rotary impulse, which follows just before the subscriber's dial reaches its normal position, will energize the rotary relay of the second selector. This, in turn, energizes the private magnet which makes a single movement of its armature and allows the escapement

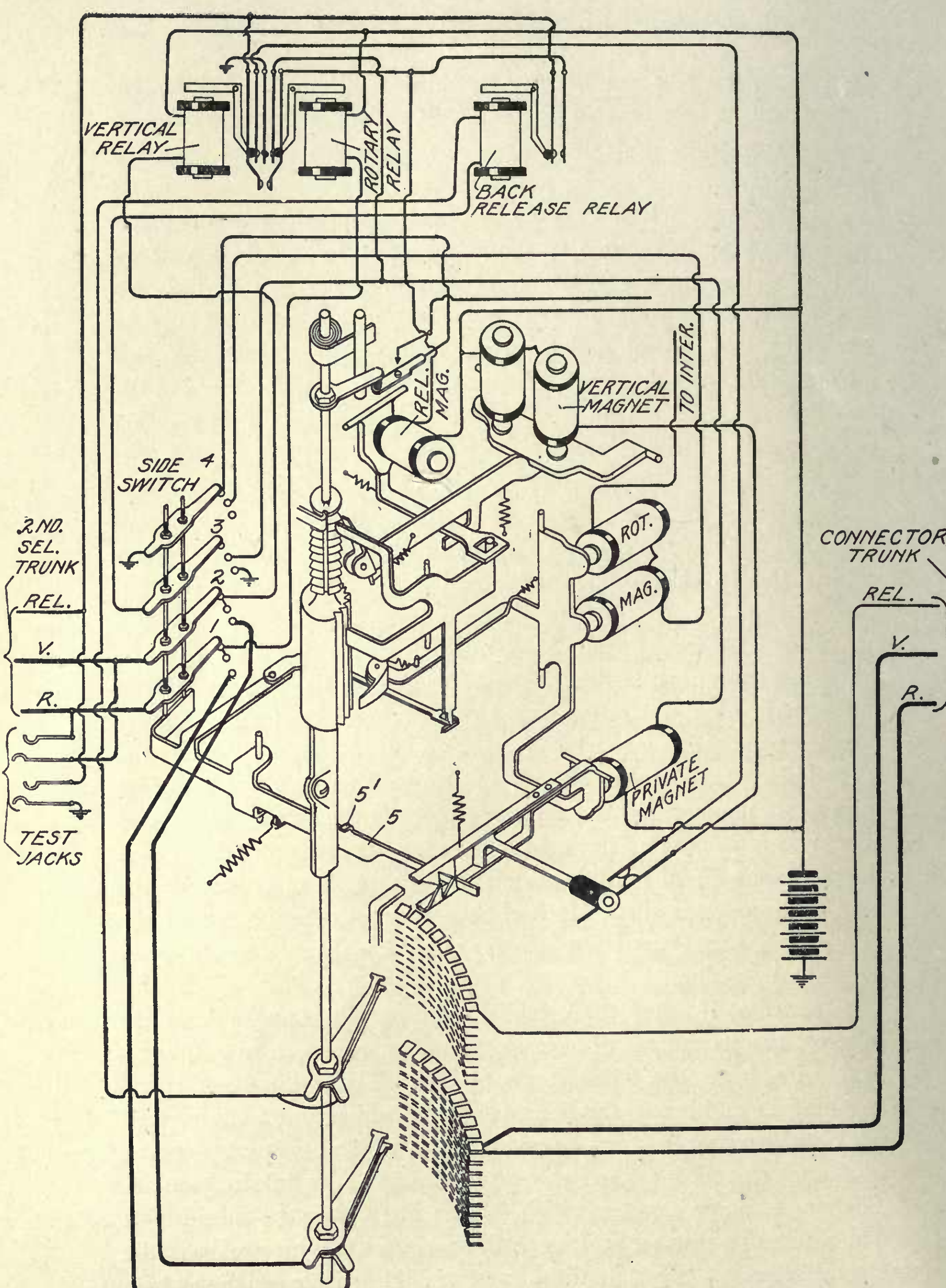


Fig. 394. Circuits of Second Selector

finger on the side switch arm to move one step and bring the side switch contacts into the second position.

Second Position of Side Switch. No detailed discussion of this is necessary, since, with the side switch in its second position, the actions which occur in causing the wipers of the second selector to seek and connect with an idle trunk line, are exactly the same as in the case of the first selector. When the second selector wipers finally reach a resting place on the bank contacts, the private magnet armature, operated during the hunting process, is released and the side switch is thus shifted into the third position.

Third Position of Side Switch. The moving of the side switch into its final position brings about the same state of affairs with respect to the second selector that already exists with respect to the first selector. The trunk line is cut straight through and all bridge circuits or bi-paths from it are cut off. The same guarding conditions are established to prevent other lines or other pieces of apparatus from making connections that will interfere with the one being established, and the same provisions are made for working the back release when the proper impulse comes from the connector, and for passing this back release impulse on to the first selector in the same way that the first selector passes it on to the line switch. The line of the calling subscriber has now been extended to a connector, and that connector is one of a group—usually ten—which alone has the ability to reach the particular hundred lines containing the line of the desired subscriber. The selection has, therefore, been narrowed down from one in ten thousand to one in one hundred.

The Connector—*Its Functions.* It has already been stated that the connector is of the same general type of apparatus as the first and the second selectors. Unlike the first and the second selectors, however, the connector is required to make a double selection under the guidance of the subscriber. The first selector makes a single selection of a group under the guidance of the subscriber and then an automatic selection in that group not controlled by the subscriber. So it is with the second selector. The connector, however, makes a selection of a group of ten under the guidance of the subscriber and then, again under the guidance of the subscriber, it picks out a particular one of that group.

The connector also has other functions in relation to the ringing of the called subscriber and the giving of a busy signal to the calling subscriber in case the line wanted is found busy. It has still other functions in that the talking current, which is finally supplied to connected subscribers, is supplied through paths furnished by it.

Location of the Connectors. Connectors are the only ones of the selecting switches that are in any sense individual to the subscribers' lines. None of them is individual to a subscriber's line, but it may be said that a group of ten connectors is individual to a group of one hundred subscribers' lines. Since each group of one hundred lines has a group of connectors of its own and since each one hundred lines also has a line-switch unit of its own, and since the lines of this group must be multipled through the bank contacts of the connectors of this individual group and through the bank contacts of the line switches of this particular unit, it follows that on account of the wiring problems involved there is good reason for mounting the connectors in close proximity to the line switches representing the same group of lines. Some help in the grasping of this thought may result if it be remembered that the line switch is, so to speak, the point of entry of a call and that the connector is the point of exit, and, in order to reduce the amount of wiring and to economize space, the point of exit and the point of entry are made as close together as possible.

The relative locations and grouping of the line switches and connectors are clearly shown in Fig. 395, which is a rear view of the same line-switch unit that was illustrated in Figs. 387 and 388.

Operation of the Connector. The circuits of the connector are shown in Fig. 396. In addition to the features that have been pointed out in the first and the second selectors, all of which are to be found, with some modifications, perhaps, in the connector, there must be considered the features in the connector of busy-signal operation, of ringing the called subscriber, of battery supply to both subscribers, and of the trunk release operation. These may be best understood by tracing through the operations of the connector from the time it is picked up by a second selector until the connection is finally completed, or until the busy signal has been given in case completion was found impossible. As in the first and the second selectors, the sequence of operations is determined by the position of the side switch.

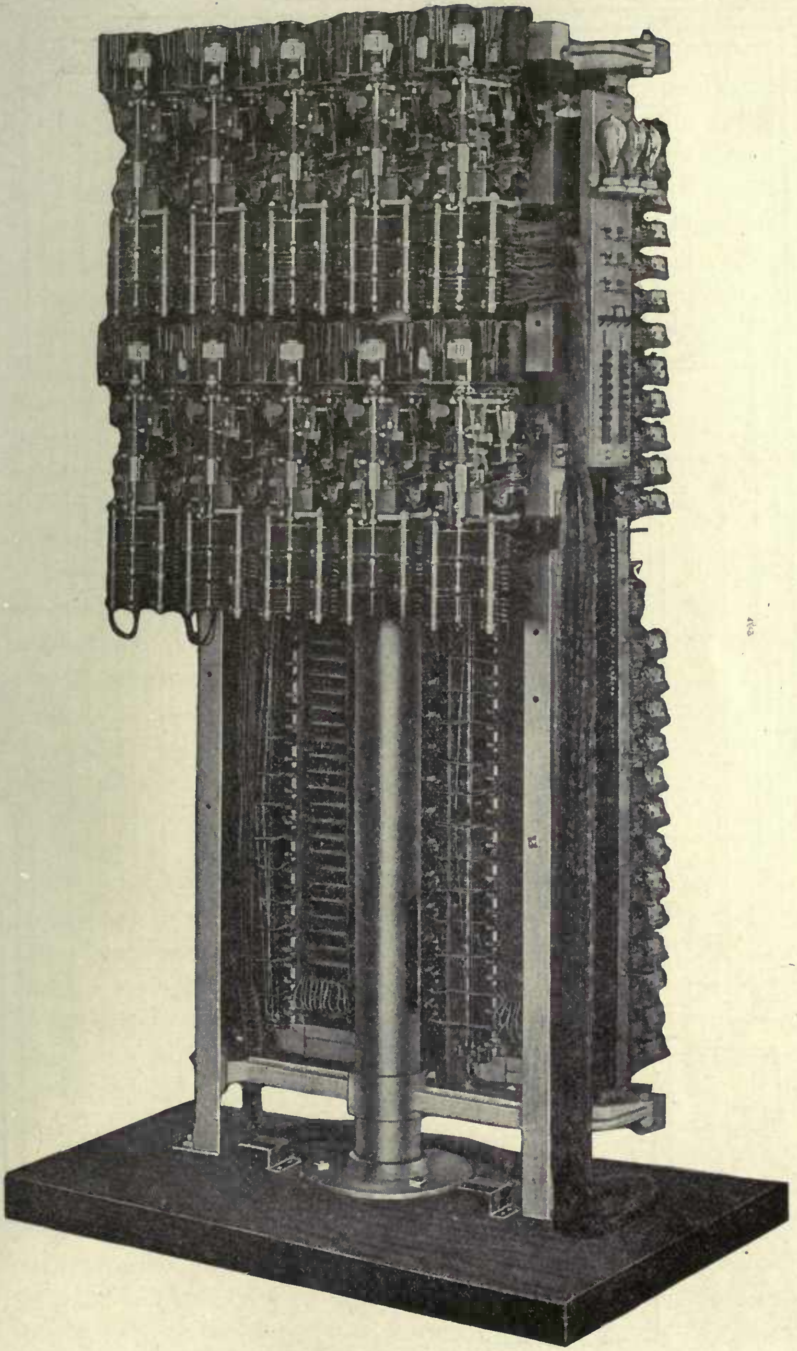


Fig. 395. Connector Side of Line-Switch Unit

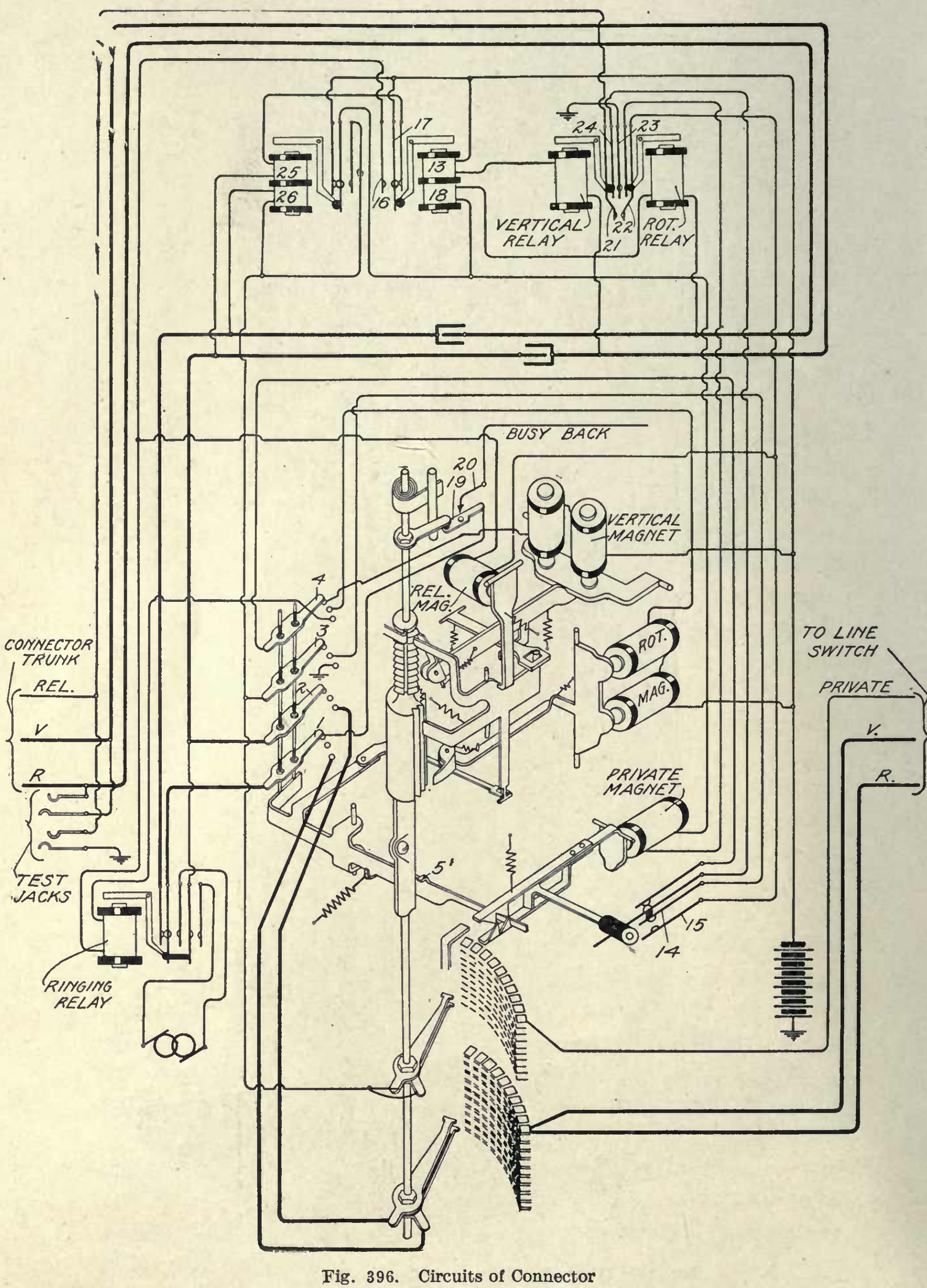


Fig. 396. Circuits of Connector

First Position of Side Switch. The connector in a ten-thousand-line system is the recipient of the impulses resulting from the third and fourth movements of the subscriber's dial. Considering the third movement of the subscriber's dial, the first impulse resulting from it comes over the rotary side of the line and results in the rotary relay attracting its armature once. This results in a single impulse through the private magnet which, however, does nothing because the projection *5'* strikes against a projection on the selector shaft. These two projections interfere only when the selector shaft is in its normal position. Then follows the series of impulses from the subscriber's station corresponding to the tens digit in the called subscriber's number. These pass over the vertical side of the line and through the vertical relay, energizing that relay a corresponding number of times.

The vertical magnet, as in the case of the first and the second selectors, is included in the circuit controlled by the vertical relay andthis results in the connector shaft being stepped up to the level corresponding to the particular tens group containing the called subscriber's number. It will be noted that the impulses from the vertical side of the line, which cause this selection, pass through one winding *13* of the calling battery supply relay. This relay is operated by these vertical selecting impulses, but in this position of the side switch the closure of its local circuits accomplishes nothing.

Immediately after the tens group of selecting impulses over the vertical side of the line, there follows a single rotary impulse from the subscriber's station which, as in the case of the first and the second selectors, energizes the rotary relay and causes it to give one impulse to the private magnet. This impulse is now able, since the shaft has moved from its normal position, to release the side switch arm one notch, and the side switch, therefore, moves into its second position.

Second Position of Side Switch. It is principally in this second position of the side switch that the connector selecting function differs from that of the first and the second selector. There is no trunk to be hunted, but rather the rotary movement of the connector wipers must be made in response to the impulses, from the subscriber's station, which correspond to the units digit in the selected number. The first impulse corresponding to the fourth movement of the subscriber's dial is a rotary one, and, as usual, it passes through the rotary relay winding and this, in turn, gives an impulse to the private magnet. The private magnet at this time has already released the side switch arm to its second position, but it is unable to release it further because of a feather on the wiper shaft—which projects just far enough to engage the lug *5'*, when the shaft is in its normal angular position—thus preventing the side switch arm from moving farther than its second position.

Then follows over the vertical side of the line the last set of selecting impulses corresponding to the units digit. This, as before, energizes the vertical relay, but in the second position of the side switch, it is to be noted, that the vertical relay no longer controls the vertical magnet; the side switch has shifted the control of the vertical relay to the rotary magnet. The rotary magnet is, therefore, energized a number of times corresponding to the last digit in the called number and the wipers of the connectors are thus brought to the contacts of the line sought—their final goal. At this point many things may happen, and the things that do happen depend on whether the called subscriber's line is idle or busy.

Called-Line Busy:—It will first be assumed that the called line is busy. The testing operation at the connectors occurs in the second position of the side switch. If the called line is busy, it will be either because it is connected to by some other connector or because it has itself made a call. In the former case the private contacts of that line in the banks of all the connectors serving that hundreds group of lines will be grounded through the private wiper of some other connector. That this is so, may be seen by tracing the circuit from the private wiper on the shaft to the third side switch wiper which is grounded in the third position; the other connector that has already engaged the line will, of course, have its side switch in its final, or third position. Again, if the line called is busy, because a call has already been made from this line to some other line, the private contacts on the connectors corresponding to the line will be grounded, as will be seen by tracing from the private bank contacts, which are shown in Fig. 396, through the private wire to the line switch, which is shown in Fig. 389, and from thence to ground through the springs *19* and *20*, which are brought together when the line switch is operated.

In any event, therefore, the determining condition of a busy line is that its private bank contacts on all connectors of its group shall be grounded. Under the present assumed condition, therefore, the connector wipers, which have been brought to the bank contacts of the desired line, will find a ground at the private bank contact. The connector shaft stops for an instant on the contacts of this busy line and immediately there follows over the rotary side of the line the inevitable single rotary impulse. This energizes the rotary relay and this, as usual, energizes the private magnet. Remembering now that the connector side switch is in its second position and that the private wiper of the connector has found a ground, we may trace back from the private wiper through the third side switch wiper to its second contact; thence through the contact springs *14* and *15*, closed by the private magnet; thence through the release magnet; thence through the contact springs *16* and *17* of the calling battery supply relay to the live side of the battery. This calling battery supply relay will, at this time, have its core energized because the coil *18* is in series with the rotary relay coil which, as just stated, was energized by the last rotary impulse. This series of operations has led to the energizing of the release magnet, and, as a result, the double dog of the connector is pulled out of the connector shaft ratchets and the shaft and the side switch are restored to their normal position.

Busy-Back Signal:—The connector has dropped back to normal in all respects. The calling subscriber, not knowing this, presses his ringing button. This grounds the vertical side of the line at his station and operates the vertical relay at the connector. This steps the shaft of the connector up one step and causes the closure of the contacts *19* and *20* at the top of the connector shaft. This establishes a connection to a circuit carrying periodically interrupted battery current on which an inductive hum is placed. This circuit may be traced from this source through the springs *20* and *19* to the first wiper of the side switch, thence through the normally closed contacts of the ringing relay to the rotary side of the line, and the varying potential to which this path is subjected produces an inductive flow back to the calling subscriber's telephone, and gives him the necessary signal which consists of a hum or buzzing noise with which all users of automatic systems soon become familiar.

Release on Busy Connection:—The connector, since its last release, has been stepped up one notch and must again be released. When the subscriber hangs up his receiver after receiving the busy signal, he grounds both sides of his line momentarily by the action of the springs *21, 22,* and *23* of Fig. 384. This operates the rotary and the vertical relays on the connector simultaneously and brings together for the first time the springs *21* and *22* of Fig. 396. This establishes a connection from the battery through the springs *16* and *17* on the calling battery supply relay, thence through the release magnet of the connector, thence through the springs *22* and *21* of the vertical and the rotary relay, thence through the release trunk back to the second selector. From here the circuit passes through the private wiper of that selector and the back release relay to ground through the third side switch wiper which is in the third position. Considering this circuit in respect to its action on the connector it is obvious that it energizes the release magnet on the connector which restores the connector to normal as before. At the second selector this circuit passed through the back release relay, which closed a circuit through the release magnet and through the back release relay contacts, thence back over the second selector release trunk to the back release relay of the first selector, and through the third wiper of the side switch on that selector to ground, since that side switch also is in its third position. The current through this circuit energizes the release magnet of the second selector and restores it to its normal position and also energizes the back release relay of the first selector. This, in turn, closes the circuit from the battery through the release magnet of the first selector and contacts of the back release relay to ground. This works the release magnet of the first selector and restores that selector to normal. The contacts on the first selector release magnet, shown in Fig. 390, are closed by the action of the release magnet and this closes the path from ground back through the first selector release wire, and through the contacts *13* and *14* of the line switch, through the line switch release magnet to battery, and this restores the line switch to normal.

The reason for the term *back release* will now be apparent. The release operation at the connector is relayed back to the second selector; that of the second selector back to the first selector; and that of the first selector back to the line switch. Until this plan was adopted, the release magnet of each selector and connector involved in a connection was left bridged across the talking circuit so as to be available for release; and it sometimes occurred that a first selector would be released before a second selector or connector, which latter switches would thus be left off-normal until rescued by an attendant. The back release plan makes it impossible for the connection necessary for the release of a switch to be torn down until the release is actually accomplished.

Called Line Found Idle:—It will be remembered that, before the digression necessary to trace through the operations occurring upon the finding of a busy line, the connector wipers had been brought, by the influence of the calling subscriber's impulses, into engagement with the contacts of the desired line; that the connector side switch was in its second position; and that the final rotary impulse following the last series of selecting impulses had not been sent. The condition now to be assumed is that the called subscriber's line is free and the private wiper, therefore, has found and rests on an ungrounded private bank contact. The final rotary impulse which immediately follows will operate the rotary relay and this, in turn, will operate the private magnet. This happened under the assumed condition that the line was busy, but in that case the release magnet was also operated at the same time and restored all conditions to normal. Under the present condition the operation of the private magnet will perform its usual function and move the side switch of the connector into its third position.

Third Position of Side Switch. When the side switch of the connector moves to its third position, it, as usual, cuts the talking circuit straight through from the vertical and the rotary sides of the trunk leading from the previous selector to the outgoing terminal of the subscriber's line, which may be traced upon Fig. 396 back through the line switch, shown in Fig. 389. Several things are to be noted about the talking circuit so established: First, the inclusion of the condensers in the vertical and the rotary sides of the connector circuit. The purpose of this will be referred to later. Second, the inclusion in this circuit at the connector of a pair of normally closed contacts in the ringing relay. It may be said in passing that the ringing relay corresponds exactly in function to a ringing key in a manual switchboard. Third, the talking circuit leading from the connector to the called subscriber's line passes on one side through the springs *24* and *25* of the bridge cut-off relay of the line switch, which is shown in Fig. 389. These springs are normally open and would prevent the completion of the talking circuit but for the fact that the bridge cut-off relay of the line switch is energized over the private wire leading to the connector bank and then through the connector wiper to the third side switch wiper which, at this time, is in its third position. The talking circuit is thus complete. The operation of this bridge cut-off relay on the line switch has not only completed the talking circuit but it has also opened the circuit of the trip magnet of the line switch so as to prevent the operation of the trip magnet by the subscriber on that line in case he should attempt to make a call during the interval between the time when his line was connected with by the connector and the time when he answers the call.

The third wiper of the connector side switch when moved into its third position, puts the ground on all of the private bank contacts of the line chosen and thus guards that line against connection by others, as already described. It also operates the bridge cut-off relay of the line switch as just mentioned.

The fourth wiper of the side switch, when moved into its third position, establishes such a connection as will place the ringing relay under the control of the vertical relay. This may be seen by tracing from ground to the vertical relay springs *23* and *24*, thence through the normally closed upper pair of contacts on the private magnet, thence through the fourth wiper on the side switch to its third contact, thence through the ringing relay magnet, and through the springs *16* and *17* of the calling battery supply relay and to battery. The calling battery supply relay winding being in series with the vertical relay winding, the two operate together and close the two normally open points in the ringing relay circuit. This ringing relay acts as an ordinary ringing key and connects the generator to the called subscriber's line in an obvious manner, at the same time opening the talking circuit back of the ringing relay in order to prevent the ringing current chattering the relays in the circuit back of it. All that remains now is for the called subscriber to respond. When he does he closes the metallic circuit of the line through his talking apparatus.

Battery Supply to Connected Subscriber. Throughout the whole process of building up a connection, it will be remembered that both sides of the calling line are connected through the respective vertical and rotary relays involved in building up the connection with the live side of the battery. At the time when the connection is finally established and the called subscriber rung, both sides of the calling line are connected through various relay windings to the live side of the battery. Such a condition leaves both sides of the line at the same potential and, therefore, there is no tendency for current to flow through the calling subscriber's talking apparatus, even though it is connected across the circuit of the line. It remains, therefore, to be seen how these conditions are so changed after the building up of a connection as to supply the calling subscriber with talking current.

The calling subscriber can get no current until the called subscriber responds. When the connection is first made with the called subscriber's line, battery connection to his line is made from the live side of battery through the normally closed contacts of the calling battery supply relay, thence through the winding *25* of the called battery supply relay to the vertical side of the called line. The grounded side of the battery is connected to the rotary side of his line through the third wiper of the connector and the coil *26* of the called battery supply relay. As a result, this subscriber receives proper talking current through the coils *25* and *26*, and this relay is operated by the flow of this current. The operation of this called battery supply relay merely shifts the connection of the rotary side of the calling subscriber's line from its normal battery connection, to ground, and thus the battery is placed straight across the calling subscriber's line so as to supply talking current. This supply circuit to the calling subscriber may be traced from the live side of the battery through the winding *13* of the calling battery supply relay and the winding of the vertical relay to the vertical side of the line, and from the grounded side of battery through the third side switch wiper in its third position to the now closed pair of contacts in the called battery supply relay through the coil *18* of the calling battery supply relay and the coil of the rotary relay to the rotary side of the line.

It will be noted that the system of battery supply is that of the standard condenser and retardation coil scheme largely employed in manual practice; and that aside from the coils through which the battery current is supplied to the connected subscribers, there are no taps from, or bridges across, the two sides of the talking circuit.

Release after Conversation. It remains now only to secure the disconnection of the subscribers after they are through talking. When the calling subscriber hangs up, the whole disconnection is brought about, all of the apparatus, including connector, selectors, and line switch, returning to normal. This is done by the back release system and is accomplished in almost the same way as has already been described in connection with the disconnect after an unsuccessful call. There is this difference, however: after an unsuccessful call when the line called for was found busy, the release was made while the connector side switch was in its normal position. In the present case, the release must be made with the connector side switch in its third position and with the talking battery bridged across the metallic circuit rather than connected between each limb of the line and ground. It must be remembered that the calling battery supply relay, while traversed by current during the conversation, is not magnetically energized because, with the current flowing through the metallic circuit of the line, the two windings exert a differential effect. As soon, however, as the calling subscriber hangs up his receiver, this differential action ceases, due to the grounding of both sides of the line at the subscriber's station. This relay, therefore, operates and cuts off battery from the called battery supply relay and this, in turn, releases its armature and thus changes the connection of the rotary side of the calling line from ground to live side of the battery. The normal condition of the battery connection now being restored, both the vertical and the rotary relays at the connector become operated, due to the ground on both sides of the line at the subscriber's station, and this, as we have seen, is the condition which brings about the operation of the connector release magnet, and the relaying back of the disconnect impulse successively through the selectors to the line switch.

Multi-Office System. In exchanges involving more than one office, the same general principles and mode of operation already outlined apply. If the total number of subscribers in the multi-office exchange is to be less than ten thousand, then four digit numbers suffice, and the first movement of the dial may be made to select the office into which the connection is to go, the subscribers' lines being so numbered with respect to the offices that each office will contain only certain thousands. The choosing of the thousand by the calling subscriber, therefore, takes care in itself of the choice of offices. Where, however, a multi-office exchange is to provide for connections among a greater number of lines than ten thousand and less than one hundred thousand, then it will take five movements of the dial to make the selection—the five movements corresponding either to the five digits in a number or to the name of an office, as indicated on the dial, and the four digits of a smaller number. The lines may all carry five digit numbers or, what is considered better practice, may be designated by an office name followed by a four digit number. In this latter case the numbers of the subscribers' lines will in each case be contained in one or more of the tens of thousands groups, no number having more than four digits. And the first movement of the dial, whether the name or number plan be adopted, will select an office; or, looking at it another way, will select a group of ten thousand and this being done, the next four successive movements of the dial will select the numbers in that ten thousand in just the same way that has been already described.

Certain difficulties arise, however, in multi-office working due to the fact that the three-wire trunks between offices would in most cases be objectionable. As long as the trunks extend between the various groups of apparatus in the same office, it is cheaper to provide three wires for each of them than it is to make any additional complication in the apparatus. Where the trunking is done between offices, however, the system may be so modified as to work over two wire inter-office trunks.

The Trunk Repeater. The purpose of the trunk repeater is to enable the inter-office trunking to be done over two wires. It may be said that the trunk repeater is a device placed in the outgoing trunk circuit at the office in which a call originates, which will do over the two wires of the trunk leading from it to the distant office just the same thing that the subscriber's signal transmitter does over the two wires of the subscriber's lines. It has certain other functions in regard to feeding the battery for talking purposes back to the calling subscriber's line, taking the place in this respect of the calling battery feed relay in the connector in a single office exchange.

The circuits of a trunk repeater are shown in Fig. 397. In considering it, it must be understood that the three wires entering the figure at the left are the vertical, rotary, and release wires of a second selector trunk leading from the first selector banks in the same office. The two wires leading from the right of the figure are those extending to the distant office, and terminate there in second selectors. The vertical and the rotary sides of this trunk as shown at the left will receive the impulses from the subscriber's station com-

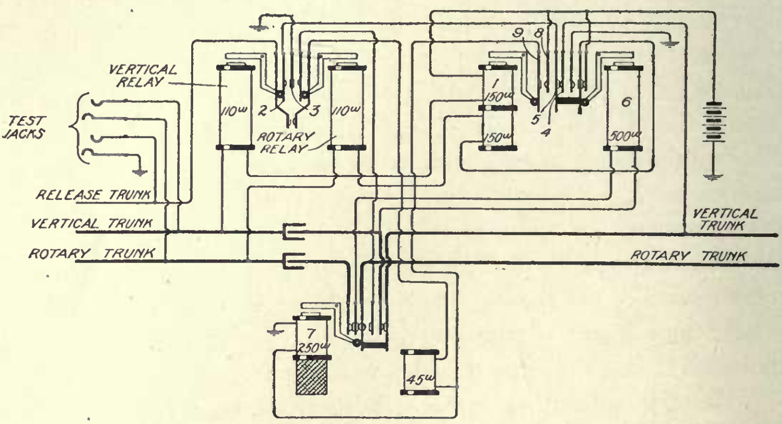


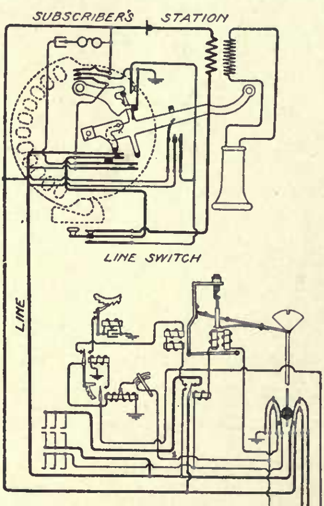
Fig. 397. Circuits of Trunk Repeater

ing through the line switch and the first selector, as usual. The vertical impulses will pass through the winding of the vertical relay and through the winding *1* of the calling battery supply relay and thence to battery, the same as on a connector. These impulses will work the armatures of both of these relays in unison. The movements of the vertical relay armature in response to these impulses will cause corresponding impulses to flow over a circuit which may be traced from ground, through the springs *3* and *2* of the vertical relay, the springs *4* and *5* of the bridged relay *6* and thence to the vertical side of the trunk and to the distant office, where it passes into a second selector and through its vertical relay to battery. Thus the vertical impulses are passed on over the two-wire trunk to the second selector at the distant office. It becomes necessary, however, to prevent these impulses from passing back through the winding of the bridge relay *6* and this is done by means of the sluggish relay *7*. This relay receives local battery impulses in unison with those sent over the trunk by the vertical relay, these being supplied from the battery at the local office through the contacts *8* and *9* of the calling battery supply relay, which works in unison with the vertical relay. These rapidly recurring impulses are too fast for the sluggish relay *7* to follow. And this relay merely pulls up its armature and cuts off both sides of the trunk leading back to the first selector. The rotary impulses are repeated to the rotary side of the two-wire trunk in a similar way.

Considering now the operation of the trunk repeater in the reverse direction, the action of the bridging relay *6* is of vital importance. Normally both sides of trunk line are connected to the live side of the battery and, therefore, there is no difference of potential between them and no tendency to operate the bridged relay. When the connection has been fully established to the subscriber at the distant office, and that subscriber has responded, the action of his battery supply relay will, as before stated, change the connection of the rotary side of the line from battery to ground, and thus bridge the battery at the distant exchange across the trunk. This action will pull up the bridged relay *6* at the trunk repeater and will perform exactly the same function with respect to the connection of the battery with the calling subscriber's line. In other words, it will change the connection of the rotary side of the calling line from battery to ground, thus establishing the necessary difference in potential to give the calling subscriber the necessary current for transmission purposes. The disconnect feature is about the same as already described. When the calling subscriber hangs up his receiver both the vertical and rotary relays of the trunk repeater operate, which places the ground on both sides of the two-wire trunk to the distant office, which is the condition for releasing all of the apparatus there.

For the purpose of convenience the simplified diagram of Fig. 398 has been prepared, which shows the complete connection from a calling subscriber to a called subscriber in a multi-office exchange, wherein the first movement of the dial is employed to establish the connection to the proper office and the four succeeding movements to make a selection among ten thousand lines in that office. This circuit, therefore, employs at the first office the line switch, the first selector, and the trunk repeater; and at the second office the second selector, third selector, connector, and line switch.

The third selector is omitted from Fig. 398, but this will cause no confusion, since it is exactly like the second selector. The circuits shown are exactly like those previously described but in drawing them the main idea has been to simplify the connections to the greatest possible extent at a sacrifice in the clearness with which the mechanical inter-relation of parts is shown. No correct understanding of the circuits of an automatic system is possible without a clear idea of the mechanical functions performed by the different parts, and, therefore, we have described what are apparently the more complex circuit drawings first. It is believed that the student, in attempting to gain an understanding of this marvel of mechanical and electrical intricacy, will find his task less burdensome if he will refer freely to both the simplified circuit drawing of Fig. 398 and the more complex ones preceding it. By doing so he will often be enabled to clear up a doubtful circuit point from the simpler diagram and a doubtful mechanical point from those diagrams which represent more clearly the mechanical relation of parts.



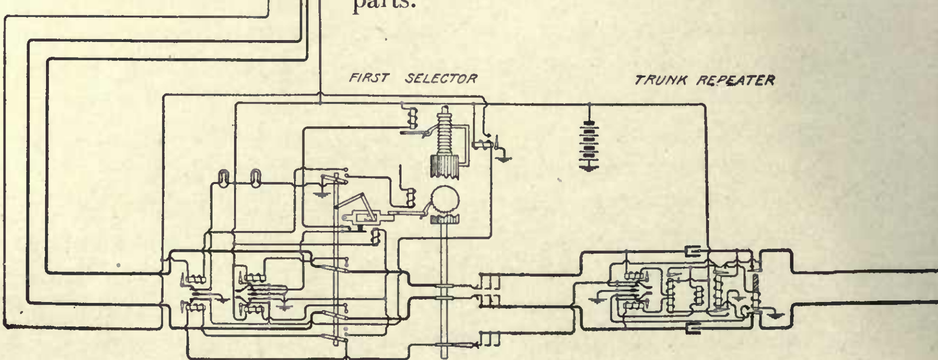
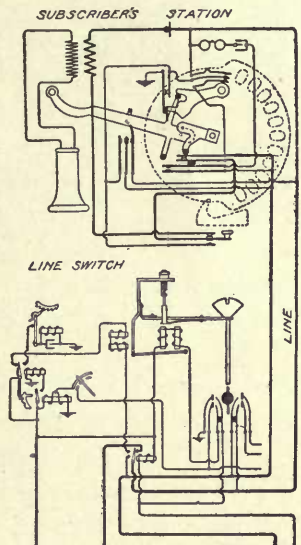
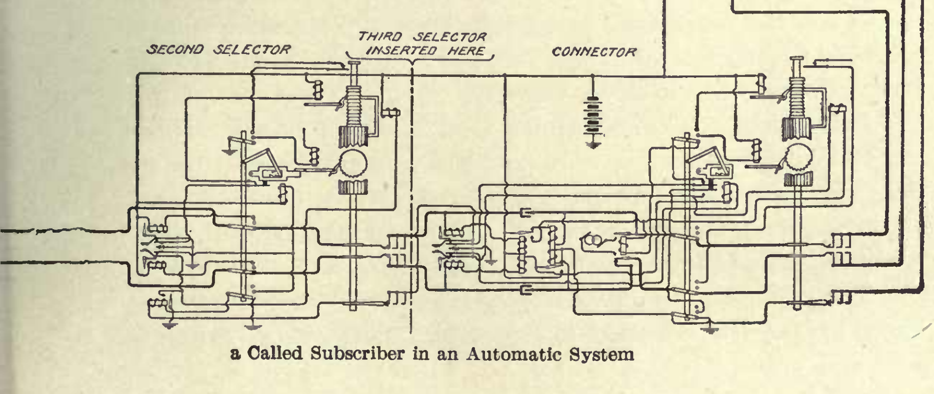


Fig. 398. Connection between a Calling and

Automatic Sub-Offices. Obviously, the system of trunking employed in automatic exchanges lends itself with great facility to the subdivision of an exchange into a large number of comparatively small office districts and the establishment of branch offices or sub-offices at the centers of these districts.

The trunking between large offices has already been described. An attractive feature of the automatic system is the establishment of so-called sub-stations or sub-offices. Where there is, in an outlying district, a distinct group of subscribers whose lines may readily be centered at a common point within that district and where the number of such subscribers and lines is insufficient to establish a fully equipped office, it is possible to establish a so-called sub-station or sub-office connected with the main office of that district by trunk lines. At this sub-office there are placed only line switches and connectors. When a call is originated on one of these sub-office lines, the line switch acts instantly to connect that line with one of the trunks leading to the main office of that district, at which this trunk terminates in a first selector. From there on, the connection is the same as that in a system in which no sub-offices are employed. Calls coming into this sub-office over trunk





a Called Subscriber in an Automatic System

lines from the main office are received on the connectors at the sub-office and the connection is made with the sub-office line by the connector in the usual manner. This arrangement, it is seen, amounts merely to a stretching of the connector trunks for a given group of lines so that they will reach out from a main office to a sub-office, it being more economical to lengthen the smaller number of trunks and by so doing to decrease in length the larger number of subscribers' lines.

The Rotary Connector. For certain purposes it becomes desirable in automatic work to employ a special form of connector which will have in itself a certain ability to make automatic selection of one of a group of previously chosen trunks in much the same manner as the first and second selectors automatically choose the first idle one of a group of trunks.

Such a use is demanded in private branch-exchange working where a given business establishment, for instance, has a plurality of lines connecting its own private switchboard with the central office. The directory number of all these lines is, for convenience, made the same, and it is important, therefore, that when a person attempts to make a connection with this establishment, he will not fail to get his connection simply because the first one of these lines happens to be busy. For such use a given horizontal row of connector terminals or a part of such a row is assigned to the lines leading to the private branch exchange and the connector is so modified as to have a certain "discretionary" power of its own. As a result, when the common number of all these lines is called, the connector will choose the first one, if it is not already engaged by some other connector, but if it is, it will pass on to the next, and so on until an idle one is found. It is only when the connector has hunted through the entire group of lines and found them all busy that it will refuse to connect and will give the busy signal to the calling subscriber.

Party Lines. The description of this system as given above has been confined entirely to direct line working; however, party lines may be and are frequently employed.

The circuits and apparatus used with direct lines are, with slight modifications, applicable to use with party lines.

The harmonic method of ringing is employed and the stations are so arranged with respect to the connectors that those requiring the same frequency for ringing the bells are in groups served by the same set of connectors.

The party lines are operated on the principle commonly known in manual practice as the jack per station arrangement. Each party line will, therefore, have sets of terminals appearing in separate hundreds; the connectors associated with each of these hundreds being so arranged as to impress the proper frequency of ringing current on the line.

From the subscribers' standpoint the operation is the same as for direct lines, as the particular hundreds digit of a number serves to select one of a group of connectors capable of connecting the proper ringing current to the line.

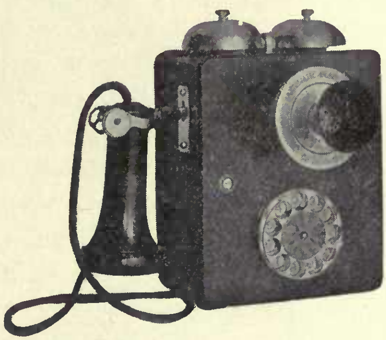


Fig. 399. Wall Set for Two-Wire System

To avoid confusion, which would be caused by a subscriber on a party line attempting to make a call when the line is already in use by some other subscriber, the subscribers' stations are so arranged that when the line is in use all other stations on the line are locked out.

The Two-Wire Automatic System. The two-wire system that has recently been introduced by the Automatic Electric Company brings about the very important result of accomplishing all of the automatic switching over metallic circuit lines without the use of ground or common returns. The system is thus relieved of the disturbing influences to which the three-wire system is sometimes subjected, due to differences in earth potential between various portions of the system, which may add to or subtract from the battery potential and alter the net potential available between two distant points. The introduction of this system has also made possible certain other incidental features of advantage, one of which is a great simplification and reduction in size of the subscriber's station signal-transmitting apparatus.

With the doing away of the ground as a return circuit, it becomes impossible to send vertical impulses over one side of the line and to follow them by single rotary impulses over the other side of the line.

Yet it becomes necessary to distinguish between the pure selective impulses and those impulses which dictate a change of function at the central office. The plan has, therefore, been adopted of accomplishing the selection in each case by short and rapidly recurring impulses and of accomplishing those functions formerly brought about by the single impulse over the rotary side of the line by a pause between the respective series of selective impulses. This is accomplished at the central office by replacing the vertical and the rotary relays of the three-wire system by a quick-acting and a sluggish relay, respectively; the quick-acting relay performing the functions previously carried out by the vertical relay, and the sluggish relay acting only during the pauses between the successive series of quick impulses to do the things formerly done by the rotary relay. This has resulted in a delightful simplification of subscriber's apparatus, since it is now necessary only to provide a device which will connect the two sides of the line together the required number of times in quick succession and then allow a pause with the circuit closed while the subscriber is getting ready to transmit another set of impulses corresponding to another digit. The calling device has no mechanical function co-acting with any of the other parts of the telephone and may be considered as a separate mechanical device electrically connected with the line. The transmitting device is not much larger than a large watch and a good idea of it may be had from Fig. 399, which shows the latest wall set, and Fig. 400, which shows the latest desk set of the Automatic Electric Company. We regret the fact that this company has made the request that the complete details of their two-wire system be not published at this time.

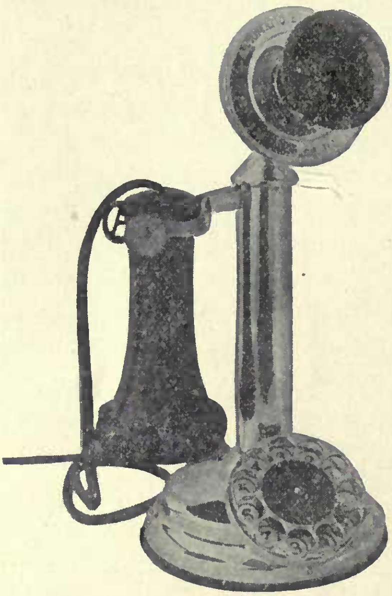


Fig. 400. Desk Stand for Two-Wire System

CHAPTER XXX

THE LORIMER AUTOMATIC SYSTEM

The Lorimer automatic telephone system has not been commercially used in this country but is in commercial operation in a few places in Canada. It is interesting from several points of view. It was invented, built, and installed by the Lorimer Brothers—Hoyt, George William, and Egbert—of Brantford, Ontario. These young men without previous telephonic training and, according to their statements, without ever having seen the inside of a telephone office, conceived and developed this system and put it in practical operation. With the struggles and efforts of these young men in accomplishing this feat we have some familiarity, and it impresses us as one of the most remarkable inventive achievements that has come to our attention, regardless of whatever the merits or demerits of the system may be.

The Lorimer system is interesting also from the fact that, in most cases, it represents the mechanical rather than the electrical way of doing things. The switches are power driven and electrically controlled rather than electrically driven and electrically controlled, as in the system of the Automatic Electric Company.

The subscriber's station apparatus consists of the usual receiver, speech transmitter, call bell, and hook switch, and in addition a signal transmitter arranged to be manipulated by the subscriber so as to control the operation of the central-office apparatus in connecting with any desired line in the system.

The central-office apparatus is designed throughout upon the principle of switching by means of power-driven switches which are under the control of the signal transmitters of the calling subscriber's station. The switches employed in making a connection are all so arranged with respect to constantly rotating shafts that the movable member of such switches may be connected to the shafts by means of electromagnets controlled directly or indirectly by relays, which, in turn, are brought under the control of the signal transmitters.

The circuits are so designed in many instances that the changes necessary for the different steps are brought about by the movement of the switches themselves, thus permitting the use of circuits which are rather simple. The switches employed are all of a rotary type; the co-ordinate selection, which is accomplished in the Automatic Electric Company's system by a vertical and rotary movement, being brought about in this system by the independent rotation of two switches.

Subscriber's Station Equipment. A subscriber's desk-stand set, except the call bell, is shown in Fig. 401, and a wall set complete in Fig. 402. In both of these illustrations may be seen the familiar transmitter, receiver, and hook switch, and in the wall set, the call bell. The portion of these telephone sets which is unfamiliar at present is the part which is enclosed in the enlarged base of the desk stand and the protruding device below the speech transmitter in the wall set—the signal transmitter referred to earlier in the chapter. The small push button and small plate through which the number may be seen directly below the transmitter in Fig. 402, are for the purpose of registering calls.

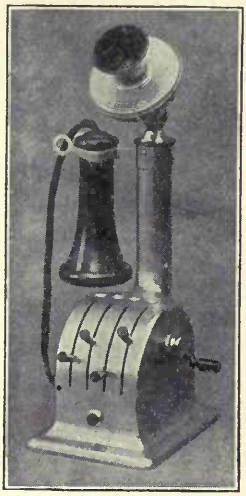


Fig. 401. Lorimer Automatic Desk Stand

The signal transmitter is a device whose function is to record mechanically the number of the subscriber's station with which connection is desired, and to transmit that record to the central office by a system of electrical impulses over the line conductors. Instead of operating by its own initiative, the signal transmitter is adapted to respond to central-office control in transmitting electrically the number which has been recorded mechanically upon it.

The signal transmitter shown removed from the base of the desk stand at the left in Fig. 403 comprises in part four sets of contact pins having ten pins in each set, one set for each of the digits of a four-digit number. There are also several additional contact pins for signaling and auxiliary controlling purposes. All of these contact pins are arranged upon the circumference of a circle and a movable brush mounted upon a shaft at the center of the circle is adapted to be rotated by a clock spring and to make contact with each of the pins successively. The call is started, after the number desired has been set on the dial, by giving the crank at the right of the signal transmitter a complete turn and thus winding the spring. The shaft carrying the signal transmitter brush carries also an escapement wheel, the pallet of which is directly controlled by an electromagnet.

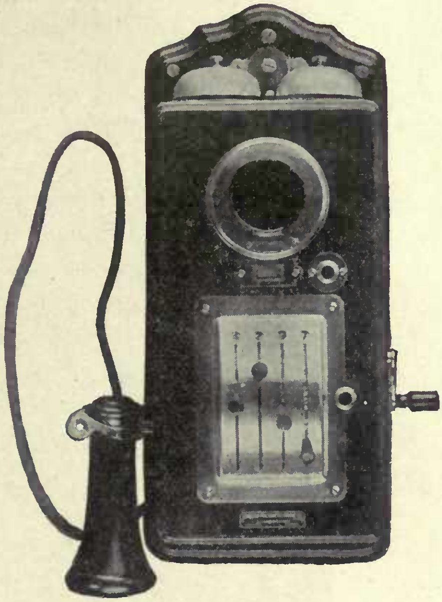


Fig. 402. Lorimer Automatic Wall Set

The four dials with the numerals printed on them are attached to four levers, respectively, and are moved by their levers opposite windows, near the top of the casing. Through each of these windows a single numeral may be seen on the corresponding one of the dials. The dials may be adjusted so that the four numerals seen will read from left to right to correspond to the number of the line with which connection is desired.

The setting of the dials so that the number desired shows at the small circular opening results in connecting the earth or a common return conductor to one pin of each set of ten pins, the pin grounded in each set depending upon the numerical value of the digit for which the dial is set.

The circle of contact pins is set in an insulating disk, the signal transmitting brush operates upon the pins on one side of the disk, and electrical fingers attached to the dials operate upon the pins on the other side of the disk. The escapement wheel is a single toothed disk attached directly to the shaft which carries the signal brush and its pallet is attached rigidly to the magnet armature.

Once a call has been turned in, the entire subscriber's station equipment is locked beyond power of the subscriber to tamper with it in any way, rendering it impossible either to defeat the call which has been started or to prevent the subscriber's station as a whole from returning completely to normal position and thus restoring itself for regular service. The key shown just below the signal transmitter in the case of the desk stand, and at the right in the wall set, is for the purpose of operating a relay at the central

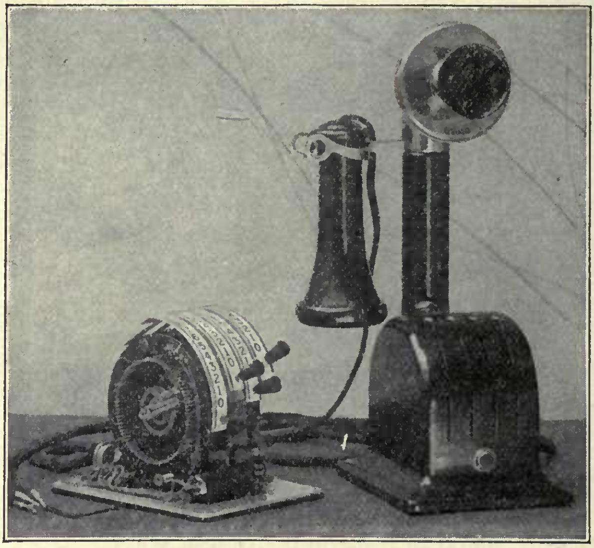


Fig. 403. Desk Stand with Signal Transmitter Removed

office which, in turn, connects ringing current to the line of the subscriber with which connection has been made, and thus actuates the call bell.

As the number set up at the signal transmitter remains in full view until reset for some other number, it is easily checked by inspection and also lessens the labor involved in making a second call for the same line, which is frequently necessary when the line is found busy the first time called.

Central-Office Apparatus. The subscriber's lines are divided into groups of one hundred lines each at the central office, each group being served by a single unit of central-office apparatus.

In a central-office unit there is "sectional apparatus" which appears but once for the unit of one hundred lines; "divisional apparatus" which appears a number of times for each unit, depending upon the traffic; and "line apparatus" which appears one hundred times for each unit or once for each line.

The sectional apparatus comprises devices whose duties are, first, to detect a calling line, and second, to assign to the calling line a set of idle divisional apparatus which serves to perform the necessary switching functions and complete the connection.

The sets of divisional apparatus, or, as called in this system, "divisions," are common to a section and are employed in a manner similar to the connecting cords of a manual switchboard. The number of these divisions provided for each section is, therefore, determined by the number of simultaneous connections resulting from calls originating in the section. It has been the custom in building this apparatus to provide each section with seven divisions or connective elements.

The line apparatus comprises one relay, having a single winding, and two pairs of contacts operated by its armature. This device is substantially the well known cut-off relay almost universally employed in common-battery systems. The fixed multiple contacts of the lines in the switching banks of the connecting apparatus are considered as pertaining to the various pieces of apparatus on which they are found rather than to their respective lines. A good idea may be obtained of the arrangement of the sectional and divisional apparatus by referring to Fig. 404, which is one unit of a thousand-line equipment. The apparatus in the vertical row at the extreme left of the illustration is the sectional apparatus, while the remaining seven vertical rows of apparatus are the divisions.

The Section. The sectional appararus for each unit consists of three separate devices called for convenience a *decimal indicator,* a *division starter,* and a *decimal-register controller.* All of these devices are normally motionless when idle. The energization of the decimal indicator, in response to the inauguration of a call at a subscriber's station, results immediately in an action of the division starter which starts a division to connect with the line calling. It results also in the starting of the decimal-register controller, the remaining unit of sectional apparatus.

It is thus seen that upon the starting of a call by a subscriber, all of the sectional apparatus belonging to his one hundred lines immediately becomes active, the division starter acting to start a division, the decimal indicator becoming energized to indicate the tens group in which the call has appeared, and the decimal-register controller becoming active to adjust the decimal register of the division assigned by the division starter. The division starter having assigned a division for the exclusive use of this particular call, passes to a position from which it may start a similar idle division when the next call is received. The decimal register controller makes its half revolution for the call and comes to rest, awaiting a subsequent call, and the decimal indicator continues energized but only momentarily, since it is released by the action of the cut-off relay when the call is taken in charge by the divisional connective devices.

Calls may follow each other rapidly, the connective devices being entirely independent of each other after having been assigned to the respective calling lines. As has been described, the decimal indicator starts the division starter and the decimal-register controller in quick succession. The division starter, shown at the extreme bottom of the left-hand row of Fig. 404, is a cylinder switch of the same general type as used throughout this system. In it the terminals of a switch in each division appear as fixed contact points in a circle over which move the brushes of the division starter.

The decimal-register controller has the duties of transmitting to the divisional apparatus a series of current impulses corresponding in number to the numerical value of the tens digit of the calling line. This is effected by providing before a movable brush ten contacts from which the brush may receive current. These contacts are normally not connected to battery, so that the brush in passing over them does not receive current from them; however, when the brush has reached the contact corresponding in number to the tens digit of the calling line, a relay associated with the decimal-register controller charges the contacts with the potential of the main battery, and each of the remaining contacts passed over by the brush sends a current impulse to a device designed to indicate on the division selected for the call the tens digit of the calling line.

The Connective Division. The connective division, seven of which are shown in Fig. 404, is an assemblage of switches comprising, as a whole, a set suitable for a complete connection from calling to called subscriber. Each connective division in the unit illustrated is completely equipped to care for a called number of three digits, *i. e.*, each division will connect its calling line with any one of one thousand lines which may be called. By a system of interconnecting between divisions, each division may be equipped with interconnecting apparatus so as to make it possible to complete a call with any one of ten thousand lines. Each connecting division of a ten-thousand-line exchange comprises six major switches. Of the six major

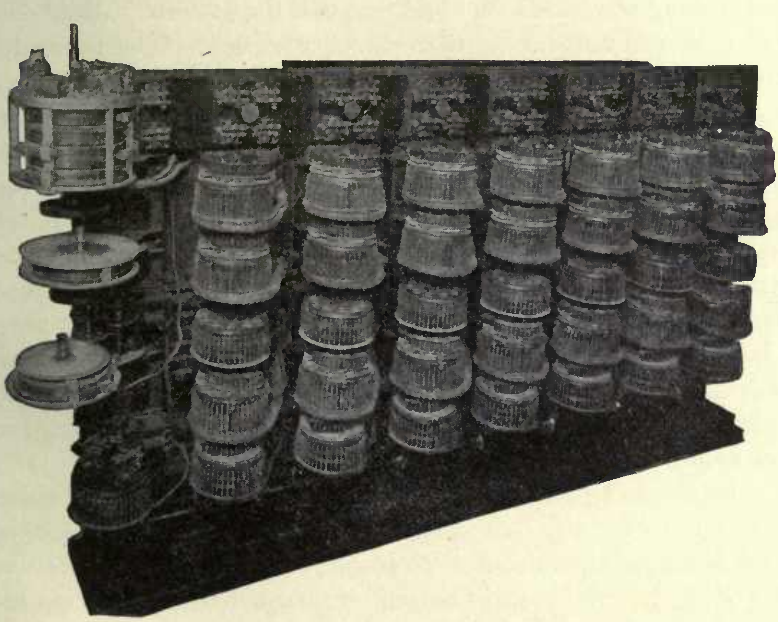


Fig. 404. Unit of Switching Apparatus

switches, one is termed a *secondary connector*, another an *interconnector*, and the four remaining are termed the *primary portion* of the division.

Before taking up the operation of the switches, the mechanical nature of the switches themselves will be described. The switches are built with a contact bank cylindrical in form and with internal movable brushes traveling in a rotary manner in circular paths upon horizontal rows of contacts fixed in the cylindrical banks. For driving these brushes a constantly rotating main power-driven shaft is provided. Between each shaft and the rotating brushes of each major switch is an electric clutch, which, by the movement of an armature, causes the brushes of the switch to partake of the motion of the shaft and by the return of the armature to come again to rest. The motion of the brushes of the major switches, or cylinder switches, as they are frequently called because of their form, is constantly in the same direction. They have a normal position upon a set of the cylinder contacts. They leave their normal position and take any predetermined position as controlled by the magnets of the clutch, and, having served the transient purpose, they return to their normal position by traversing the remainder of their complete revolution and stopping in their position of rest or idleness.

The mechanical construction of each of the cylinder switches is such that it may disengage its clutch and bring its brushes to rest only with the brushes in some one of a number of predetermined positions. The locations of the brushes in these positions of rest, or "stop" positions, as they are called, may differ with the different cylinder switches, according to the nature of the duty required of the switch, and the total number of stop positions also may vary. The primary and secondary connectors, the interconnector selectors, and the interconnectors each have eleven stop positions; the rotary switch has eight stop positions; the signal-transmitter controller has but two.

In the six cylinder switches making up a connective division and required for any conversation, in a ten-thousand-line exchange some of the switches are set to positions which are determined by the control of the calling subscriber and represent by their selective positions the value of some digit of the calling or called subscriber's number. Others are switches controlling the call in its progress and controlling the switches responsive to the call. These latter switches take positions independent of the numbers.

In addition to the major switches, there are upon each division four minor switches termed *registers*. Each consists of an arc of fixed contacts accompanied by a set of brushes which sweep over the contacts. Instead of being driven by an electromagnet, the register brushes are placed under tension of a spring which tends at all times to draw them forward. They are then restrained by an escapement device similar to a pallet escapement in a clock, the pallet being controlled by the register's magnets. When a series of impulses are received by the register magnets, the pallet is actuated a corresponding number of times and the register brushes are permitted to move forward under tension of their powerful propelling spring. Each register is associated with a major switch, and the register brushes are engaged by a cam upon the associated major switch, and are restored to normal position against the tension of their propelling spring, the force of restoration being obtained from the main shaft.

The electrical clutches which connect and disconnect the movable brushes of the major switches from the main driving shaft are controlled in all instances by circuits local to the central office. In some instances these circuits include relay contacts and are controlled by a relay. In other instances they are formed solely through switch contacts. In all cases the control, when from a distance, is received upon relays suitable for being controlled by the small currents which are adapted to flow over long lines. In all instances the power for moving a brush is derived from the main shaft and only the control of the movement is derived from electromagnets, relays, or other electric sources. In many instances the clutch circuit is closed through contacts of its own switch and, therefore, may be closed only when its switch is in some predetermined position. All of the switches are mechanically powerful and designed particularly to sustain the wear of long-continued and oft-repeated usage. This is true also of the moving parts which carry the brushes and of the journals sustaining those parts.

The Switches of the Connective Division. The six major switches of the connecting division are as follows:

The Primary Connector:—The function of this switch is to connect the conductors of the calling line with the switching devices of the connective division. Associated with this switch is a register termed the *decimal register.* The one hundred lines of the section are terminated in fixed multiple contacts in the cylinder switch of the primary connector. The calling line is selected and connected with by adjusting the decimal register to a position corresponding to the calling line's tens digit and adjusting the brushes of the cylinder switch to a position corresponding to the calling line's unit digit.

The Rotary Switch:—This is a master switch, or pilot switch, consisting of a cylinder switch without register. Its duty is the control of other switches and the completion of circuits formed in part through other switches. It is the pilot switch and the switch of initiative and control for the entire connective division.

Signal-Transmitter Controller:—The primary function of this switch is the generation of signaling impulses of two classes. Impulses of the first class pass over central-office circuits only and are effective upon magnets of the divers major and minor switches; impulses of the second class pass over a line conductor of the calling line and are effective upon the signal transmitter at the subscriber's station. The impulses sent out over the line to the subscriber's station cause the brush to pass over the contacts and thereby indicate the numerical values of the various digits set by the dials. This switch also enters in an important manner into the circuits involved in the testing of the called line for the busy condition. It is controlled by the rotary switch.

Interconnector Selector:—In an exchange using four digits in the numbers, the register of the interconnector selector is adjusted in each call to a position corresponding to the numerical value of the thousands digit of the called number. The cylinder switch then acts to select an idle trunk. The switch is controlled by the rotary switch in connection with the signal transmitter controller.

Interconnector:—This switch is similar to the interconnector selector in design and in function. It is a cylinder switch with register. The register is adjusted in each call to a position corresponding to the numerical value of the hundreds digit of the number called and the cylinder switch then operates to select an idle trunk. The switch is controlled by the rotary switch in connection with the signal transmitter controller.

Secondary Connector:—This switch contains in its cylinder bank of contacts the multiple points of one hundred subscribers' lines and its function is to connect the conductors of the called line to the conductors of the connective division. This is accomplished by adjusting the register to correspond to the value of the tens digit of the line desired and by adjusting the cylinder brushes to correspond to the value of the units digit of the line. The switch is controlled by the rotary switch in connection with the signal-transmitter controller.

Operation. A brief description of the progress of a call from its institution to the complete connection and subsequent disconnection begins with the adjustment of the dial indicators of the telephone set and the turning of the crank of the signal transmitter one revolution. This act, performed by the calling subscriber, connects one of the line conductors to earth. Immediately the decimal indicator associated with the section in which the calling line terminates is energized and starts the division starter. The division starter instantly starts the rotary switch of an idle division. The rotary switch now starts the decimal-register controller and connects to it the decimal register of the primary connector of the division selected.

All of the above acts in the central office occur practically simultaneously. The impulses generated by the controller are effective upon the decimal register of the started division and, therefore, adjust that register to a position corresponding to the tens value of the calling line.

The rotary switch now disconnects the tens register and starts the cylinder brushes of the primary connector which automatically stop when they encounter the calling line. At this instant the cut-off relay of the line is energized and the decimal indicator is released. The call now is clear of all sectional apparatus and another call may come through immediately, being assigned in charge of another idle division.

The total time in which any call is in charge of the sectional apparatus, *i. e.*, the total time from the grounding of the line conductor at the sub-station until the line has been connected with by the primary connector of some division of that section and the sectional apparatus has been released by the operation of the cut-off relay, approximates two-fifths of a second.

The next operation initiated by the rotary switch is the starting of the signal-transmitter controller of the connective division, which, in turn, adjusts the register of the interconnector selector to a position corresponding to the thousands digit of the number of the called line as indicated by the signal transmitter at the calling station. This selects an interconnector serving the lines of the selected thousand.

This initial selection being completed the rotary switch readjusts the circuits of the connective division in such manner that in the further progress of the signal-transmitter controller, its impulses will be effective upon the register of the selected interconnector. In this manner, the register of the interconnector, which may be upon the same connective division as the rotary switch handling the call, or which may be the interconnector of some other division, as determined by the number of the called subscriber, is adjusted to a position corresponding to the second or hundreds digit of the number called. The cylinder switch of the interconnector then selects and appropriates an idle trunk extending to a secondary connector upon some connective division serving the hundred selected.

The rotary switch again shifts the circuits of the connective division in such manner that the signal-transmitter controller is effective upon the secondary connector, both register and cylinder, and adjusts the register and cylinder, respectively, with their brushes in contact with the tens and units digits, respectively, of the number of the called line.

The conductors of the called line now are connected through the secondary connector, the interconnector, and the interconnector selector to the rotary switch; the conductors of the calling line are connected through the primary connector to the rotary switch; thus completely connecting the lines except at the rotary switch. To effect the connecting together of the two lines, both rotary switch and signal-transmitter controller must pass forward into their next positions, the connection when thus effected being made through conductors containing a repeating coil and main battery connection for supplying talking current to the two lines and containing also ringing and supervisory relays.

The called line is tested to determine if busy during the short interval in which the rotary switch takes a short step to connect the calling and the called lines. In this step of the rotary switch the busy-test relay is connected to the guard wire or busy-test wire of the called line, and if that line be busy, the relay interferes with the control exercised by the rotary switch upon the signal-transmitter controller, and the controller is prevented from taking the step required to connect the line. Thus, when a busy line is encountered, the final step of the rotary switch is taken to set up the conversation conditions, but the signal-transmitter controller does not take its final step; by this failure of the signal-transmitter controller due to the action of the busy-test relay, the calling line is not connected to the called line but is connected to a busy-back tone generator instead.

Whether the line encountered be busy or idle, the connective division remains in its condition as then adjusted until the subscriber hangs his receiver upon the hook switch to obtain disconnection. The ringing of the bell of the called station is done directly by the calling subscriber in pressing the ringing key.

The disconnection is effected, when the receiver of the calling line is hung up, by the supervisory relay in the central office, whose winding is included in the line circuit, and whose contacts act directly to start the rotary switch. In disconnecting, the rotary switch starts the primary and the secondary connectors and thus instantly releases both the calling and the called lines. Thereafter the rotary switch in passing from position to position restores switch after switch of the connective division to normal and finally itself returns to normal in preparation for its assignment to service in answering a subsequent call.

CHAPTER XXXI

THE AUTOMANUAL SYSTEM

Two systems of telephony are now in common use in this country —the manual system and the automatic. With the growth of the automatic, and the gradually ripening conviction, which is now fully matured in the minds of most telephone engineers, that automatic switching is practical, there has been a growing tendency toward doing automatically many of the things that had previously been done manually. One of the results of this tendency has been the production of the *automanual* system, the invention of Edward E. Clement, an engineer and patent attorney, of Washington, D. C. In connection with Mr. Clement's name, as inventor, must be mentioned that of Charles H North, whose excellent work as a designer and manufacturer has contributed much toward the present excellence of this highly interesting system.

Characteristics of System. The name "automanual" is coined from the two words, automatic and manual, and is intended to suggest the idea that the system partakes in part of the features of the automatic system and in part of those of the manual system.

We regret that neither space nor the professional relation which we have had with the development of this system will permit us to make public an extended and detailed description of its apparatus and circuits. Only the general features of the system may, therefore, be dealt with.

The underlying idea of the automanual system is to relieve the subscriber of all work in connection with the building up of his connection, except the asking for it; to complicate the subscriber's station equipment in no way, it being left the same as in the common-battery manual system; to do away with manual apparatus, such as jacks, cords and plugs, at the central office, and to substitute for it automatic switching apparatus which will be guided in its movements, not by the subscriber, but by a very much smaller number of operators than would be necessary to manipulate a manual switchboard.

General Features of Operation. A broad view of the operation of the system is this. The subscriber desiring to make a call takes down his receiver, and this causes a lamp to light in front of an operator. The operator presses a button and is in telephonic communication with the subscriber. Receiving the number desired, the operator sets it up on a keyboard in just about the same way that a typist will set up the letters of a short word on a typewriting machine. The setting up of the number on the keyboard being accomplished, the proper condition of control of the associated automatic apparatus at the central office is established and the operator has no further connection with the call. The automatic switching apparatus guided by the conditions set up on the operator's keyboard proceeds to make the proper selection of trunks and to establish the proper connections through them to build up a talking circuit between the calling subscriber and the called and to ring the called subscriber's bell, or, if his line is found busy, the apparatus refuses to connect with it and sends a busy signal back to the calling subscriber. The operator performs no work in disconnecting the subscribers, that being automatically taken care of when they hang up their receivers at the close of the conversation.

From the foregoing it will be seen that there is this fundamental difference between the automatic and the automanual—the automatic system dispenses entirely with the central-office operator for all ordinary switching functions; the automanual employs operators but attempts to so facilitate their work that they may handle very many more calls than would be possible in a manual system, and at the same time secures the advantages of secrecy which the automatic system secures to its subscribers.

Subscriber's Apparatus. One of the main points in the controversy concerning automatic *versus* manual systems is whether or not it is desirable to have the subscriber ask for his connection or to have him make certain simple movements with his fingers which will lead to his securing it. The developers of the automanual system have taken the position that the most desirable way, so far as the subscriber is concerned, is to let him ask for it. It is probable that this point will not be a deciding one in the choice of future systems, since it already seems to be proven that the subscribers in automatic systems are willing to go through the necessary movements to mechanically set up the call. The advantage which the auto-

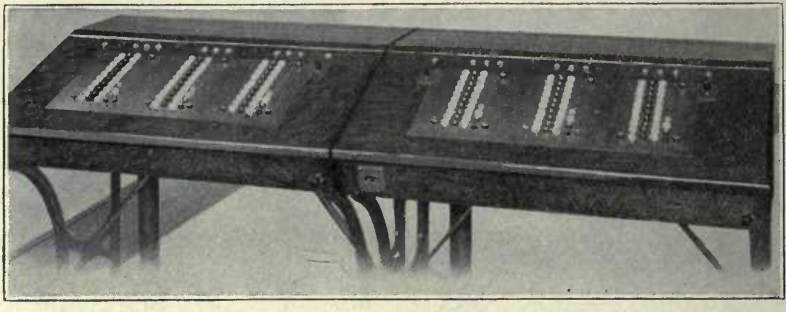


Fig. 405. Operators' Key Tables

manual system shares with the manual, however, in the greater simplicity of its subscriber's station apparatus, cannot be gainsaid.

Operator's Equipment. The general form of the operator's equipment is shown in Fig. 405. A closer view of the top of one of the key tables is shown in Fig. 406. As will be seen, the equipment

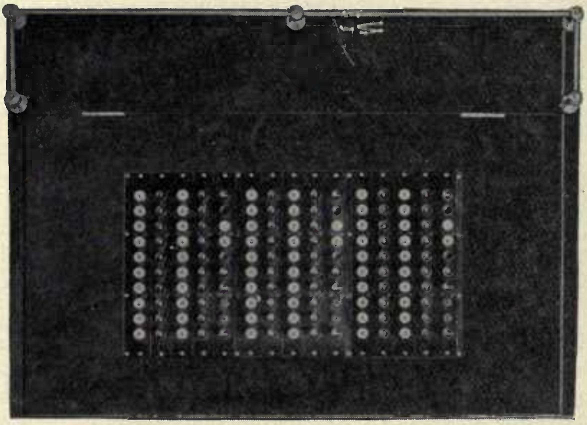


Fig. 406. Top View of Key Table

on each operator's position consists of three separate sets of push-button keys closely resembling in external appearance the keys of a typewriter or adding machine. Immediately above each set of keys are the signal lamps belonging to that set.

The operator's keys are arranged in strips of ten, placed *across* rather than *lengthwise* on the key shelf. One of these strips is shown in Fig. 407. There are as many strips of keys in each set as there are digits in the subscribers' numbers, *i. e.*, three in a system having

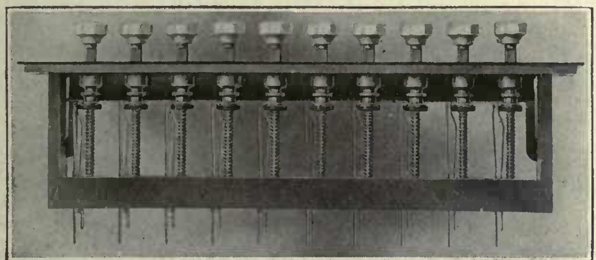


Fig. 407. Strip of Selecting Keys

a capacity of less than one thousand; four in a system of less than ten thousand; and so on. In addition to the number keys of each set is a partial row of keys, including what is called a *starting key* and also keys for making the party-line selection.

The simplicity of the operator's key equipment is one of its at-

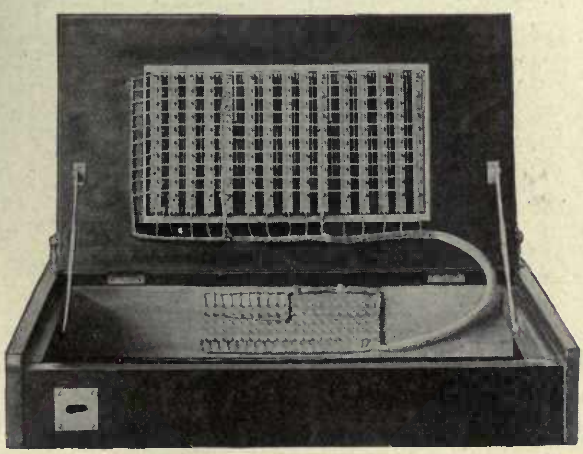


Fig. 408. Wiring of Key Shelf

tractive features. Fig. 408 shows one of the key shelves opened so as to expose to view all of the apparatus and wiring that is placed before the operator. The reason for providing more than one key set on each operator's position is, that after a call has been set up on one key set, a few seconds is required before the automatic apparatus controlled by the key set can do its work and release the key set ready for another call. The provision of more than one key set makes it

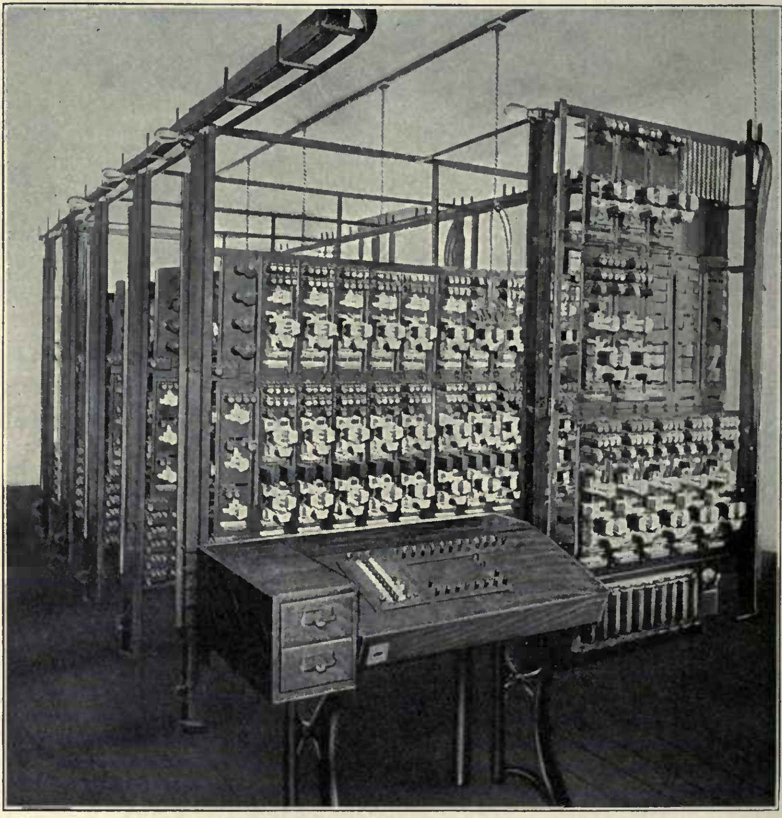


Fig. 409. Switch Room of Automanual Central Office

possible for the operator to start setting up another call on another key set without waiting for the first to be released by the automatic apparatus.

Automatic Switching Equipment. A general view of the arrangement of automatic switches in an exchange established by the North Electric Company at Ashtabula, Ohio, is shown in Fig. 409. The desk in the foreground is that of the wire chief. This automatic apparatus consists largely of relays and automatic selecting switches.

The switches are of the step-by-step type, having vertical and rotary movements, and an idea of one of them, minus its contact banks, is given in Fig. 410. The control of the automatic switches by the operator's key sets is through the medium of a power-driven, impulse-sending machine. From this machine impulses are taken corresponding to the numbers of the keys depressed.

Automatic Distribution of Calls. A feature of great interest in this system is the manner in which the incoming calls are distributed among the operators. From each key set an operator's trunk is extended to what is called a secondary selector switch, through which it may be connected to a primary selector trunk and calling line. When a subscriber calls by taking down his receiver, his line relay pulls up and causes a primary selector switch to connect his line with an idle local trunk or link circuit, at the same time starting up a secondary selector switch which immediately connects the primary trunk and the calling line to an operator's idle key set. If an operator is at the time engaged in setting up a call on a key set, or if that key set is still acting to control the sending of impulses to the automatic switches, it may be said to be busy, and it is not selected by this preliminary selecting apparatus in response to an incoming call. As soon, however, as the necessary impulses have been taken from the key set by the automatic apparatus, that key set is released and is again ready to receive a call. In this way

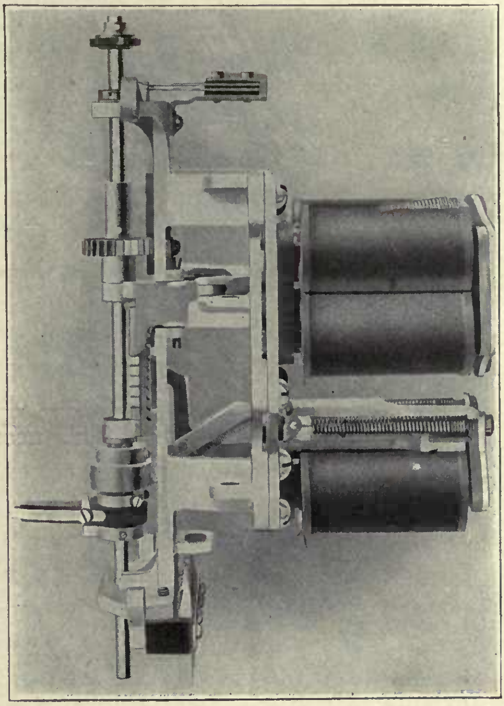


Fig. 410. Selecting Switch

the calls come before each operator only as that operator is able and ready to receive them.

Setting up a Connection. As soon as the key-set lamp lights, in response to such an incoming call, the operator presses a listening button, receives the number from the subscriber, and depresses the corresponding number buttons on that key set, thereby determining the numbers in each of the series of impulses to be sent to the selector and the connector switches to make the desired connection. The operator repeats this number to the calling subscriber as she sets it up, and then presses the starting button, whereupon her work is done so far as that call is concerned. If, upon repeating the call to the subscriber, the operator finds that she is in error, she may change the number set up at any time before she has pressed the starting button.

Building up a Connection. The keys so set up determine the number of impulses that will be transmitted by the impulse-sending machine to the selector and the connector switches. These switches, impelled by these impulses, establish the connection if the line called for is not already connected to. If a party-line station is called for, the proper station on it will be selectively rung as determined by the party-line key depressed by the operator. If the line is found busy, the connector switch refuses to make the connection and places a busy-back signal on the calling line.

Speed in Handling Calls. This necessarily brief outline gives an idea only of the more striking features of the automanual system. A study of the rapidity with which calls may be handled in actual practice shows remarkable results as compared with manual methods of operating. The operators set up the number keys corresponding to a called number with the same rapidity that the keys of a typewriter are pressed in spelling a word. In fact, even greater speed is possible, since it is noticed that the operators frequently will depress all of the keys of a number at once, as by a single striking movement of the fingers. The rapidity with which this is done defies accurate timing by a stop watch in the hands of an expert. It is practically true, therefore, that the time consumed by the operator in handling any one call is that which is taken in getting the number from the subscriber and in repeating it back to him.

Owing to the difficulty of securing accurate traffic data by

TABLE XI

Total Time Consumed by Operator in Handling Calls on Automanual System

First 100 Calls		
Longest Individual Period	12.40	seconds
Average five longest Individual Periods	7.44	seconds
Average ten longest Individual Periods	6.34	seconds
Shortest Individual Period	1.60	seconds
Average five shortest Individual Periods	1.92	seconds
Average ten shortest Individual Periods	1.96	seconds
Average Entire 100 Calls	3.396	seconds
Hourly Rate at which calls were being handled	1060	

Second 100 Calls		
Longest Individual Period	7.60	seconds
Average five longest Individual Periods	5.52	seconds
Average ten longest Individual Periods	5.34	seconds
Shortest Individual Period	2.00	seconds
Average five shortest Individual Periods	2.04	seconds
Average ten shortest Individual Periods	2.18	seconds
Average Entire 100 Calls	3.374	seconds
Hourly Rate at which calls were being handled	1067	

Third 100 Calls		
Longest Individual Period	5.40	seconds
Average five longest Individual Periods	5.32	seconds
Average ten longest Individual Periods	4.44	seconds
Shortest Individual Period	1.60	seconds
Average five shortest Individual Periods	1.65	seconds
Average ten shortest Individual Periods	1.80	seconds
Average Entire 100 Calls	3.160	seconds
Hourly Rate at which calls were being handled	1139	

means of a stop watch, an automatic, electrical timing device, capable of registering seconds and hundredths of a second, has been used in studying the performance of this system in regular operation at Ashtabula Harbor. The operators were not informed that the records were being taken, and the data tabulated represents the work of two operators in handling regular subscribers' calls. The figures in Table XI are given by C. H. North as representing the total time consumed by the operator from the time her line lamp was lighted until her work in connection with the call was finished, and it included, therefore, the pressing of the listening button, the receiving of the number from the subscriber, repeating it back to him, setting up the connection on the keys, and pressing the starting key.

It will be seen that the average time for each 100 calls is quite uniform and is slightly over three seconds. The considerable variation in the individual calls, ranging from a maximum of 12.40 seconds down to a minimum of 1.60 seconds, is due almost entirely to the difference between the subscribers in the speed with which they can give their numbers. These figures indicate that, in each of the tests, calls were being handled at the rate of more than one thousand per hour by each operator.

The test of the subscriber's waiting time, *i. e.*, the time that he waited for the operator to answer, for one hundred calls made without the knowledge of the operator, showed the results as given in Table XII, in which a split second stop watch was used in making the observations.

TABLE XII

Subscribers' Waiting Time

Number of Calls Tested	100	
Longest Individual Period	5.20	seconds
Average 5 Longest Individual Periods	4.64	seconds
Average 10 Longest Individual Periods	3.80	seconds
Shortest Individual Period	1.00	seconds
Average 5 Shortest Individual Periods	1.28	seconds
Average 10 Shortest Individual Periods	1.34	seconds
Average Entire 100 Calls	2.07	seconds

The length of time which the subscriber has to wait before receiving an answer from the operator is, of course, one of the factors that enters into the giving of good telephone service, and the times shown by this test are considerably shorter than ordinarily maintained in manual practice. The waiting time of the subscriber is not, of course, a part of the time that is consumed by the operator, and the real economy so far as the operator's time is concerned is shown in the tests recorded in Table XI.

CHAPTER XXXII

POWER PLANTS

The power plant is an organization of devices to furnish to a telephone system the several kinds of current, at proper pressures, for the performance of the several general electrical tasks within the exchange.

Kinds of Currents Employed. Sources of both direct and alternating current are required and a single exchange may employ these for one or more of the following purposes:

Direct Current. Current which flows always in one direction whether steady or varying, is referred to as direct current, and may be required for transmitters, for relays, for line, supervisory, and auxiliary signals, for busy tests, for automatic switches, for call registers, for telegraphy, and in the form of pulsating current for the ringing of biased bells.

Alternating Current. Sources of alternating current are required for the ringing of bells, for busy-back and other automatic signals to subscribers, for howler signals to attract the attention of subscribers who have left their receivers off their hooks, and for signaling over composite lines.

Types of Power Plants. Clearly the requirements for current supply differ greatly for magneto and common-battery systems. There is, however, no great difference between the power plants required for the automatic and the manual common-battery systems.

In the simplest form of telephone system—two magneto telephones on a private line—the power plant at each station consists of two elements: one, the magneto generator, which is a translating device for turning hand power into alternating current for ringing the bell of the distant station; and the other, a primary battery which furnishes current to energize the transmitter. In such a system, therefore, each telephone has its own power plant. The term power plant, however, as commonly employed in telephone work, refers more particularly to the organization of devices at the central office for furnishing the required kinds of current, and it is to power plants in this sense that this chapter is devoted.

Magneto Systems. If magneto lines be connected to a switchboard, the current for throwing the drop at the switchboard is furnished by the subscriber's generator, and the current for energizing the subscriber's transmitter is furnished by the local battery at his station; but sources of current must be provided for enabling the central-office operator to signal or talk to the subscribers. These are about the only needs for which current must be furnished in an ordinary magneto central office. If a multiple board is employed, direct current is also needed for the purpose of the busy test and also for operating the drop restoring circuits, if the electrical method of restoring the drops is employed.

Common-Battery Systems. In common-battery systems the requirements are very much more extensive. The subscribers' telephones have no power plants of their own, but are provided with a common source of direct current located at the central office for supplying the talking current, and for operating the central-office signals, and the operators are provided with one or more common sources of alternating or pulsating current for ringing the subscribers' bells. Common-battery equipment requires the use of currents of different kinds for a greater number of auxiliary purposes than does magneto equipment. These facts make the power plant in a common-battery office much more important than in a magneto office.

Operators' Transmitter Supply. In a small magneto exchange, the transmitter current may be had from primary batteries, a separate battery being employed for each operator's set. When there are more than three or four operators, however, it is usual, even in magneto offices, to obtain the transmitter current from a common storage battery. A storage battery has the fortunate quality of very low internal resistance, therefore a number of operators' transmitters may be actuated by one source without introducing cross-talk. In other words, a storage battery is a current-furnishing device of good regulation, the variation of consumption in one circuit leading from it causing slight variation in the currents of other circuits leading from it. If this were not so, cross-talk would exist between the telephones of the operators' positions connected to the same battery. This regulating quality enables the multiple feeding of telephone circuits to be carried further than the mere supplying of operators' sets and is the quality which makes possible the successful use of a storage battery as the single source of transmitter current for common-battery central-office equipment.

In furnishing a plurality of operators' transmitters from a common battery, the importance of low resistance and inductance in the portion of the path that is common to all of the circuits must not be overlooked. Not only is a battery of extremely low resistance required, but also conductors leading from it that are common to two or more of the circuits should be of very low resistance and consequently large in cross-section and as short as possible. In common-battery offices there is obviously no need of employing a separate battery for the operators' transmitters, since they may readily be supplied from the common storage battery which supplies direct current to the subscribers' lines.

Ringing-Current Supply. *Magneto Generators.* As a central-office equipment is required to ring many subscribers' bells, only the small ones find it convenient to ring them by means of hand-operated magneto generators. Small magneto switchboards are usually equipped so that each operator is provided with a hand-generator, but even where such is the case some source of ringing current not manually operated is desirable. In larger switchboards the hand generators are entirely dispensed with.

The magneto generator may be driven by a belt from any convenient constantly moving pulley, and the early telephone exchanges were often equipped with such generators having better bearings and more current capacity than those in magneto telephones. These were adapted to be run constantly from some source of power, delivering ringing current to the operators' keyboards at from 16 to 20 cycles per second.

Pole Changers. Vibrating pole changers were also used in the early exchanges, but passed out of use, partly because of poor design, but more because of the absence of good forms of primary batteries for vibrating them and for furnishing the direct currents to be transformed into alternating line current for ringing the bells. The pole changer was redesigned after the beginning of the great spread of telephony in the United States in 1893. Today it is firmly established as an element of good telephone practice. Fig. 411 illustrates the principle upon which one of the well-known pole changers—the

Warner—operates. In this *1* is an electromagnet supplied by a constant-current battery *2* to keep the vibratory system continually in motion. This motor magnet and its battery work in a local circuit and cause vibration in exactly the same manner as the armature of an ordinary electric door bell is caused to vibrate. The battery from which the ringing current is derived is indicated at *3*, and the poles of this are connected, respectively, to the vibrating contacts *4* and *5*. These contacts are merely the moving members of a pole changing switch, and a study of the action will readily show that when these moving parts engage the right-hand contacts, current will flow to the line supposed to be connected to the terminals *6* and *7* in one direction, while, when these parts engage the left-hand contacts, current will flow to the line in the reverse direction. The circuit of the condenser shown is controlled by the armature of the relay *8*.

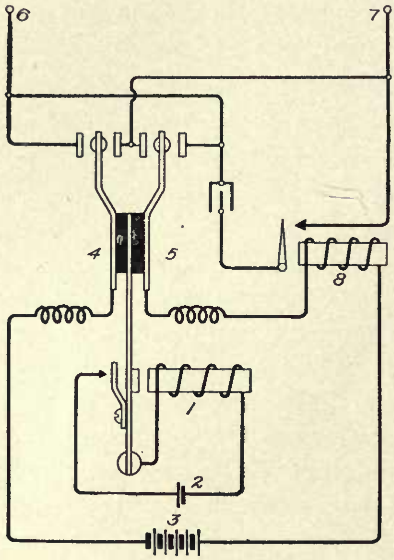


Fig. 411. Warner Pole Changer

The winding of this relay is put directly in the circuit of the main battery *3*, so that whenever current is drawn from this battery to ring a distant bell, this relay will be operated and will bridge the condenser across the circuit of the line. The purpose of the condenser is to make the impulses flowing from the pole changer less abrupt, and the reason for having its bridged circuit normally broken is to prevent a waste of current from the battery *3*, due to the energy which would otherwise be consumed by the condenser if it were left permanently across the line.

Pole changers for ringing bells of harmonic party lines are required to produce alternating currents of practically constant frequencies. The ideal arrangement is to cause the direct currents from a storage battery to be alternated by means of the pole changers, and then transformed into higher voltages required for ringing purposes, the transformer also serving to smooth the current wave, making it more suitable for ringing purposes. In Fig. 412 such an arrangement, adapted to develop currents for harmonic ringing on party lines, is shown. The regular common battery of the central office is indicated at *1*, *2* being an auxiliary battery of dry cells, the purpose of which will be presently referred to. At the right of the battery *1* there is shown the calling plug with its associated party-line ringing keys adapted to impress the several frequencies on the subscribers' lines. The method by which the current from the main storage battery passes through the motor magnets of the several vibrators,

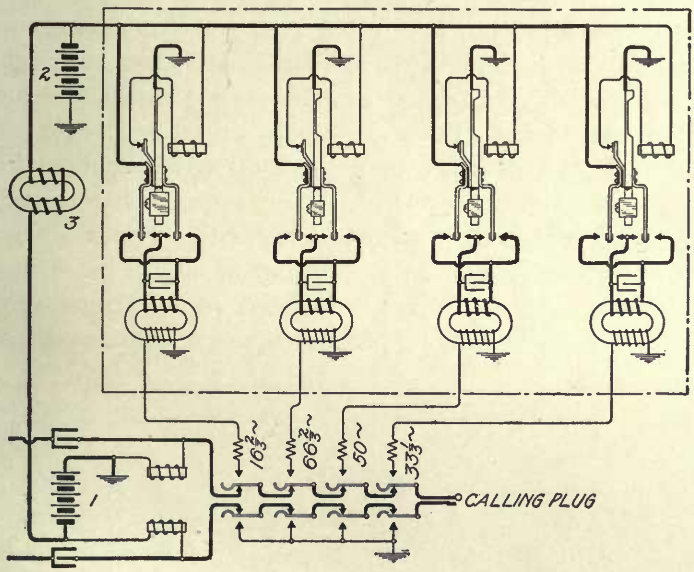


Fig. 412. Pole Changers for Harmonic Ringing

and by which the primary currents through the transformers are made to alternate at the respective frequencies of these vibrators, will be obvious from the drawing. It is also clear that the secondary currents developed in these transformers are led to the several ringing keys so as to be available for connection with the subscribers' lines at the will of the operator. The condensers are bridged across the primary windings of the transformers for the purpose of aiding in smoothing out the current waves. The use of the auxiliary battery *2* and the retardation coil *3* in the main supply lead is for the purpose preventing the pulsating currents drawn from the main battery *1* from making the battery "noisy." These two batteries have like poles connected to the supply lead, and the auxiliary battery furnishes no current to the system except when the electromotive force of the impulse flowing from the main battery is choked down by the impedance coil and the deficiency is then momentarily supplied for each wave by the auxiliary battery. This is the method developed by the Dean Electric Company for preventing the pole-changer system from causing disturbances on lines supplied from the same main battery.

Ringing Dynamos. Alternating and pulsating currents for ringing purposes are also largely furnished from alternating-current dynamos similar to those used in commercial power and lighting work, but specially designed to produce ringing currents of proper frequency and voltage. These are usually driven by electric motors deriving their current either from the commercial supply mains or from the central-office battery. In large exchanges harmonic ringers are usually operated by alternating-current generators driven by motors, a separate dynamo being provided to furnish the current of each frequency. Fig. 413 shows a set of four such generators directly connected to a common motor. As no source of commercial power

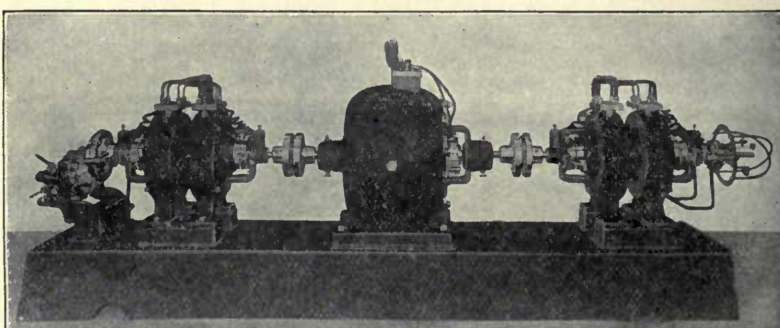


Fig. 413. Multi-Cyclic Generator Set

for driving such generators is absolutely uniform, and since the frequency of the ringing current must remain very close to a constant predetermined rate, some means must be employed for holding the generators at a constant speed of revolution, and this is done by means of a governor shown at the right-hand end of the shaft in

Fig. 413. The principle of this governor is shown in Fig. 414. A weighted spring acts, by centrifugal force, to make a contact against an adjustable screw, when the speed of the shaft rises a predetermined amount. This spring and its contact are connected to two collector rings *1* and *2* on the motor shaft, and connection is made with these by the brushes *3* and *4*. The closing of the governor

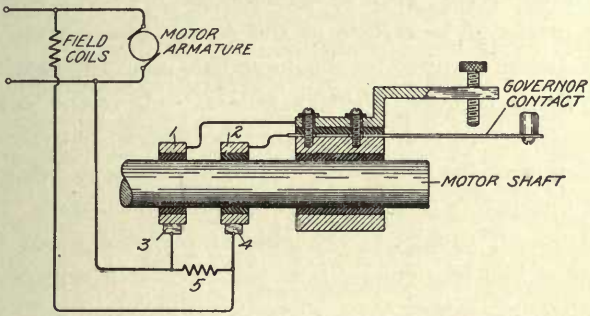


Fig. 414. Governor for Harmonic Ringing Generators

contact serves, therefore, merely to short-circuit the resistance *5*, which is normally included in the shunt field of the motor. This governor is based on the principle that weakening the field increases the speed. It acts to insert the resistance in series with the field winding when the speed falls, and this. in turn, results in restoring the speed to normal.

Auxiliary Signaling Currents. Alternating currents, such as those employed for busy signals to subscribers in automatic systems, those for causing loud tones in receivers which have been left off the hook switch, and those for producing loud tones in calling receivers connected to composite lines, all need to be of much higher frequency than alternating current for ringing bells. The simplest way of producing such tones is by means of an interrupter like that of a vibrating bell; but this is not the most reliable way and it is usual to produce busy or "busy-back" currents by rotating commutators to interrupt a steady current at the required rate. As the usual busy-back signal is a series of recurrent tones about one-half second long, interspersed with periods of silence, the rapidly commuted direct current is required to be further commuted at a slow rate, and this is conveniently done by associating a high-speed commutator with a low-speed one Such an arrangement may be seen at the left-hand end of the multicyclic alternating machine shown in Fig. 413. This commuting device is usually associated with the ringing machine because that is the one thing about a central office that is available for imparting continuous rotary motion.

Primary Sources. Most telephone power plants consume commercial electric power and deliver special electric current. Usually some translating device, such as a motor-generator or a mercury-arc rectifier, is employed to transform the commercial current into the specialized current required for the immediate uses of the exchange.

Charging from Direct-Current Mains. In some cases commercial direct current is used to charge the storage batteries without the intervention of the translating devices, resistances being used in series with the battery to regulate the amount of current. Commercial direct current usually is available at pressures from 110 volts and upward, while telephone power plants contain storage batteries rarely of pressures higher than 50 volts. To charge a 50-volt storage battery direct from 110-volt mains results in the loss of about half the energy purchased, this lost energy being set free in the form of heat generated in the resistance devices. Notwithstanding this, it is sometimes economical to charge directly from the commercial direct-current power mains, but only in small offices where the total amount of current consumed is not large and where the greatest simplicity in equipment is desirable. It is better, however, in nearly all cases, to convert the purchased power from the received voltage to the required voltage by some form of translating device, such as a rotary converter or a mercury-arc rectifier.

Rotary Converters. Broadly speaking, a rotary converter consists of a motor adapted to the voltage and kind of current received, mechanically coupled to a generator adapted to produce current of the required kind and voltage. The harmonic ringing machine shown in Fig. 413 is an example of this, this particular one being adapted to receive direct current at ordinary commercial pressure and to deliver four different alternating currents of suitable pressures and frequencies. It is to be understood, however, that the conversion may be from direct current to direct current, from alternating to direct, or from direct to alternating. Such a device where the motor is a separate and distinct machine from the generator or generators is called a *motor-generator*. It is usual to connect the motors and the generators together directly by a coupling having some flexibility, as shown in Fig. 413, so as to prevent undue friction in the bearings.

As an alternative to the converting device made up of a motor coupled to a generator, both motor and generator windings may be combined on the same core and rotate within the same field. Such a rotary converter has been called a *dynamotor*. As a rule the dynamotor is only suitable for small power-plant work. It has the following objectionable features: (*a*) It is difficult to regulate its output, since the same field serves for both the motor and the dynamo windings. For this reason its main use is as a ringing machine where the regulation of the output is not an important factor. (*b*) Furthermore, the fact that the motor and dynamo armature windings are on the same core makes it difficult to guard against breakdowns of the insulation between the two windings, especially when the driving current is of high voltage.

Charging Dynamos. The dynamo for charging the storage battery is, of course, a direct-current machine and may be a part of a motor generator or it may derive its power from some other than an electric motor, such as a gas or steam engine. It should be able to develop a voltage slightly above that of the voltage of the storage battery when at its maximum charge, so as always to be able to deliver current to the charging battery regardless of the state of charge. A 30-volt generator, for example, can charge eleven cells in series economically; a 60-volt generator can charge twenty-five cells in series economically.

Battery-charging generators are controlled as to their output by varying a resistance in series with their fields. Such machines are usually shunt-wound. Sometimes they are compound-wound, but compounding is less important in telephone generators than in some other uses. A feature of great importance in the design of charging generators is smoothness of current. If it were possible to design generators to produce absolutely even or smooth current, the storage battery would not be such an essential feature to common-battery exchanges, because then the generator might deliver its current directly to the bus bars of the office without any storage-battery connection and without causing noise on the lines. Such generators have been built in small units. Even if these smooth current generators were commercially developed to a degree to produce absolutely no noise on the lines, the storage battery would still be used, since its action as a reservoir for electrical energy is important. It not only dispenses with the necessity of running the generators continuously, but it also affords a safeguard against breakdowns which is one of its important uses.

The ability to carry the load of a central office directly on the charging generator without the use of a storage battery is of no importance except in an emergency which takes the storage battery wholly out of service. Since the beginning of common-battery working such emergencies have happened a negligible number of times. Far more communities have lacked telephone service because of accidents beyond human control than because of storage-battery failures.

In power plants serving large offices, the demand upon the storage battery is great enough to require large plate areas in each cell. The internal resistance, therefore, is small and considerable fluctuations may exist in the charging current without their being heard in the talking circuits. The amount of noise to be heard depends also on the type of charging generator. Increasing the number of armature coils and commutator segments increases the smoothness of the charging current. The shape of the generator pole pieces is also a factor in securing such smoothness.

If, with a given machine and storage battery, the talking circuits are disturbed by the charging current, relief may be obtained by inserting a large impedance in the charging circuit. This impedance requires to be of low resistance, because whatever heat is developed in it is lost energy. This means that the best conditions exist when the resistance is low and the inductance large. These conditions are satisfied by using in the impedance coil many turns of large wire and an ample iron core.

Dynamotors are not generally suitable for charging purposes. Not only is the difficulty in regulating their output a disadvantage, but the fact that the primary and secondary windings are so closely associated on the armature core makes them carry into the charging current, not only the commutator noises of the generator end, but of the motor end as well.

Mercury-Arc Rectifiers. In common-battery offices serving a few hundred lines, and where the commercial supply is alternating current, it is good practice to transform it into direct-battery charging current by means of a mercury-arc rectifier. It is a device broadly similar to the mercury-arc lamp produced by Peter Cooper Hewitt. It contains no moving parts and operates at high efficiency without introducing noises into the telephone lines. It requires little care and has good length of life.

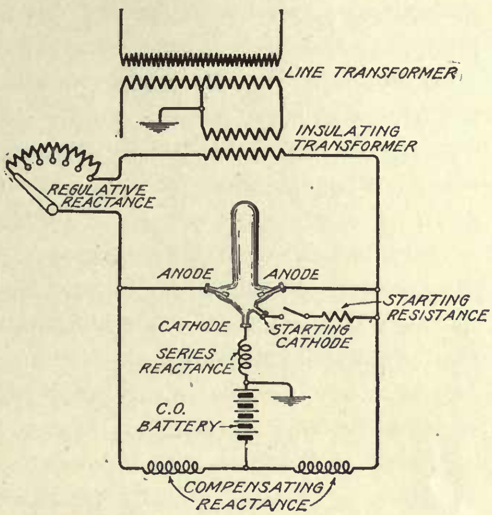


Fig. 415. Mercury-Arc Rectifier Circuits

The circuit of a mercury-arc rectifier charging outfit is shown in Fig. 415. The mercury-arc rectifier proper consists of a glass bulb containing vacuum and a small amount of mercury. When its terminals are connected, as indicated—the two anodes across an alternating-current source and the cathode with a circuit that is to be supplied with direct current—this device has the peculiarity of action that current will flow alternately from the two anodes always to the cathode and never from it. The cathode, therefore, becomes a source of positive potential and, as such, is used in charging the storage battery through the series reactance coil and the compensating reactances, as indicated. The line transformer shown at the upper portion of Fig. 415, is the one for converting the high-potential alternating current to the comparatively low-potential current required for the action of the rectifier. The transformer below this has a one-to-one ratio, and is called the insulating transformer. Its purpose is to safeguard the telephone apparatus and circuits against abnormal potentials from the line, and also to prevent the ground, which is commonly placed on the neutral wire of transformers on commercial lighting circuits, from interfering with the ground that is commonly placed on the positive pole of the central-office battery.

Provision Against Breakdown. In order to provide against breakdown of service, a well-designed telephone power plant should have available more than one primary source of power and more than one charging unit and ringing unit.

Duplicate Primary Sources. In large cities where the commercial power service is highly developed and a breakdown of the generating station is practically impossible, it is customary to depend on that service alone. In order to insure against loss of power due to an accident to portions of the distributing system, it is the common custom to run two entirely separate power leads into the office, coming, if possible, from different parts of the system so that a breakdown on one section will not deprive the telephone exchange of primary power. In smaller places where the commercial service is not so reliable, it is usual to provide, in addition to the commercial electric-power service, an independent source of power in the form of a gas or steam engine. This may be run as a regular source, the commercial service being employed as an emergency or *vice versâ,* as economy may dictate. In providing a gas engine for driving charging dynamos, it is important to obtain one having as good regulation as possible, in order to obtain a charging current of practically constant voltage.

Duplicate Charging Machines. The storage batteries of telephone exchanges are usually provided of sufficient capacity to supply the direct-current needs of the office for twenty-four hours after a full charge has been given them. This in itself is a strong safeguard against breakdown. In addition to this the charging machines should be in duplicate, so that a burnt-out armature or other damage to one of the charging units will not disable the plant.

Duplicate Ringing Machines. It is equally important that the ringing machines, whether of the rotary or vibrating type, be in duplicate. For large exchanges the ringing machines are usually dynamos, and it is not unusual to have one of these driven from the commercial power mains and the other from the storage battery. With this arrangement complete failure of all sources of primary power would still leave the exchange operative as long as sufficient charge remains in the storage battery.

Capacity of Power Units. In designing telephone switchboards it is the common practice to so design the frameworks that the space for multiple jacks is in excess of that required for the original installation. In a like manner, the power plant is also designed with a view of being readily increased in capacity to an amount sufficient to provide current for the ultimate number of subscribers' lines for which the switchboard is designed. The motor generators, or whatever means are provided for charging the storage batteries, are usually installed of sufficient size to care for the ultimate requirements of the office. The ringing machines are also provided for the ultimate equipment. However, in the case of the storage battery, it is common practice to provide the battery tanks of sufficient size to care for the ultimate capacity, while the plates are installed for a capacity only slightly in excess of that required for the original installation. As the equipment of subscribers' lines is increased, additional plates may, therefore, be added to the cells without replacing the storage battery as a whole, and without making extraordinary provisions to prevent the interruption of service. It is also customary to provide charging and supply leads from the storage battery of carrying capacity sufficient for the ultimate requirements of the office.

Storage Battery. The storage battery is the power plant element which has made common-battery systems possible. The common-battery system is the element which has made the present wide development of telephony possible.

A storage-battery cell is an electro-chemical device in which a chemical state is changed by the passage of current through the cell, this state tending to revert when a current is allowed to flow in the opposite direction. A storage cell consists of two conductors in a solution, the nature and the relation of these three elements being such that when a direct current is made to pass from one conductor to the other through the solution, the compelled chemical change is proportional to the product of the current and its duration. When the two conductors are joined by a path over which current may flow, a current does flow in the opposite direction to that which charged the cell.

All storage batteries so far in extensive use in telephone systems are composed of lead plates in a solution of sulphuric acid in water called the *electrolyte*. In charging, the current tends to oxidize the lead of one plate and de-oxidize the other. In discharging, the tendency is toward equilibrium.

The containers, employed in telephone work, for the plates and electrolyte are either of glass or wood with a lead lining, the glass jars being used for the smaller sized plates of small capacity cells, while the lead-lined wooden tanks are employed with the larger capacity cells. The potential of a cell is slightly over two volts and is independent of the shape or size of the plates for a given type of battery. The storage capacity of a cell is determined by the size and the number of plates. Therefore, by increasing the number of plates and the areas of their surfaces, the ampere-hour capacity of the cell is correspondingly increased. The desired potential of the battery is obtained by connecting the proper number of cells in series. Storage-battery cells used in telephone work vary from 2 plates having an area of 12 square inches each, to cells having over 50 plates, each plate having an area of 240 square inches. The ampere-hour capacity of these batteries varies from 6 ampere hours to 4,000 ampere hours, respectively, when used at an average 8-hour discharge rate. In Fig. 416 is illustrated a storage cell employing a glass container and having fifteen plates. Each plate is 11 inches high and $10\frac{1}{2}$ inches wide, with an area, therefore, of 115.5 square inches. Such a cell has a normal capacity of 560 ampere hours. The type illustrated is one made by the Electric Storage Battery Company of Philadelphia, Pa.*

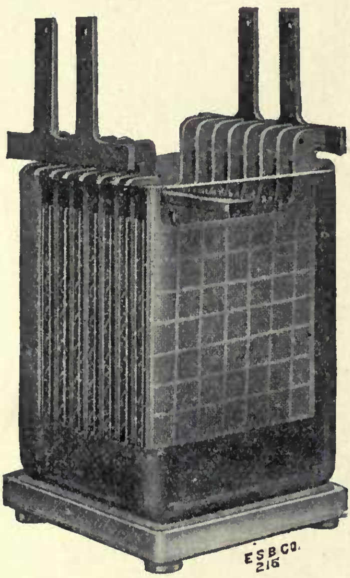


Fig. 416. Storage Cell

Installation. In installing the glass jars it is customary to place them in trays partially filled with sand. They are, however, at times installed on insulators so designed as to prevent moisture from causing leakage between the cells. The cells using wooden tanks are placed on glass or porcelain insulators, and the tanks are

*The instructions given later in this chapter are for batteries of this make, although they are applicable in many respects to all types commonly used in telephone work.

placed with enough clearance between them to prevent the lead lining of adjacent tanks from being in contact and thereby short-circuiting the cells. After the positive and the negative plates have been installed in the tanks, their respective terminals are connected to bus bars, these bus bars being, for the small types of battery, lead-covered clamping bolts, while in the larger types reinforced lead bus bars are employed, to which the plates are securely joined by a process called lead burning. This process consists in melting a portion of the bus bar and the terminal lug of the plate by a flame of very high temperature, thus fusing each individual plate to the proper bus bar. The plates of adjacent cells are connected to the same bus bar, thus eliminating the necessity of any other connection between the cells.

Initial Charge. As soon as the plates have been installed in the tanks and welded to the bus bars, the cell should be filled with electrolyte having a specific gravity of 1.180 to 1.190 to one-half inch above the tops of the plates and then the charge should be immediately started at about the normal rate. In the case of a battery consisting of cells of large capacity, it is customary to place the electrolyte in the cells as nearly simultaneously as possible rather than to completely fill the cells in consecutive order. When the electrolyte is placed in the cells simultaneously, the charge is started at a very much reduced rate before the cells are completely filled, the rate being increased as the cells are filled, the normal rate of charge being reached when the cells are completely filled. Readings should be taken hourly of the specific gravity and temperature of the electrolyte, voltage of the cells, and amperage of charging current. A record or log should be kept of the specific gravity and voltage of each of the cells of the battery regularly during the life of the battery and it is well to commence this record with the initial charge.

The initial charge should be maintained for at least ten hours after the time when the voltage and specific gravity have reached a maximum. If for any reason it is impractical to continue the initial charge uninterrupted, the first period of charging should be at least from twelve to fifteen hours. However, every effort should be made to have the initial charge continuous, as an interruption tends to increase the time necessary for the initial charge, and if the time be too long between the periods of the initial charge, the efficiency and capacity of the cells are liable to be affected. In case of a large battery, precaution should be taken to insure that the ventilation is exceptionally good, because if it is not good the temperature is liable to increase considerably and thereby cause an undue amount of evaporation from the cells.

The object of the temperature readings taken during the charge is to enable corrections to be made to the specific gravity readings as obtained by the hydrometer, in order that the correct specific gravity may be ascertained. This correction is made by adding .001 specific gravity for each three degrees in temperature above 70° Fahrenheit, or subtracting the same amount for each three degrees below 70° Fahrenheit. At the time the cells begin to gas they should be gone over carefully to see that they gas evenly, and also to detect and remedy early in the charging period any defects which may exist. If there is any doubt in regard to the time at which the cells reach a maximum voltage and specific gravity, the charge should be continued sufficiently long before the last ten hours of the charge are commenced to eliminate any such doubt, as in many cases poor efficiency and low capacity of a cell later in its life may be traced to an insufficient initial charge.

Operation. After the battery has been put in commission the periodic charges should be carefully watched, as excessive charging causes disintegration and decreases the life and capacity of the battery; while, on the other hand, undercharging will result in sulphating of the plates and decrease of capacity, and, if the undercharge be great, will result in a disintegration of the plates. It is, therefore, essential that the battery be charged regularly and at the rate specified for the particular battery in question. In order to minimize the chance of either continuously overcharging or undercharging the battery, the charges are divided into two classes, namely, regular charges and overcharges. The regular charges are the periodic charges for the purpose of restoring the capacity of the battery after discharge. The overcharges, which should occur once a week or once in every two weeks, according to the use of the battery, are for the purpose of insuring that all cells have received their proper charge, for reducing such sulphating as may have occurred on cells undercharged, and for keeping the plates, in general, in a healthy condition. The specific gravity of the electrolyte, the voltage of the battery, and the amount of gasing observed are all indications of the amount of charge which the battery has received and should all be considered when practicable. Either the specific gravity or voltage may be used as the routine method of determining the proper charge, but, however, if the proper charge is determined by the voltage readings, this should be frequently checked by the specific gravity, and *vice versâ*.

During the charging and discharging of a battery the level of the electrolyte in the cells will fall. As the portion of the electrolyte which is evaporated is mainly water, the electrolyte may be readily restored to its normal level by adding distilled water or carefully collected rain water.

Pilot Cell. As the specific gravity of all the cells of a battery, after having once been properly adjusted, will vary the same in all the cells during use, it has been found satisfactory to use one cell, commonly termed the pilot cell, for taking the regular specific gravity readings and only reading the specific gravity of all the cells occasionally or on the overcharge. This cell must be representative of all the cells of the battery, and if the battery is so subdivided in use that several sets of cells are liable to receive different usage, a pilot cell should be selected for each group.

Overcharge. If the battery is charged daily, it should receive an overcharge once a week, or if charged less frequently, an overcharge should be given at least once every two weeks. In making an overcharge this should be done at a constant rate and at a rate specified for the battery. During the overcharge the voltage of the battery and the specific gravity of the pilot cell should be taken every fifteen minutes from the time the gasing begins. The charge should be continued until five consecutive, specific-gravity readings are practically the same. The voltage of the battery should not increase during the last hour of the charge.

As the principal object of the overcharge is to insure that all of the cells have received the proper charge, it must, therefore, be continued long enough to not only properly charge the most efficient cells, but also to properly charge those which are lower in efficiency. The longer the interval between overcharges, the greater will be the variation between the cells and, therefore, it is necessary to continue the overcharge longer when the interval between overcharges is as great as two weeks. Before the overcharge is made the cells should be carefully inspected for short circuits and other abnormal conditions. These inspections may best be made by submerging an electric lamp in the cell, if the cell be of wood, or of allowing it to shine through from the outside, if it be of glass. By this means any foreign material may be readily detected and removed before serious damage is caused. In making these inspections it must be borne in mind that whatever tools or implements are used must be non-metallic and of some insulating material.

Regular Charge. Regular charges are the periodic charges for restoring the capacity of the battery, and should be made as frequently as the use of the battery demands. The voltage of the cells is a good guide for determining when the battery should be recharged. The voltage of a cell should never be allowed to drop below 1.8 volts, and it is usually considered better practice to recharge when the battery has reached 1.9 volts. If a battery is to remain idle for even a short time, it should be left in a completely charged condition.

The regular charges for cells completely equipped with plates should be continued until the specific gravity of the pilot cell has risen to five points below the maximum attained on the preceding overcharge, or, if only partially equipped with plates, until it has risen to three points below the previous maximum. The voltage per cell at this time should be from .05 volts to .1 volts below that obtained on the previous overcharge. At this time all the cells should be gasing, but not as freely as on an overcharge.

Low Cells. An unhealthy condition in a cell usually manifests itself in one of the following ways: Falling off in specific gravity or voltage relative to the rest of the cells, lack of gasing when charged, and color of the plates, either noticeably lighter or darker than those of other cells of the battery. When any of the above conditions are found in a cell, the cell should receive immediate attention, as a delay may mean serious trouble. The cell should be thoroughly inspected to determine if a short-circuit exists, either caused by some foreign substance, by an excess of sediment in the bottom of the tank, or by portions of the plates themselves. If such a condition is found, the cause should be immediately removed and, if the defect has been of short duration, the next overcharge will probably restore it to normal condition. If the defect has existed for some time, it is often necessary to give the cell a separate charge. This may be done by connecting it directly to the charging generator with temporary leads and thus bring it back to its normal condition. It is sometimes found necessary to replace the cell in order to restore the battery to its normal condition.

Sediment. The cells of the battery should be carefully watched to prevent the sediment which collects in the bottom of the jar or tank during use from reaching the bottom of the plates, thereby causing short circuits between them. When the sediment in the cell has reached within one-half inch of the bottom of the plates, it should be removed at once. With small cells using glass jars this can most easily be done directly after an overcharge by carefully drawing off the electrolyte without disturbing the sediment and then removing it from the jar. The plates and electrolyte should be replaced in the jar as soon as convenient to prevent the plates from becoming dry. If the plates are large and in wooden tanks, the sediment can most easily be removed by means of a scoop made especially for the purpose. The preferable time to clean the tanks is just before an overcharge.

Replacing Batteries. There comes a time in the life of nearly every central-office equipment when the storage battery must be completely renewed. This is due to the fact that the life of even the best of storage batteries is not as great as the life of the average switchboard equipment. It may also be due to the necessity for greater capacity than can be secured with the existing battery tanks, usually caused by underestimating the traffic the office will be required to handle. Again, it is sometimes necessary to make extensive alterations in an existing battery, perhaps due to the necessity for changing its location. To change a battery one cell at a time, keeping the others in commission meanwhile, has often been done, but it is always expensive and unsatisfactory and is likely to shorten the life of the battery, due to improper and irregular forming of the plates during the initial charge. The advent of the electric automobile industry has brought with it a convenient means for overcoming this difficulty. Portable storage cells for automobile use are available in almost every locality and may often be rented at small cost. A sufficient number of such cells may be temporarily installed, enough of them being placed in multiple to give the necessary output. By floating a temporary battery so formed across the charging mains and running the generators continuously, a temporary source of current supply may be had at small expense for running the exchange during the period required for alterations. Usually a time of low traffic is chosen for making the changes, such as from Saturday evening to Monday morning. Very large central-office batteries, serving as many as 6,000 lines, have thus been taken out of service and replaced without interfering with the traffic and with the use of but a comparatively few portable cells. One precaution has to be observed in such work, and that is not to subject the portable cells to too great an overcharge, due to the great excess of generator over battery capacity. This is easily avoided by watching the ammeters to see that the input is not in too great excess of the output, and if necessary, by frequently stopping the machines to avoid this.

Power Switchboard. The clearing-house of the telephone power plant is the power board. In most cases, it carries switches, meters, and protective devices.

Switches. The switches most essential are those for opening and closing the motor and the generator circuits of the charging sets and with these usually are associated the starting rheostats of the motors and the field rheostats of the generators. The starting rheostats are adapted to allow resistance to be removed from the motor armature circuit, allowing the armature to gain speed and increase its counter-electromotive force without overheating. The accepted type has means for opening the driving circuit automatically in case its voltage should fall, thus preventing a temporary interruption of driving current from damaging the motor armature on its return to normal voltage.

Meters. The meters usually are voltmeters and ammeters, the former being adapted to read the several voltages of direct currents in the power plant. An important one to be known is the voltage of the generator before beginning a battery charge, so that the generator may not be thrown on the storage battery while generating a voltage less than that of the battery. If this were done, the battery would discharge through the generator armature. The voltmeter enables the voltage of the charging generator to be kept above that of the battery, as the latter rises during charge. It enables the

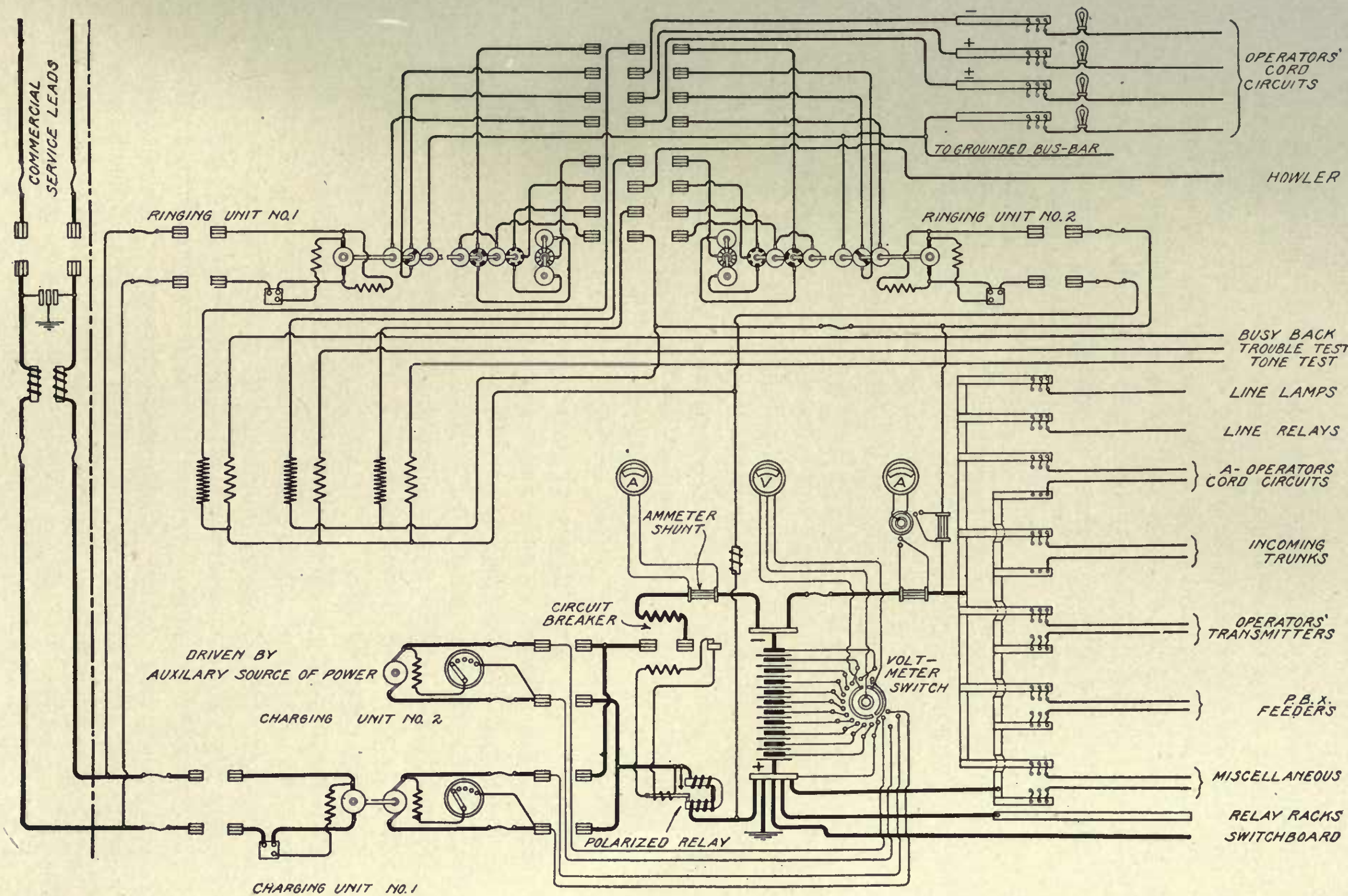


Fig. 417. Power-Plant Circuits

performance of several cells of the battery to be observed. A convenient way is to connect the terminals of the several cells to jacks on the power board and to terminate the voltmeter in a plug.

The ammeter, with suitable connections, enables the battery-charge rate to be kept normal and the battery discharge to be observed. In order to economize power, it is best to charge the battery during the hours of heavy load. The generator output then divides, the switchboard taking what the load requires, the battery receiving the remainder.

In systems requiring the terminal voltage of the equipment to be kept constant within close limits, either it is necessary to use two batteries—never drawing current from a battery during charge—or to provide means of compensating for the rise of voltage while the battery is under charge. The latter is the more modern method and is done either by using fewer cells when the voltage per cell is higher or by inserting counter-electromotive force cells in the discharge leads, opposing the discharge by more or fewer cells as the voltage of the battery is higher or lower. In either method, switches on the power board enable the insertion and removal of the necessary end cells or counter-electromotive force cells.

Protective Devices. The protective devices required on a power board are principally *circuit-breakers* and *fuses.* Circuit-breakers are adapted to open motor and generator circuits when their currents are too great, too small, or in the wrong direction. Fuses are adapted to open circuits when the currents in them are too great. The best type is that in which the operation of the fuses sounds or shows an alarm, or both.

Power-Plant Circuits. The circuit arrangement of central-office power plants is subject to wide variation according to conditions. The type of telephone switchboard equipment, whether magneto or common-battery, automatic or manual, will, of course, largely affect the circuit arrangement of the power plant. Fig. 417 shows a typical example of good practice in this respect for use with a common-battery manual switchboard equipment. Besides showing the switches for handling the various machines and the charge-and-discharge leads from the storage battery, this diagram shows how current from the storage battery is delivered to various parts of the central-office equipment.

CHAPTER XXXIII

HOUSING CENTRAL-OFFICE EQUIPMENT

The Central-Office Building. Proper arrangement of the central-office equipment depends largely upon the design of the central-office building. The problem involved should not be solved by the architect alone. The most careful co-operation between the engineer and the architect is necessary in order that the various parts of the telephonic equipment may be properly related, and that the wires connecting them with each other and with the outside lines be disposed of with due regard to safety, economy, and convenience. So many factors enter into the design of a central-office building that it is impossible to lay down more than the most general rules. The attainment of an ideal is often impossible, because of the fact that the building is usually in congested districts, and its very shape and size must be governed by the lot on which it is built, and by the immediate surroundings. Frequently, also, the building must be used for other purposes than those of a telephone office, so that the several purposes must be considered in its design. Again, old buildings, designed for other purposes, must sometimes be altered to meet the requirements of a telephone office, and this is perhaps the most difficult problem of all.

The exterior of the building is a matter that may be largely decided by the architect and owner after the general character of the building has been determined. One important feature, however, and one that has been overlooked in many cases that we know of, is to so arrange the building that switchboard sections and other bulky portions of the apparatus, which are necessarily assembled at the factory rather than on the site, may be brought into the building without tearing down the walls.

Fire Hazard. The apparatus to be housed in a central-office building often represents a cost running into the hundreds of thousands of dollars; but whether of large or small first cost, it is evident that its destruction might incur a very much greater loss than that represented by its replacement value. In guarding the central-office equipment against destruction by fire or other causes, the telephone company is concerned to a very much greater extent than the mere cost of the physical property; since it is guarding the thing which makes it possible to do business. While the cost of the central office and its contents may be small in comparison with the total investment in outside plant and other portions of the equipment, it is yet true that these larger portions of the investment become useless with the loss of the central office.

There is another consideration, and that is the moral obligation of the operating company to the public. A complete breakdown of telephone service for any considerable period of time in a large city is in the nature of a public calamity.

For these reasons the safeguarding of the central office against damage by fire and water should be in all cases a feature of fundamental importance, and should influence not only the character of the building itself, but in many cases the choice of its location.

Size of Building. It goes without saying that the building must be large enough to accommodate the switchboards and other apparatus that is required to be installed. The requirement does not end here, however. Telephone exchange systems have, with few exceptions, grown very much faster than was expected when they were originally installed. Many buildings have had to be abandoned because outgrown. In planning the building, therefore, the engineer should always have in mind its ultimate requirements. It is not always necessary that the building shall be made large enough at the outset to take care of the ultimate requirements, but where this is not done, the way should be left clear for adding to it when necessity demands.

Strength of Building. The major portion of telephone central-office apparatus, whether automatic or manual, is not of such weight as to demand excessive strength in the floors and walls of buildings. Exceptions to this may be found in the storage battery, in the power machinery, especially where subject to vibration, and in certain cases in the cable runs. After the ultimate size of the equipment has been determined, the engineer and the architect should confer on this point, particularly with reference to the heavier portions of the apparatus, to make sure that adequate strength is provided. The approximate weights of all parts of central-office equipments may readily be ascertained from the manufacturers.

Provision for Employes. In manual offices particularly it has been found to be not only humane, but economical to provide adequate quarters for the employes, both in the operating rooms and places where they actually perform their work, and in the places where they may assemble for recreation and rest. The work of the telephone operator, particularly in large cities, is of such a nature as often to demand frequent periods of rest. This is true not only on account of the nervous strain on the operator, but also on account of the necessity, brought about by the demands of economy, for varying the number of operators in accordance with the traffic load. These features accentuate the demand for proper rooms where recreation, rest, and nourishment may be had.

Provision for Cable Runways. In very small offices no special structural provision need be made in the design of the building itself for the entrance of the outside cables, and for the disposal of the cables and wires leading between various portions of the apparatus. For large offices, however, this must necessarily enter as an important feature in the structure of the building itself. It is important that the cables be arranged systematically and in such a way that they will be protected against injury and at the same time be accessible either for repairs or replacement, or for the addition of new cables to provide for growth. Disorderly arrangement of the wires or cables results in disorder indeed, with increased maintenance cost, uneconomical use of space, inaccessibility, liability to injury, and general unsightliness.

The carrying of cables from the basement to the upper floors or between floors elsewhere must be provided for in a way that will not be wasteful of space, and arrangements must be made for supporting the cables in their vertical runs. In the aggregate their weight may be great, and furthermore each individual cable must be so supported that its sheath will not be subject to undue strain. Another factor which must be considered in vertical cable runs is the guarding against such runs forming natural flues through which flames or heated gases would pass, in the event of even an unimportant fire at their lower ends.

Arrangement of Apparatus in Small Manual Offices. Where a common-battery multiple switchboard equipment is used, at least three principal rooms should be provided—one for the multiple switchboard proper; one for the terminal and power apparatus, including the distributing frames, racks, and power machinery; and the third for the storage battery. These should adjoin each other for purposes of convenience and of economy in wiring.

Floor Plans for Small Manual Offices. As was pointed out, there are several plans of disposing of the main and intermediate distributing frames and the line and cut-off relay racks. The one most practiced is to mount the relay rack alongside the main and intermediate distributing frame in the terminal room. A typical

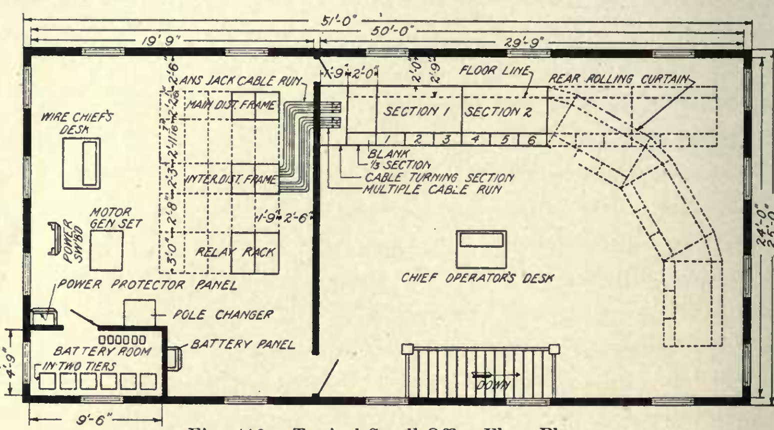


Fig. 418. Typical Small Office Floor Plan

floor plan of such an arrangement for a small office, employing as a maximum five sections of multiple switchboards, is shown in Fig. 418. This is an ideal arrangement well adapted for a rectangular floor space and on that account may often be put into effect. It should be noted that the switchboard grows from left to right, and that alternative arrangements are shown for disposing of those sections beyond the second. The cable turning section through which the multiple and answering jacks are led to the terminal frames is placed as close as possible to the terminal frames. This results in a considerable saving in cable. An interesting feature of this floor plan is the arrangement of unitary sections of main and intermediate frames and relay racks, representing recent practice of the Western Electric Company. The iron work of the three racks is built in sections and these are structurally connected across so that the first section of the main frame, the intermediate frame, and the relay rack form one unit, the structural iron work which ties them together forming the runway for the cables between them. But two of these units, including two sections of each frame, are shown installed, the provision for growth being indicated by dotted lines.

The battery room in this case provides for the disposal of the battery cells in two tiers. This room is merely partitioned off from the distributing or terminal room. Where this is done the partition walls should be plastered on both sides so as to prevent, as far as possible, the entrance of any battery fumes into the apparatus rooms.

The wire chief's desk, as will be noted, is located in such a position as to give easy access from it not only to the distributing frames and relay rack, but to the power apparatus as well.

Combined Main and Intermediate Frames. For use in small exchanges, the Western Electric Company has recently put on the market a combined main and intermediate distributing frame. This is constructed about the same as an ordinary main frame, the protectors being on one side and the line and intermediate frame terminals on the other. The lower half of the terminals on each vertical bay is devoted to the outside line terminals and the upper half is devoted to intermediate frame terminals. This arrangement is indicated in the elevation in Fig. 419. With the use of this combined main and intermediate frame, the floor plan of Fig. 418 may be modified, as shown in Fig. 420.

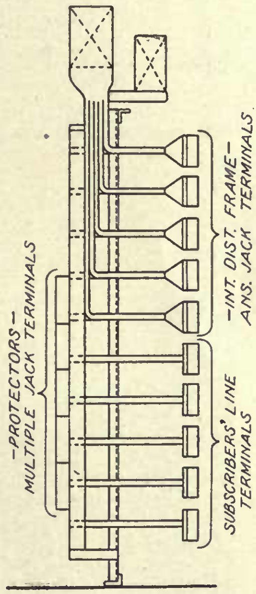


Fig. 419. Combined Main and Intermediate Frames

In Fig. 421 is given an excellent idea of terminal-room apparatus carried out in accordance with the more usual plan of employing separate main and intermediate distributing frames. At the extreme right of this figure the protector side of the main frame is shown.

It will be understood that the line cables terminate on the horizontal terminal strips on the other side of this frame and are connected

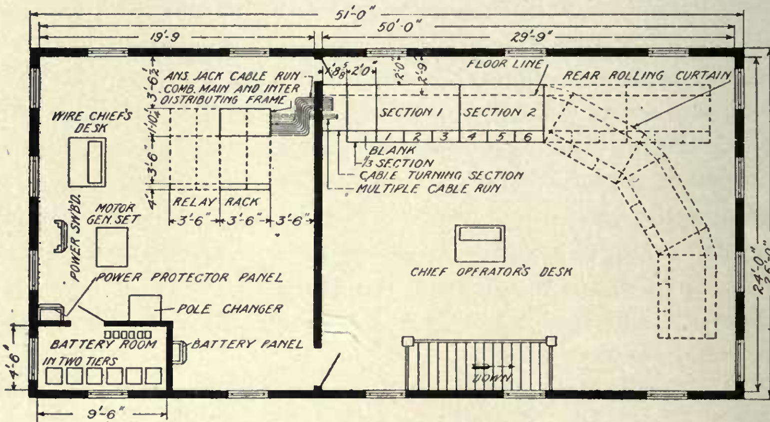


Fig. 420. Small Office Floor Plan

through the horizontal and vertical runways of the frame to the protector terminals. The intermediate frame is shown in the cen-

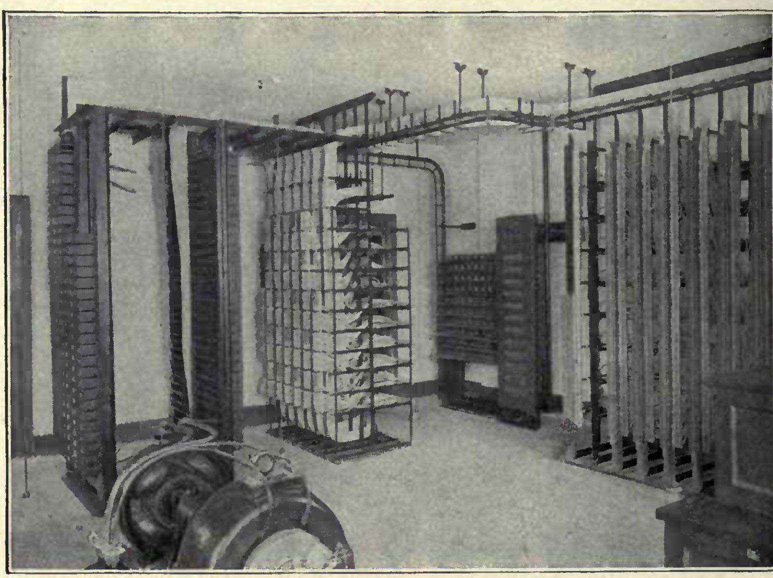


Fig. 421. Terminal Apparatus—Small Office

tral portion of the figure, the side toward the left containing the answering-jack terminals, and the side toward the right the multiple jack terminals, these latter being arranged horizontally. This horizontal and vertical arrangement of the terminals on the main and intermediate distributing frames has been the distinguishing feature between the Bell and Independent practice, the Bell Companies adhering to the horizontal and vertical arrangement, while the Independent Companies have employed the vertical arrangement on both sides. We are informed that in the future the new smaller installations of the Bell Companies will be made largely with the vertical arrangement on both sides. At the left of Fig. 421 is shown the relay rack in two sections of two bays each. This illustration also gives a good idea of the common practice in disposing of the cables between the frames in iron runways just below the ceiling of the terminal room.

Types of Line Circuits. The design of the terminal-room floor plan will depend largely on the arrangement of apparatus in the subscribers' line circuits with respect to the distributing frames and relay racks. The Bell practice in this respect has already been referred to and is illustrated in Fig. 348. In this the line and cut-off relays are permanently associated with the answering jacks and lamps, resulting in the answering-jack equipment being subject to change with respect to the multiple and the line through the jumpers of the intermediate frame. The practice of the Kellogg Company, on the other hand, has been illustrated in Fig. 353, and in this the line and cut-off relays are permanently associated with the multiple and with the line, only the answering jacks and lamps being subject to change through the jumper wires on the intermediate frame. This latter arrangement has led to a very desirable parallel arrangement of the two distributing frames and the relay rack. These are made of equal length so as to correspond bay for bay, and are placed side by side with only enough space between them for the passage of workmen—the relay rack lying between the main and intermediate frames. In this scheme all the multiple and answering-jack cables run from the intermediate distributing frame, and the cabling between the intermediate frame and the relay rack and between the relay rack and the main frame is run straight across from one rack to the other. This results in a great saving of cable within the terminal room, over that arrangement wherein the cabling from one frame to another is necessarily led along the length of the frame to its end and then passes through a single runway to the end of the other frame.

Large Manual Offices. For purposes of illustrating the practice in housing the apparatus in very large offices equipped with manual switchboards, we have chosen the Chelsea office of the New York Telephone Company as an excellent example of modern practice.

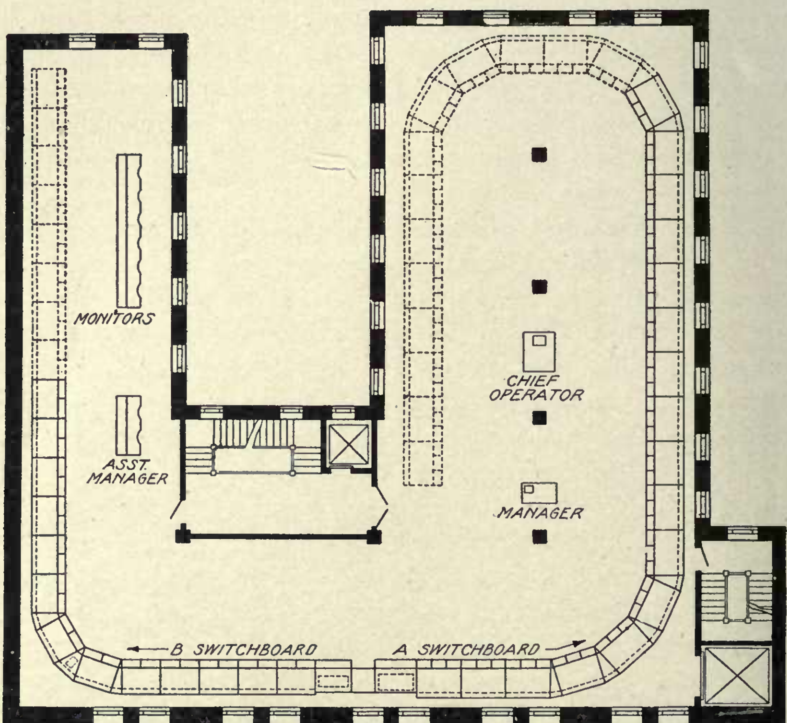


Fig. 422. Floor Plan, Operating Room, Chelsea Office, New York City

The ground plan of the building is U-shaped, in order to provide the necessary light over the rather large floor areas. The plan of the operating floor—the sixth floor of the building—is shown in Fig. 422. As will be seen, this constitutes a single operating room, the *A*-board being located in the right wing and the *B*-board in the left. The point from which both boards grow is near the center of the front of the building, the boards coming together at this point in a common cable turning section. The disposal of the various desks for the manager, chief operator, and monitors is indicated. Those switchboard sections which are shown in full lines are the ones at present installed, the provision for growth being indicated in dotted lines.

The fifth floor is devoted to the terminal room and operators' quarters, the terminal room occupying the left-hand wing and the

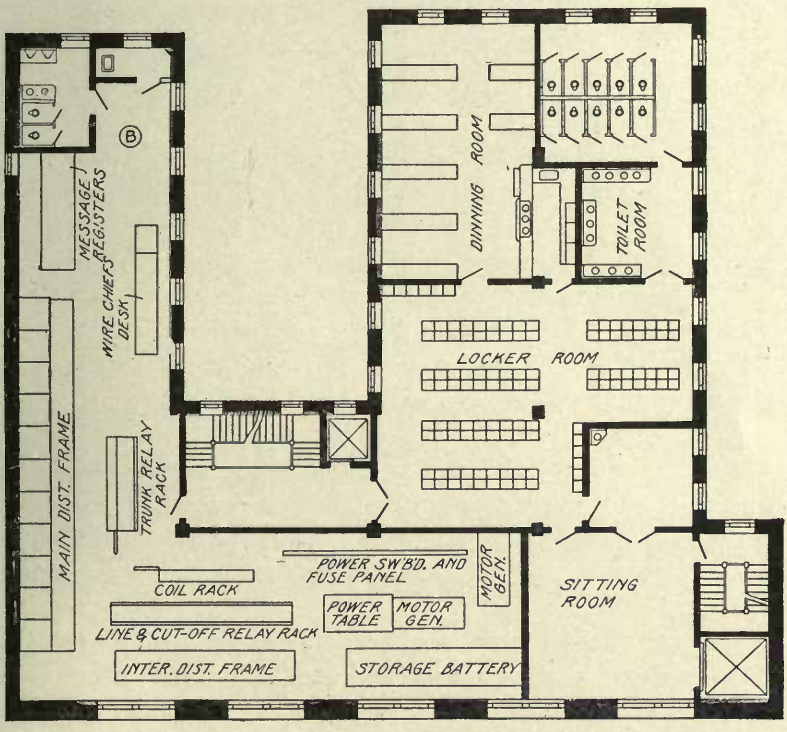


Fig. 423 Terminal Room and Operators' Quarters, Chelsea Office, New York City

major portion of the front of the building, and the operators' quarters the right-hand wing. The line and the trunk cables come up from the basement of the building at the extreme left, being supported directly on the outside wall of the building. Arriving at the fifth floor, they turn horizontally and are led under a false flooring provided with trap doors, to the protector side of the main frame. The disposal of the cables between the various frames will be more readily understood by reference to the following photographs.

A general view of a portion of the *A*-board of the Chelsea office is shown in Fig. 424, this view being taken from a point in the left-hand wing looking toward the front. In Fig. 425 is shown a closer view of a smaller portion of the board. Fig. 426 gives an excellent idea of the rear of this switchboard and of the disposal of the cables and wires. The main mass of cables at the top are those of the multiple. Immediately below these may be seen the outgoing trunk cables. The forms of the answering-jack cables lie below these and are not so readily seen, but the cables leading from these forms are led down to the runway at the bottom of the sections, and thence along the length of the board to the intermediate distributing frame on the floor below. The layer of cables, supported on the iron rack immediately above the answering-jack cable runway, shown at the extreme bottom of the view, are those containing the wires leading from the repeating coils to the cord circuits.

An interesting feature of this board is the provisions for protection against injury by fire and water. On top of the boards throughout their entire length there is laid a heavy tarpaulin curtain with straps terminating in handles hanging down from its edges. These may be seen in Fig. 426 and also in Fig. 425. The idea of this is that if the board is exposed to a water hazard, as in the case of fire, the board may be completely covered, front and rear, with this tarpaulin curtain, by merely pulling the straps. The entire force—both operators and repairmen—is drilled to assure the carrying out of this plan.

The rear of the boards is adapted to be enclosed by wooden curtains, similar to those employed in roll-top desks. These are all raised in the rear view of Fig. 426, the housing for the rolled-up curtain being shown at the extreme top of the sections. In order to guard the multiple cables and the multiple jacks against fire which might originate in the cord-circuit wiring, a heavy asbestos partition is placed immediately above the cord racks and is clearly shown in Fig. 426.

A view of the terminal and power room is shown in Fig. 427. In the upper left-hand corner the cables may be seen in their passage downward from the cable turning section between the *A*- and *B*-boards. The large group of cables shown at the extreme left is the *A*-board multiple. This passes down and then along the horizontal

Fig. 424. Subscribers' Board. Chelsea Office, New York City

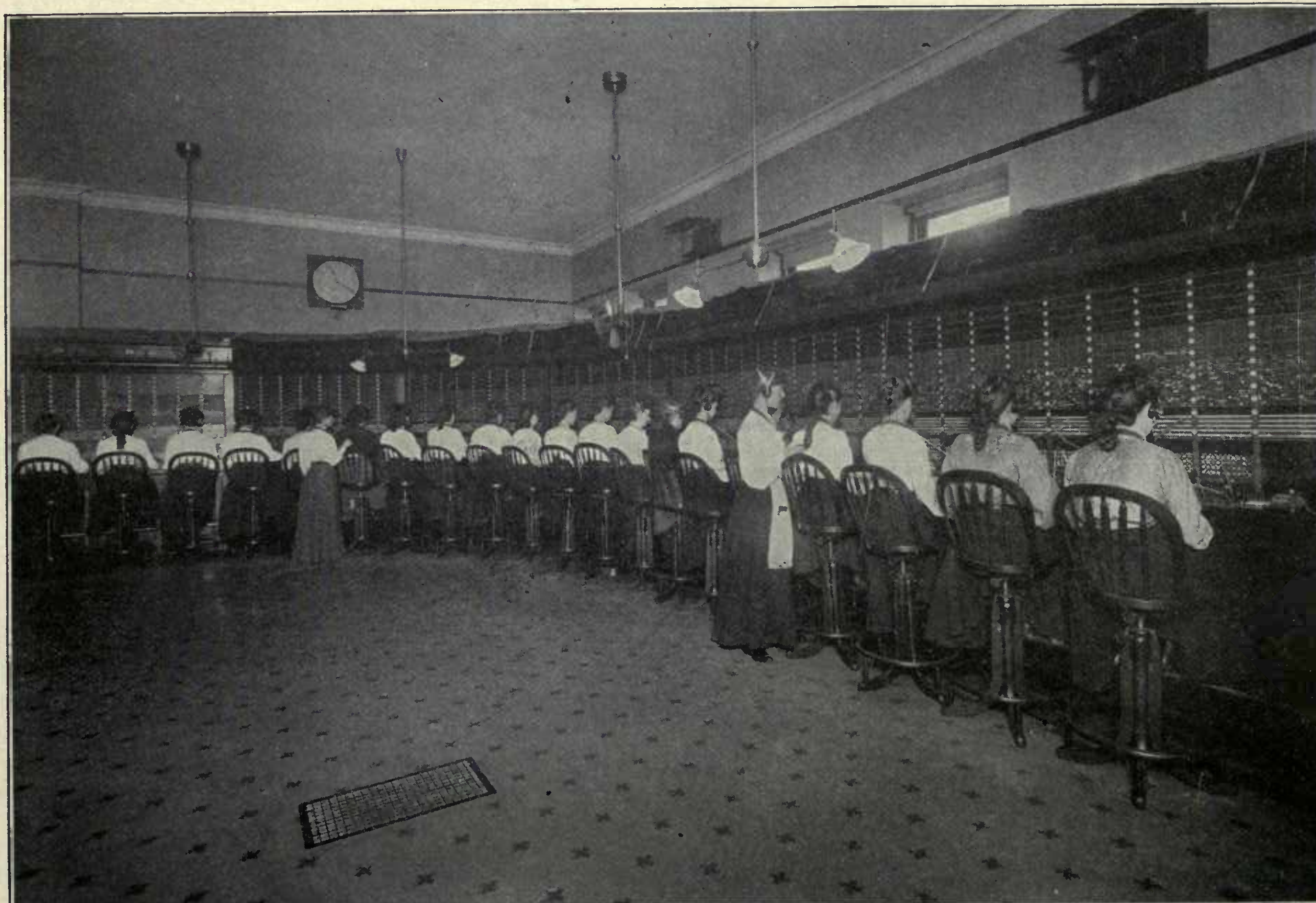


Fig. 425. Subscribers' Board. Chelsea Office, New York City

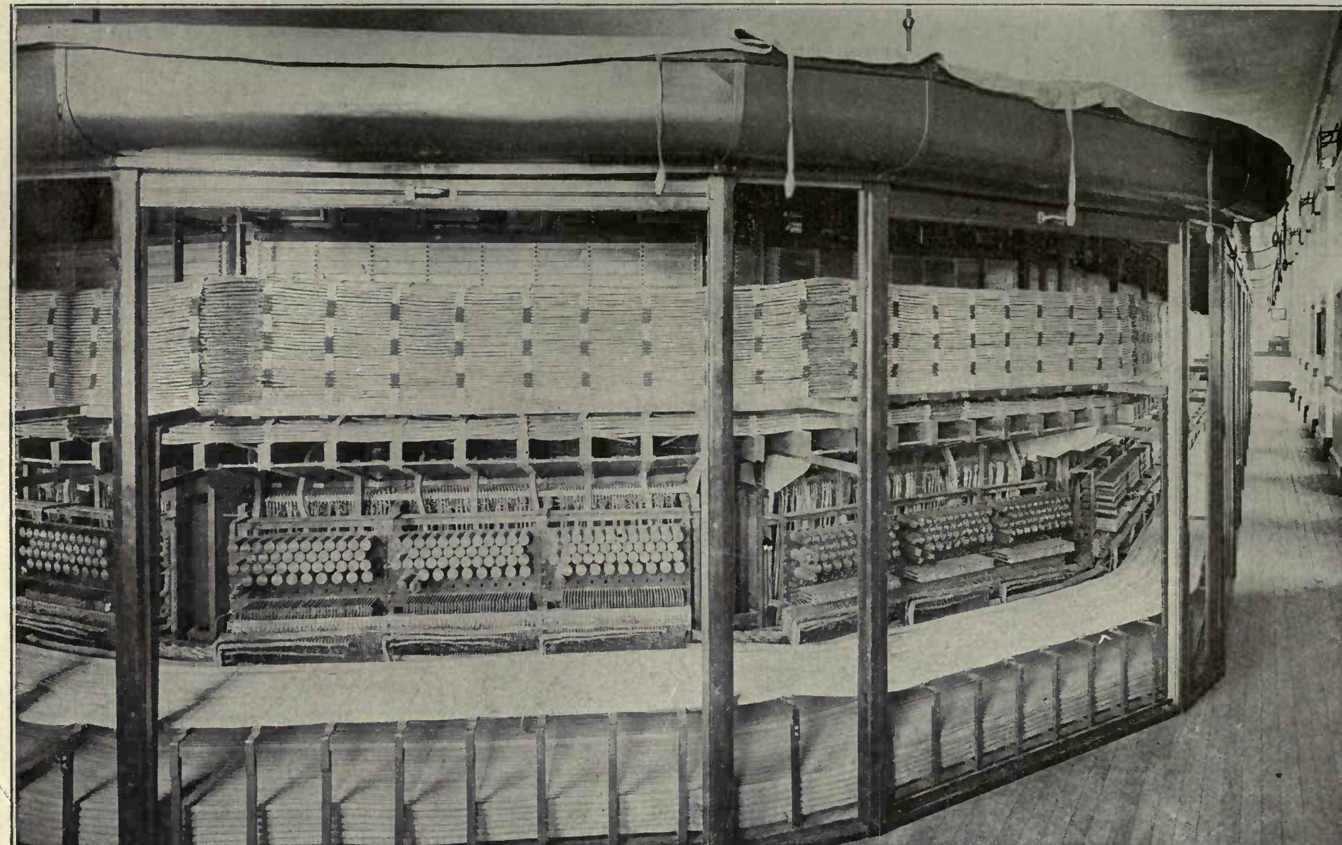


Fig. 426 Rear View Chelsea Switchboard

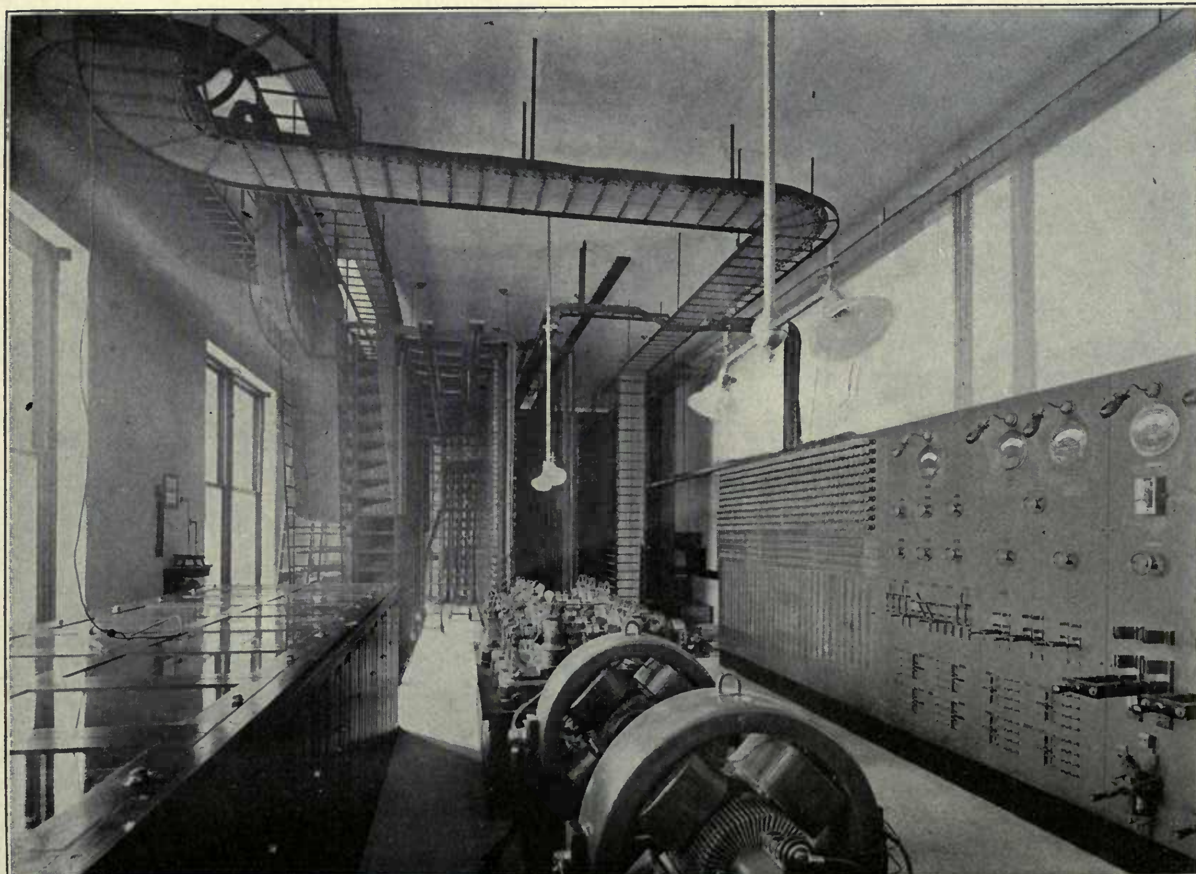


Fig. 427. Terminal and Power Apparatus. Chelsea Office

shelves of the intermediate frame, which is the frame in the extreme left of this view. The *B*-board multiple comes down through another opening in the floor, and as is shown, after passing under the *A*-board multiple joins it in the same vertical run from which it passes to the intermediate frame. The cord-circuit cables lead down through the same opening as that occupied by the *A*-board multiple and pass off to the right-hand one of the racks shown, which contains the repeating coils. The cables leading from the opening in the ceiling to the right-hand side of the intermediate distributing frame are the answering-jack cables, and from the terminals on this side of this frame other cables pass in smaller groups to the relay terminals on the relay racks which lie between the intermediate frame and the coil rack.

The power board is shown at the extreme right. The fuse panel at the left of the power board contains in its lower portion fuses for the battery supply leads to the operator's position and to private-branch exchanges, and in its upper portion lamps and fuses for the ringing generator circuits for the various operators' positions and also for private-branch exchanges.

At the lower left-hand portion of this view is shown the battery cabinet. It is the practice of the New York Telephone Company not to employ separate battery rooms, but to locate its storage batteries directly in the terminal room and to enclose them, as shown, in a wooden cabinet with glass panels, which is ventilated by means of a lead pipe extending to a flue in the wall.

One unit of charging machines, consisting of motor and generator, is shown in the immediate foreground. A duplicate of this unit is employed but is not shown in this view. The various ringing and message register machines are shown beyond the charging machines. Three of these smaller machines are for supplying ringing current and the remainder are for supplying 30-volt direct current for operating the message registers. One of the machines of each set is wound to run from the main storage battery in case of a failure of the general lighting service from which the current for operating is normally drawn.

Another view of the terminal-room apparatus is given in Fig. 428. This is taken from the point marked *B* on the floor plan of Fig. 423. At the right may be seen the message registers on which the calls of the subscribers in this office are counted as a basis for the bills for their service. At the extreme left is shown the private-

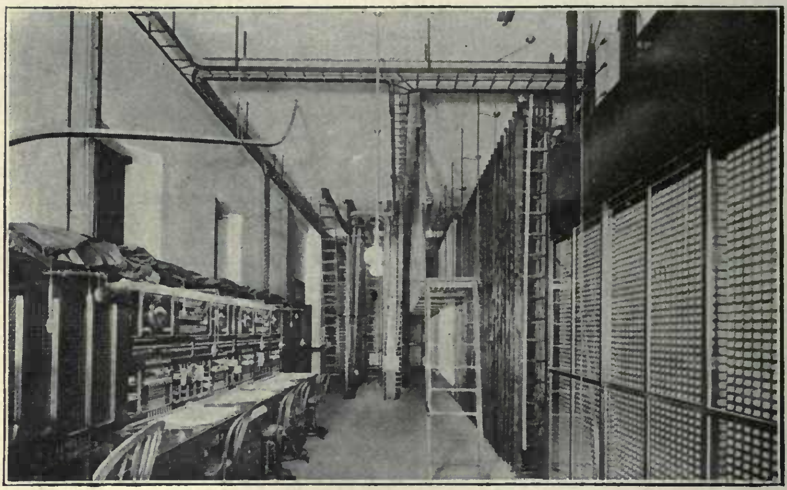


Fig. 428. Terminal Apparatus. Chelsea Office

line test board. Through this board run all of the lines leased for private use, and also all of the order wire or call lines passing through

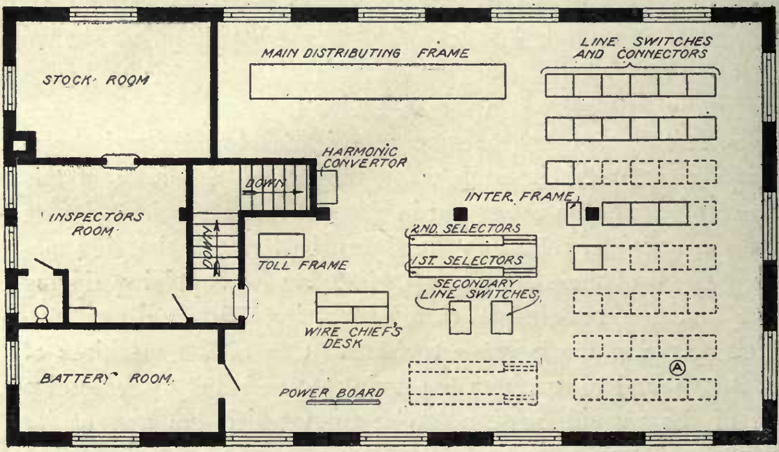


Fig. 429. Floor Plan, Automatic Office, Lansing, Michigan

this office. The purpose of such an arrangement is to facilitate the testing of such line wires. At the right of this private-line test board is shown a four-position wire chief's desk, upon which are provided facilities for making all of the tests inside and outside.

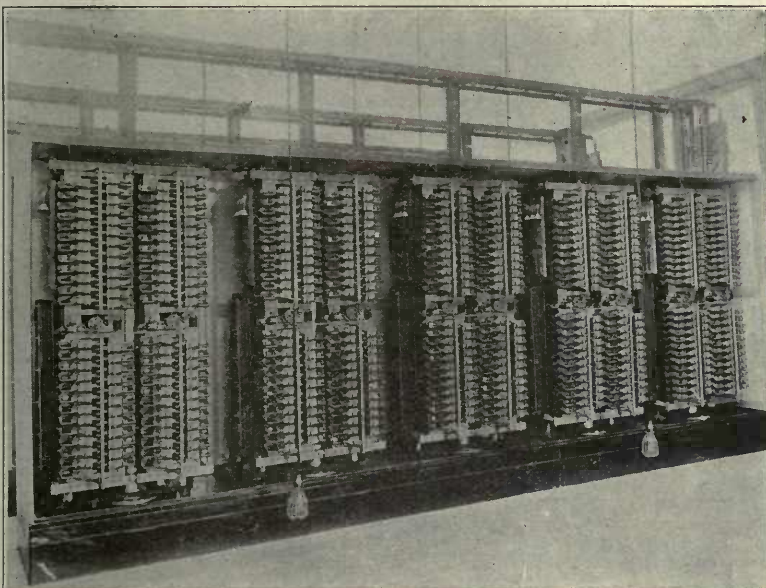


Fig. 430. Line-Switch Units

The main frame is shown at the right of Fig. 428, just to the right of a gallery from which a step-ladder leads. The left-hand side of

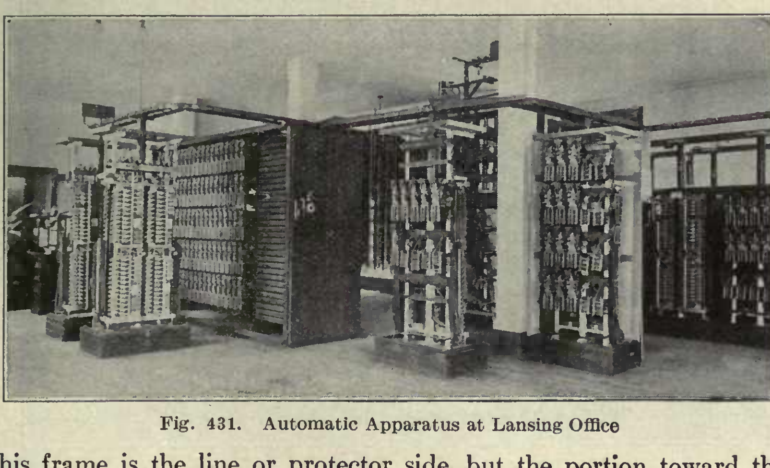


Fig. 431. Automatic Apparatus at Lansing Office

this frame is the line or protector side, but the portion toward the observer in this picture is unequipped. These equipped protector

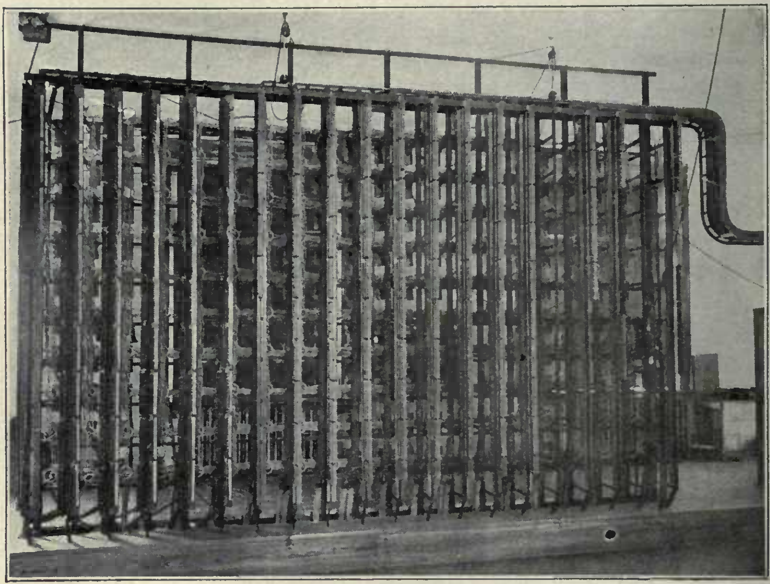


Fig. 432. Main Distributing Frame, Lansing Office

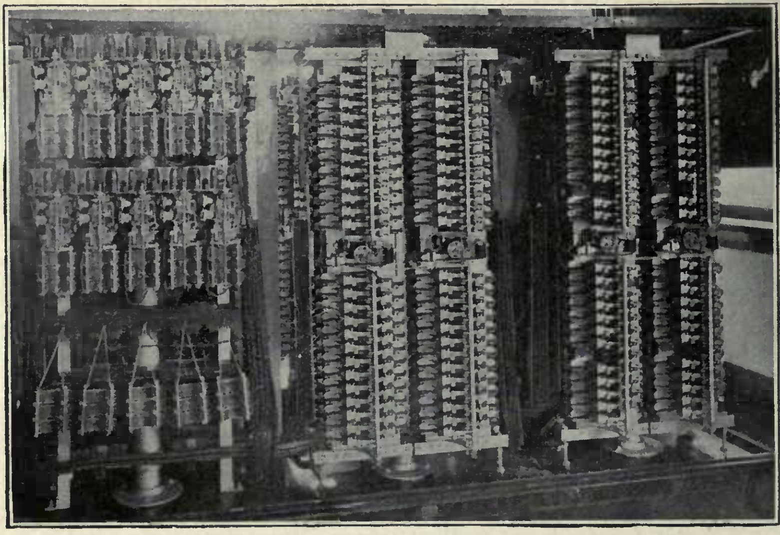


Fig. 433. Line Switches

strips carry 400 pairs of terminals each, and the consequent length of these strips makes necessary the gallery shown, in order that all of them may be readily accessible.

Automatic Offices. There is no great difference in the amount of floor space required in central offices employing automatic and manual equipment. Whatever difference there is, is likely to be in favor of the automatic. The fact that no such rigid requirement

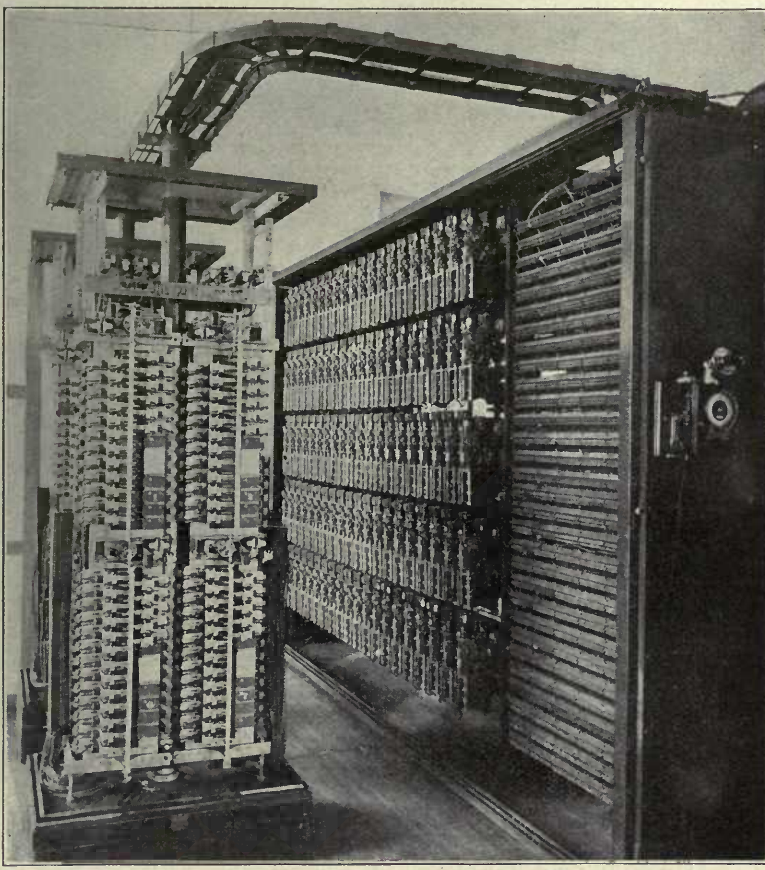


Fig. 434. Secondary Line Switches and First Selectors

exists in the arrangement of automatic apparatus, as that which makes it necessary to place the sections of a multiple board all in one row, makes it possible to utilize the available space more economically with automatic than with manual equipment.

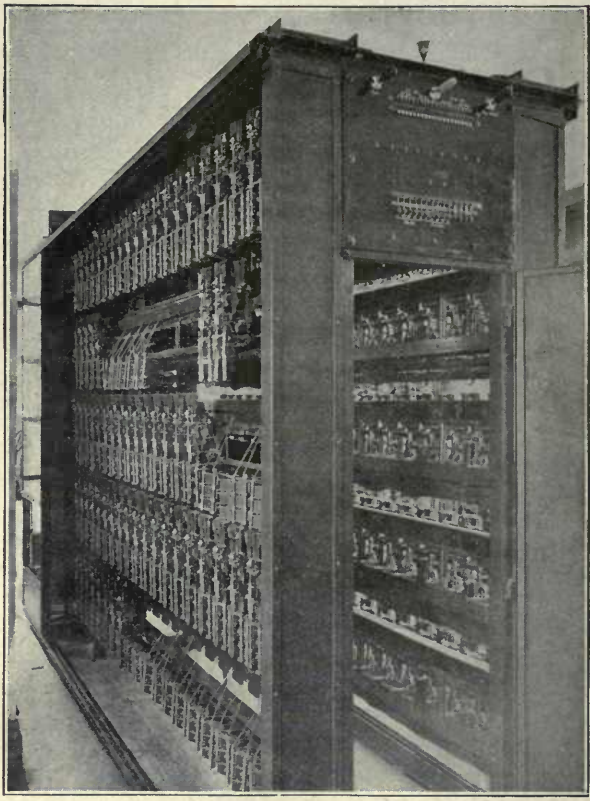


Fig. 435. Second Selectors

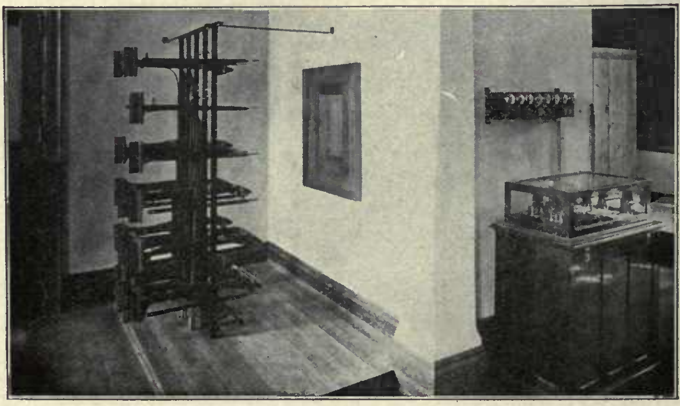


Fig. 436. Toll Distributing Frame and Harmonic Converters

In manual practice it is necessary to place the distributing frames and power apparatus in a separate room from that containing the switchboard, but in an automatic exchange no such necessity exists; in fact, so far as the distributing-frame equipment is concerned, it is considered desirable to have it located in the same room as the automatic switches.

The battery room in an automatic exchange should be entirely separate from the operating room, since the fumes from the battery would be fatal to the proper working of the automatic switches.

Typical Automatic Office. The floor-plan and views of a medium-sized automatic office at Lansing, Michigan, have been chosen as representing typical practice. The floor plan is shown in Fig. 429. The apparatus indicated in full lines represents the present equipment, and that in dotted lines the space that will be required by the expected future equipment.

In Fig. 430 is shown a group of five line-switch units, representing a total of five hundred lines. The length of such a unit is practically fourteen feet and the breadth over all about twenty-two inches.

Fig. 431 shows a general view of this Lansing office, taken from a point of view indicated at *A* on the floor plan of Fig. 429. Fig. 432 shows the main distributing frame, which is of ordinary type; Fig. 433 shows a closer view of some of the primary line switches; Fig. 434 is a view of the secondary line switches and first selectors, the latter being on the right; Fig. 435 is a view of the frequency selectors and second selectors, the former being used in connection with party-line work; and Fig. 436 is a view of the toll distributing frame and harmonic converters for party-line ringing.

A general view of the main switching room in the Grant Avenue office of the Home Telephone Company of San Francisco is given in Fig. 437, this being taken before the work of installation had been fully completed. The present capacity of the equipment is 6,000 and the ultimate 12,000 lines. This office is one of a number of similar ones recently installed for the Home Telephone Company in San Francisco, the combination of which forms by far the largest automatic exchange yet installed. The scope of the plans is such as to enable 125,000 subscribers to be served without any change in the fundamental design, and by means merely of addition in equipment and lines as demanded by the future subscriptions for telephone service.

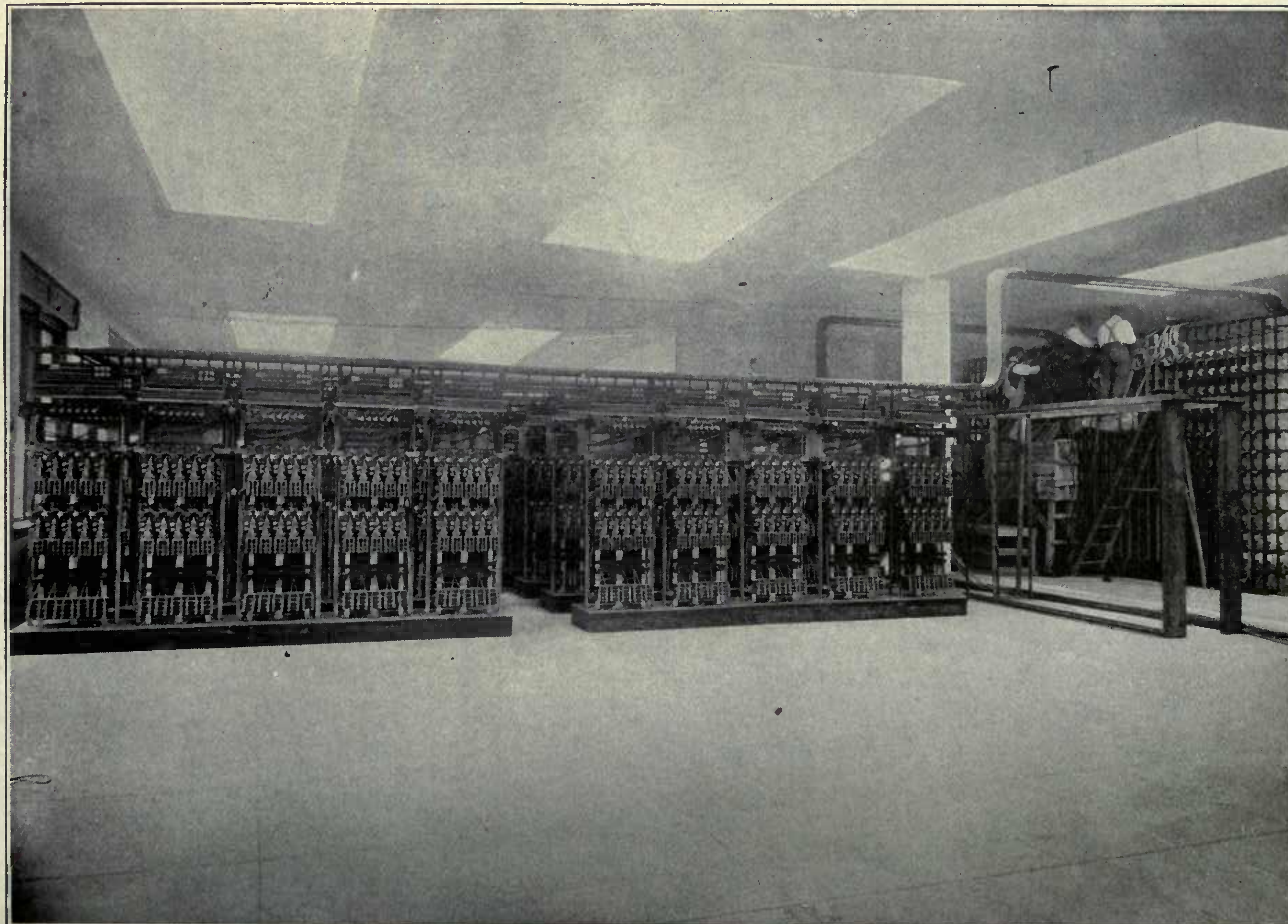


Fig. 437. Grant Avenue Office—San Francisco

CHAPTER XXXIV

PRIVATE BRANCH EXCHANGES

Definitions. A telephone exchange devoted to the purely local uses of a private establishment such as a store, factory, or business office, is a private exchange. If, in addition to being used for such local communication, it serves also for communication with the subscribers of a city exchange, it becomes in effect a branch of the city exchange and, therefore, a private branch exchange. The term "P. B. X." has become a part of the telephone man's vocabulary as an abbreviation for private branch exchange.

Private exchanges for purely local use require no separate treatment as any of the types of switching equipments for interconnecting the lines for communication, that have been or that will be described herein, may be used. The problem becomes a special one, however, when communication must also be had with the subscribers of a public exchange, since then trunking is involved in which the conditions differ materially from those encountered in trunking between the several offices in a multi-office exchange.

For such communication one or more trunk lines are led from the private branch office usually to the nearest central office of the public exchange and such trunks are called private branch-exchange trunks. They are the paths for communication between the private exchange and the public exchange. For establishing the connections either between the local lines themselves or between the local lines and the trunks, and for performing other duties that will be referred to, one or more private branch-exchange operators are employed at the switchboard of the private establishment.

The private branch exchange may operate in conjunction with a manual or an automatic public exchange, but whether manual or automatic, the private exchange is usually manually operated, although it is quite possible to make a private branch exchange that is wholly automatic and will, therefore, involve no operator at all.

Functions of the Private Branch=Exchange Operator. It is possible, as just stated, entirely to dispense with the private branch-exchange operator so far as the mere connection and disconnection of the lines is concerned. But the real function of the private branch-exchange operator is a broader one than this, and it is for this reason that even in connection with automatic public exchanges, operators are desirable at the private branches. The private branch-exchange operator is, as it were, the doorkeeper of the telephone entrance to the private establishment. She is the person first met by the public in entering this telephone door. There is the same reason, therefore, why she should be intelligent, courteous, and obliging as that the ordinary doorkeeper should possess these characteristics.

As to incoming traffic to a private branch exchange, an intelligent operator may do much toward directing the calls to the proper department or person, even though the person calling may have little idea as to whom he desires to reach. This saves the time of the person who makes the call as well as that of the people at the private branch stations, since it prevents their being unnecessarily called.

The functions of the private branch-exchange operator are no less important with respect to outgoing calls. It is the duty of the operator to obtain connections through the city exchange for the private branch subscriber, who merely asks for a certain connection and hangs up his receiver to await her call when she shall have obtained it. This saving of time of busy people by having the branch-exchange operator make their calls for them has one attending disadvantage, which is that the person in the city exchange who is called does not, when he answers his telephone, find the real party with whom he is to converse, but has to wait until that party responds to the private branch operator's call. This is akin to asking a person to call at one's office and then being out when he gets there. This drawback is greatly accentuated where both the parties that are to be involved in the connection are people high in authority in certain establishments at private branch exchanges. Some business houses have made the rule that the private branch operator shall not connect with their lines until she has actually heard the voice of the proper party at the other end. When two subscribers in two different private branch exchanges where this rule is enforced, attempt to get into communication with each other, the possibilities of trouble are obvious.

All that may be said on this matter is that the person who calls another by telephone should extend that person the same courtesies that he would had he called him in person to his office; and that a person who is called by telephone by another should meet him with the same consideration as if he had received a personal call at his office or home. The arbitrary ruling made by some corporations and persons, which results always in the "other fellow's" doing the waiting, is not ethically correct nor is it good policy.

Private Branch Switchboards. Private branch switchboards may be of common-battery or magneto types regardless of whether they work in conjunction with main office equipments having common-battery or magneto equipments. Usually a magneto private branch exchange works in conjunction with a magneto main office, but this is not always true. There are cases where the private branch equipment of modern common-battery type works in conjunction with main office equipment of the magneto type; and in some of these cases the private branch exchange has a much larger number of subscribers than the main office. This is likely to be true in large summer resort hotels located in small and otherwise unimportant rural districts. In one such case within our knowledge the private branch exchange has a larger number of stations than the total census population of the town, resulting in an apparent telephone development considerably greater than one hundred per cent.

Magneto Type. Where both the private branch and the main office equipments are of the magneto type, the private branch requirements are met by a simple magneto switchboard of the requisite size, and the trunking conditions are met by ring-down trunks extending to the main office. In this case the supervision is that of the ordinary clearing-out drop type, the operators working together as best they may.

Common-Battery Type. The cases where the private branch board is of common-battery type and the main office of magneto type are comparatively so few that they need not be treated here. Where they do occur they demand special treatment because the main portion of the traffic over the trunk lines to the city or town central office is likely to be toll traffic through that office over long-distance lines. The principal reason why the equipment of the town offices under such conditions is magneto rather than common battery is that the traffic conditions are those of short season and heavy toll, and common-battery switching equipment at the main office has no especial advantages for toll work.

For small private branch exchanges the desk type of switch board, shown in Fig. 438, is largely used. The operator frequently

Fig. 438. Desk Type, Private Branch Board

has other work to do and the desk is, therefore, a convenience. In larger private exchanges, such as those requiring more than one operator, some form of upright cabinet is employed, and if, as sometimes occurs, the branch exchange is of such size as to demand a multiple board, then the general form of the board does not differ materially from the standard types of multiple board employed in regular central office work. The most common private branch-exchange condition is that of a common-battery branch working into a common-battery main office. In such the main point to be considered is that of supervision of trunk-line connections.

Cord Type. For the larger sizes of branch exchange switchboards, the switching apparatus is practically the same as that of ordinary manual switchboards wherein the connections are made between the various lines by means of pairs of cords and plugs. The private branch-exchange trunk lines usually terminate on the private branch board in jacks but in some cases plug-ended trunks are used.

The line signals may consist in mechanical visual signals or in lamps, the choice between these depending largely on the source

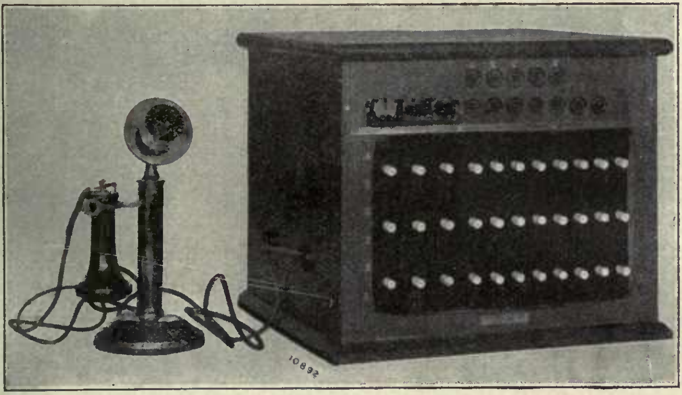


Fig. 439. Key Type, Private Branch Board

of battery supply at the branch exchange, a matter which will be considered later. The trunk-line signals at the private branch board are usually ordinary drops which are thrown when the main-exchange operator rings on the line as she would on an ordinary subscriber's line. Frequently, however, lamp signals are used for this purpose, being operated by locking relays energized when the main-office operator rings or, in some cases, operated at the time when the main-office operator plugs into the trunk-line jack.

Key Type. For small private branch-exchange switchboards, a type employing no cords and plugs has come into great favor during recent years. Instead of connecting the lines by jacks and plugs, they are connected by means of keys closely resembling ordinary ringing and listening keys. Such a switchboard is shown in Fig. 439, this having a capacity of three trunks, seven local lines, and the equivalent of five cord circuits. The drops associated with the three trunks may be seen in the upper left-hand side of the face of the switchboard. Immediately below these in three vertical rows are the keys which are used in connecting the trunks with the "cord circuits" or connecting bus wires. At the right of the drop associated

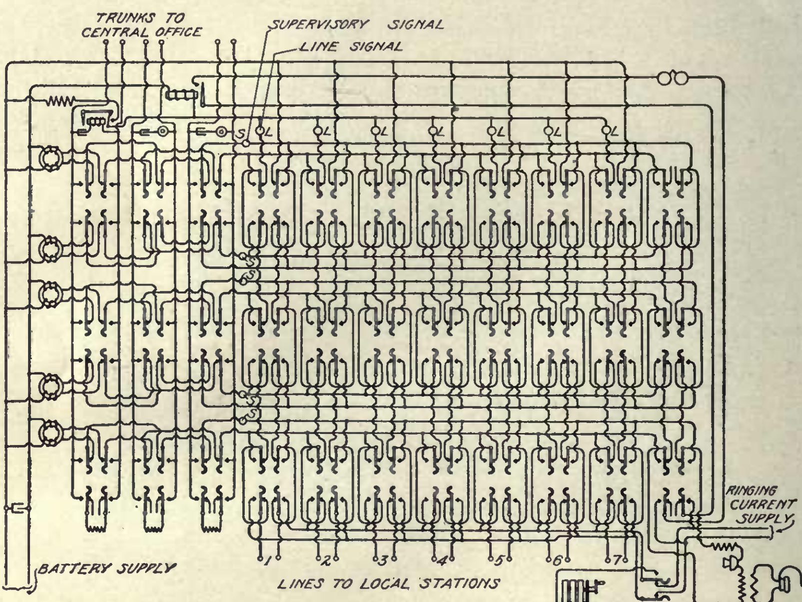


Fig. 440. Circuits, Key-Type Board

with the trunks are seven visual signals, these being the calling signals of the local lines. The seven vertical rows of keys, immediately to the right of the three trunk-line rows, are the line keys. The throwing of any one of these keys and of a trunk-line key in the same horizontal row in the same direction will connect a line with a trunk through the corresponding bus wires, leaving one of the supervisory visual signals, shown at the extreme top of the board, connected with the circuit. The keys in a single row at the right are those by means of which the operator may bridge her talking set across any of the "cord circuits." The circuits of this particular board are shown in Fig. 440. This is equipped for common-battery working, the battery feed wires being shown at the left.

Supervision of Private Branch Connections. At the main office where common-battery equipment is used, the private branch trunks terminate before the *A*-operators exactly in the same way as ordinary subscribers' lines, *i. e.*, each in an answering jack and lamp at one position and in a multiple jack on each section. It goes without saying, therefore, that the handling of a private branch call, either incoming or outgoing, should be done by the *A*-operator in the same manner as a call on an ordinary subscriber's line, and that the supervision of the connection should impose no special duties on the *A*-operator.

There has been much discussion, and no final agreement, as to the proper method of controlling the supervisory lamp at the main office of a cord that is, at the time, connected to a private branch trunk. Three general methods have been practiced:

The first method is to have the private branch subscriber directly control the supervisory lamp at the main office without producing any effect upon the private branch supervisory signal; this latter signal being displayed only after the connection has been taken down at the main office and in response to the withdrawal of the main office plug from the private branch jack. This is good practice so far as the main-office discipline is concerned but it results in a considerable disadvantage to both the city and private branch subscribers in that it is impossible for the private branch subscriber, when connected to the other, to re-signal the private branch operator without the connection being first taken down.

The second method is to have the private branch subscriber control both the supervisory signal at the private branch board and at the main board. This has the disadvantage of bringing both operators in on the circuit when the private branch subscriber signals.

The third method, and one that seems best, is to place the supervisory lamp of the private branch board alone under the control of the private branch subscriber, so that he may attract the attention of the private branch operator without disturbing the supervisory signal at the main office. The supervisory signal at the main office in this case is displayed only when the private branch operator takes down the connection. This practice results in a method of operation at the main office that involves no special action on the part of the

A-operator. She takes down the connection only when the main-office subscriber has hung up his telephone and the private branch subscriber has disconnected from the trunk.

Whatever method is employed, private branch disconnection is usually slow, and for this reason many operating companies instruct the *A*-operators to disconnect on the lighting of the supervisory lamp of the city subscriber.

With Automatic Offices. Private branch exchanges most used in connection with automatic offices employ manual switchboards, with the cord circuits of which is associated a signal transmitting device by which the operator instead of the subscriber may manipulate the automatic apparatus of the public exchange by impulses sent over the private branch-exchange trunk lines. The subscriber's equipment at the private branch stations may be either automatic or manual. Frequently the same private branch exchange will contain both kinds. With the manual sub-station equipment the operation is exactly the same as in a private branch of a manual exchange, except that the private branch operator by means of her dial makes the central-office connection instead of telling the main-office operator to do so for her. With automatic sub-station equipment at the private branch the subscribers, by removing their receivers from their hooks, call the attention of the private branch operator, who may receive their orders and make the desired central-office connection for them, or who may plug their lines through to the central office and allow the subscribers to make the connection themselves with their own dials.

In automatic equipment of the common-battery type, some change always takes place in the calling line at the time the called subscriber answers. In the three-wire system during the time of calling, both wires are of the same polarity with respect to earth. At the time of the answering of the called subscriber, the two wires assume different polarities, one being positive to the other. Such a change is sufficient for the actuation of devices local to the private exchange switchboard and may be interpreted through the calling supervisory signal in such a way as to allow it to glow during calling and not to glow after the called subscriber has answered. In the two-wire automatic system a similar change can be arranged for, with similar advantageous results.

Secrecy. In private exchanges operating in connection with automatic central offices, the secret feature of individual lines may or may not be carried into the private exchange equipment. Some patrons of automatic exchanges set a high value on the absence of any operator in a connection and transact business over such lines which they would not transact at all over manual lines or would not transact in the same way over manual lines. To some such patrons, the presence of a private exchange operator, even though employed and supervised by themselves, seems to be a disadvantage. To meet such a feeling, it is not difficult to arrange the circuits of a private exchange switchboard so that the operator may listen in upon a cord circuit at any time and overhear what is being said upon it *so long as two subscribers are not in communication on that cord circuit.* That is, she may answer a call and may speak to the calling person at any time she wishes until the called person answers. When he does answer and conversation can take place, some device operates to disconnect her listening circuit from the cord circuit, not to be connected again until at least one of the subscribers has hung up his receiver. With private exchange apparatus so arranged, the secrecy of the system is complete.

Battery Supply. There are three available methods of supplying direct current for talking and signaling purposes to private branch exchanges, each of which represents good practice under certain conditions. First, by means of pairs of wires extended from the central-office battery; second, by means of a local storage battery at the private branch exchange charged over wires from the central office; and third, by means of a local storage battery at the private exchange charged from a local source.

The choice of these three methods depends always on the local conditions and it is a desirable feature, to be employed by large operating companies, to have all private branch-exchange switchboards provided with simple convertible features contained within the switchboard for adapting it to any one of these methods of supplying current.

If a direct-current power circuit is available at the private branch exchange, it may be used for charging the local storage battery by inserting mere resistance devices in the charging leads. If the local power circuit carries alternating current, a converting device of some sort must be used and for this purpose, if the exchange is large enough to warrant it, a mercury rectifier is an economical and simple device.

The supply of current to private branch exchanges over wires leading to the central-office battery has the disadvantage of requiring one or several pairs of wires in the cables carrying the trunk wires. No special wires are run, regular pairs in the paper insulated line or trunk cables being admirably suited for the purpose. Sufficient conductivity may be provided by placing several such pairs in multiple.

If the amount of current required by the private exchange warrants it, pairs of charging wires from the central office may be fewer if a battery is charged over them than if they are used direct to the bus bars of the private exchange switchboard. If they are used in the latter way, and this is simpler for reasons of maintenance, some means must be provided to prevent the considerable resistance of the supply wires from introducing cross-talk into the circuit of the private exchange. This is accomplished by bridging a considerable capacity across the supply pairs at the private exchange—ten to twelve microfarads usually suffice. This point has already been referred to and illustrated in connection with Fig. 141.

The number of pairs of wires, or, in other words, the amount of copper in the battery lead between the central office and the private branch-exchange switchboard needs to be properly determined not only to eliminate cross-talk when the proper condensers are used with them, but to furnish the proper difference of potential at the private exchange bus bars, so that the line and supervisory signals will receive the proper current. It is a convenience in installing and maintaining private exchange switchboards of this kind to prepare tables showing the number of pairs of No. 19 gauge and No. 22 gauge wires required for a private exchange at a given distance from its central office and of a probable amount of traffic. The traffic may be expressed in the maximum number of pairs of cords which will be in use at one time. With this fact and the distance, the number of pairs of wires required may be determined.

Ringing Current. The ringing current may be provided in two ways: over pairs of wires from the city-office ringing machines or by means of a local hand generator, or both. A key should enable either of these sources of ringing current to be chosen at will.

Marking of Apparatus. All apparatus should be marked with permanent and clear labels. That private exchange switchboard is best at which an almost uninformed operator could sit and operate it at once. It is not difficult to lay out a scheme of labels which will enable such a board to be operated without any detailed instructions being given.

Desirable Features. The board should contain means of connecting certain of the local private exchange lines to the central-office trunks when the board is unattended. Also, it is desirable that it should contain means whereby any local private exchange line may be connected to the trunk so that its station will act as an ordinary subscriber's station. Whether the trunks of the private exchange lead to a manual or an automatic equipment, it often is desired to connect a local line through in that way, either so that the calling person may make his calls without the knowledge of the private exchange operator, because he wishes to make a large number of calls in succession, or because for some other reason he prefers to transact his business directly with or through the exchange than to entrust it to his operator.

CHAPTER XXXV

INTERCOMMUNICATING SYSTEMS

Definition. The term "intercommunicating" has been given to a specialized type of telephone system wherein the line belonging to each station is extended to each of the other stations, resulting in all lines extending to all stations. Each station is provided with apparatus by means of which the telephone user there may connect his own telephone with the line of the station with which he wishes to communicate, enabling him to signal and talk with the person at that station.

Limitations. The idea is simple. Each person does his own switching directly, and no operator is required. It is easy to see, however, that the system has limitations. The amount of line wire necessary in order to run each line to each station is relatively great, and becomes prohibitive except in exchanges involving a very small number of subscribers, none of which is remote from the others. Again, the amount of switching apparatus required becomes prohibitive for any but a small number of stations. As a result, twenty-five or thirty stations are considered the usual practical limit for intercommunicating systems.

Types. An intercommunicating system may be either magneto or common-battery, according to whether it uses magneto or common-battery telephones. The former is the simpler; the latter is the more generally used.

Simple Magneto System. The schematic circuit arrangement of an excellent form of magneto intercommunicating system is given in Fig. 441. In this, five metallic circuit lines are led to as many stations, an ordinary two-contact open jack being tapped off of each line at each station. A magneto bell of the bridging type is permanently bridged across each line at the station to which that line belongs. The telephone at each station is an ordinary bridging magneto set except that its bell is, in each case, connected to the line as just stated. Each telephone is connected through a flexible cord to a two-contact plug adapted to fit into any of the jacks at the same station.

The operation is almost obvious. If a person at Station *A* desires to call Station *E*, he inserts his plug into the jack of line *E* at his station and turns his generator crank. The bell of Station *E* rings regardless of where the plug of that station may be. The person at Station *E* responds by inserting his own plug in the jack of line *E*, after which the two parties are enabled to converse over a metallic circuit. It makes no difference whether the persons,

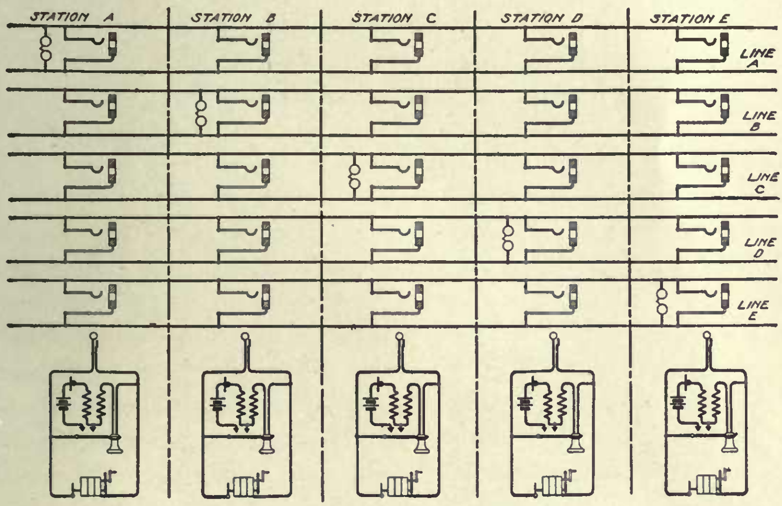


Fig. 441. Magneto Intercommunicating System

after talking, leave these plugs in the jacks or take them out, since the position of the plug does not alter the relation of the bell with the line.

This system has the advantage of great simplicity and of being about as "fool proof" as possible. It is, however, not quite as convenient to use as the later common-battery systems which require no turning of a generator crank.

Common-Battery Systems. In the more popular common-battery systems two general plans of operation are in vogue, one employing a plug and jacks at each station for switching the "home" instrument into circuit with any line, and the other employing merely push buttons for doing the same thing. These may be referred to as the plug type and the push-button type, respectively.

Kellogg Plug Type. The circuits of a plug type of intercom-

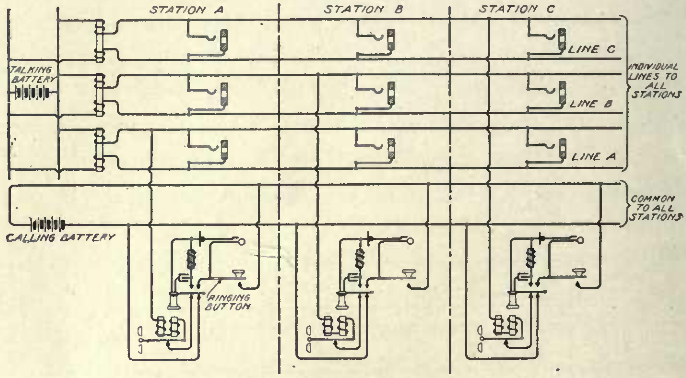


Fig. 442. Plug Type of Common-Battery Intercommunicating System

municating system, as manufactured by the Kellogg Company, are shown in Fig. 442. While only three stations are shown, the method of connecting more will be obvious.

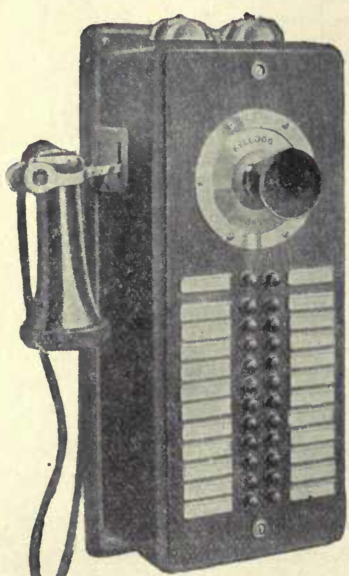


Fig. 443. Push-Button Wall Set

This system requires as many pairs of wires running to all stations as there are stations, and in addition, two common wires for ringing purposes. The talking battery feed is through retardation coils to each line. When all the hooks are down, each call bell is connected between the lower common wire and the tip side of the talking circuit individual to the corresponding station. The ringing buttons at each station are connected between the tip of the plug at that station and the upper common wire. As a result, when a person at one station desires to call another, it is only necessary for him to insert his plug in the jack of the desired station and press his ringing button; the circuit being traced from one pole of the ringing battery through the upper common ringing wire, ringing key of the station making the call, tip of plug, tip conductor of called station's line, bell of called station, and back to the ringing battery through the lower common ringing wire.

Kellogg Push-Button Type. Fig. 443 shows a Kellogg wall-type intercommunicating set employing the push-button method of selecting, and Fig. 444 shows the internal arrangement of this set.

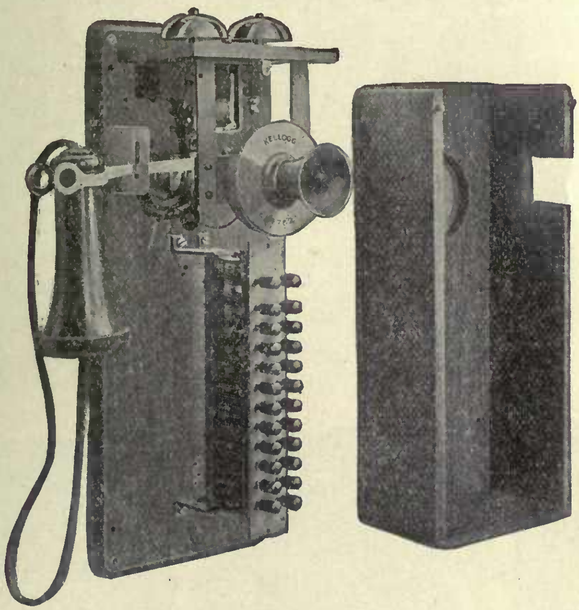


Fig. 444. Push-Button Wall Set

Western Electric System. The method of operation of the push-button key employed in the intercommunicating system of the Western Electric Company is well shown in Fig. 445. When the button is depressed all the way down, as shown in the center cut of Fig. 445, which represents the ringing position of the key, contact is made with the line wires of the station called, and ringing current is placed on the line. When the pressure is released, the button assumes an intermediate position, as shown in the right-hand cut, which represents the talking position of the key and in which the ringing contacts *1* are

2 are open, but contact with the line for talking purposes is maintained. The key is automatically held in this intermediate position by locking plate *3* until this plate is actuated by the operation of another button which releases the key so that it assumes its normal position as shown in the left-hand cut. When a button is depressed to call a

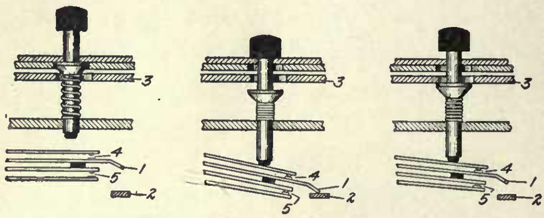


Fig. 445. Push-Button Action, Western Electric System

station, it first connects the called station's line to the calling station through the two pairs of contacts *4* and *5* and then connects the ringing battery to that line by causing the spring *1* to engage the contact *2*. The ringing current then passes through the bell at the called station, through the back contacts of the switch hook at that station, over one side of the line, and through the "way-down" contact *1* of

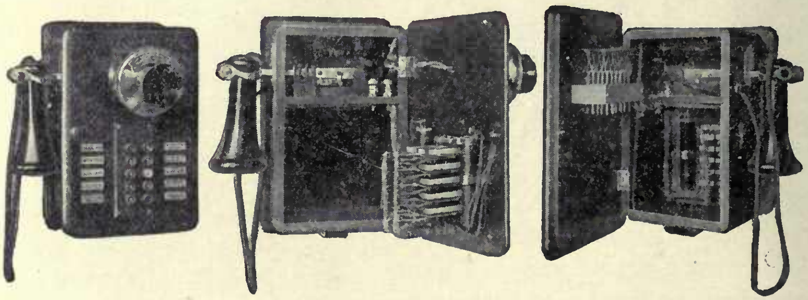


Fig. 446. Push-Button Wall Set

the button at the calling station, thence over the other side of the battery line back to the ringing battery, operating the bell at the called station.

The circuits of the Western Electric system are similar to those of Fig. 442, but adapted, of course, to the push-button arrangement of switches. Two batteries are employed, one for ringing and the other for talking, talking current being fed to the lines through retardation coils to prevent interference or cross-talk from other stations which might be connected together at the same time.

Monarch System. As the making of connections in an intercommunicating system is entirely in the hands of the user, it is desirable that the operation be simple and that carelessness on the part of the user result in as few evil effects as possible. For instance, the leaving of the receiver off its hook will, in many systems, result in such a drain on the battery as to greatly shorten its life.

The system of the Monarch Company has certain distinctive features in this respect. It is of the push-button type and as in the system just discussed, one pressure of the finger on one button clears the station of previous connections, rings the station called, and establishes a talking connection between the caller's telephone and the line desired. In addition to this, the system is designed to eliminate battery waste by so arranging the circuits that the battery current does not flow through either called or calling instrument until a complete connection is made—the calling button down at one station, the home button down at the called station, and both receivers off the hook. It does not hurt the batteries, therefore, if one neglects to hang up his receiver.

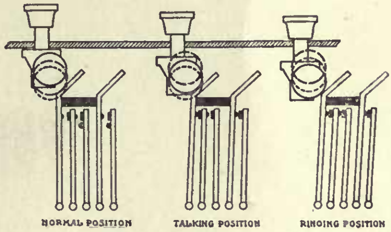


Fig. 447. Push-Button Action, Monarch System

Three views of the wall set of this system are shown in Fig. 446, which illustrates how both the door and the containing box are separately hinged for easy access to the apparatus and connecting rack. As in the Western Electric and Kellogg push-button systems, each push-button key has three positions, as shown in Fig. 447. The first button shows all the springs open, the normal position of the key. The second button is in the half-way or talking position with all the springs, except the ringing spring, in contact. The third button shows the springs all in contact, the condition which exists when ringing a station.

The mechanical construction of the key is shown in Fig. 448. Each button has a separate frame upon which the springs are mounted.

Any one of the frames with its group of contact springs may be removed without interfering with either the electrical or the mechanical operation of the others. This is a convenient feature, making possible the installation of as few stations as are needed at first, and the subsequent addition of buttons as other stations are added.

The restoring feature is a horizontal metal carriage, in construction very much like a ladder—one round pressing against each key frame, due to the tension on the carriage exerted by a single flat spring. The plunger of each button is equipped with a shoulder,

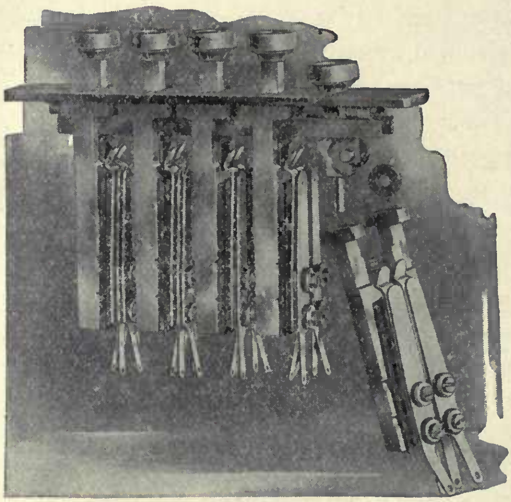


Fig. 448. Push-Button Keys

which normally is above the round of the ladder. When the button is operated, this shoulder presses against a round of the carriage forcing it over far enough so that the shoulder can slip by. The upper surface of the shoulder is flat, and on passing below the pin, allows the carriage to slip back into its normal position and the pin rests on the top of the shoulder holding the plunger down. This position places the talking springs in contact. The ringing springs are open until the plunger is pressed all the way down, then the ringing contact is made. When the pressure is released, the plunger comes back to the half-way or talking position, leaving the ringing contacts open again.

When another button is pressed, the same operation takes place and, by virtue of the carriage being temporarily displaced, the original key is left free to spring back to its normal position.

Each station is provided with a button for each other station and a "home" button. The salient feature of the system is that before a connection may be established, the button at the calling station corresponding to the station called and also the home button of the station called must be depressed, if it is not already down. The home key at any station, when depressed, transposes the sides of the line with respect to the talking apparatus. The home key also has a spring which changes the normal connection of the line at that station from the negative to the positive side of the talking battery.

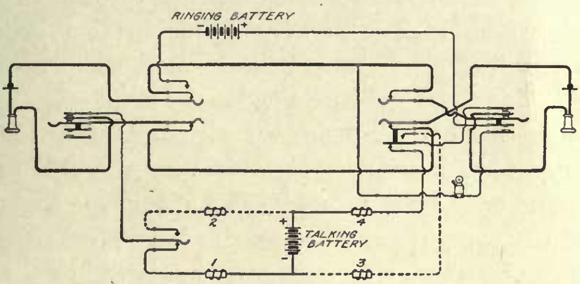


Fig. 449. Monarch Intercommunicating System

Unless, therefore, a connection between two stations is made through the calling key at one station and the home key at the other, no current can flow even though both receivers are off their hooks, because in that case no connection will exist with the positive side of the battery. This relation is shown in Fig. 449, which gives a simplified circuit arrangement for two connected stations.

Referring to Fig. 449, when the station called depresses the home button the talking circuit is then completed after the hook switch is raised. This is because the talking battery is controlled by the home key. Conductors from both the negative and the positive sides of the battery enter this key. In the normal position of the springs, the negative side of the battery is in contact with the master spring in the home key and through these springs the negative battery is applied to all the calling keys, and from there on to the hook switch. When, however, the home button is operated, the spring which carries the negative battery to the home key is opened, and the spring which carries the positive battery is closed. This puts the positive battery on at the hook switch instead of the negative battery, as in its normal condition.

In this system it is seen that a separate pair of line wires is used for each station, and in addition to these, two common pairs are run to all stations, one for ringing and one for talking battery connections.

For Private Branch Exchanges. So far the intercommunicating system has been discussed only with respect to its use in small isolated plants. It has a field of usefulness in connection with city exchange work, as it may be made to serve admirably as a private branch exchange. Where this is done, one or more trunk lines leading to an office of the city exchange are run through the intercommunicating system exactly as a local line in that system, being tapped to a jack or push button at every station. A person at any one of the stations may originate a call to the main office by inserting his plug in the trunk jack, or pushing his trunk push button. Also any station, within hearing or sight of the trunk-line signal from the main office, may answer a main-office call in the same way. In order that the convenience of a private branch exchange may be fully realized, however, it is customary to provide an attendant's station at which is placed the drop or bell on which the incoming trunk signal is received. The duty of this attendant during business hours is to answer trunk calls from the main office and finding out what party is desired, call up the proper station on the intercommunicating system. The party at that station may then connect himself with the trunk.

The practice of the Dean Company, for instance, is as follows in regard to trunking between intercommunicating systems and main offices with common-battery equipment. The attendant's station telephone cabinet contains, besides the push-button keys for local and trunk connections, a drop signal and release key, together with relays in each trunk circuit. The latter are used to hold the trunks until the desired party responds.

The main-exchange trunk lines, besides terminating at the attendant's station, are wired through the complete intercommunicating system so that any intercommunicating telephone can be connected direct to the central office by depressing the trunk key, which is provided with a button of distinctive color. The pressing of the trunk key allows the telephone to take its current from the main-office storage battery and to operate the main-office line and supervisory signals direct, without making it necessary to call on the attendant to set up the connection.

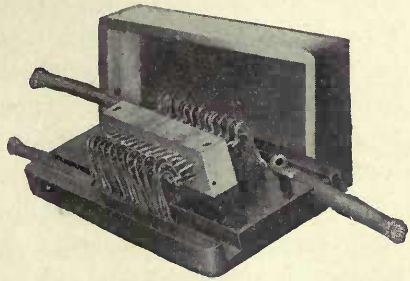


Fig. 450. Junction Box

Incoming calls from the common-battery main office to the intercommunicating system are all handled by the attendant. The main-office operator signals the intercommunicating system by ringing, the same as for a regular subscriber's line. This will operate a drop in the attendant's station cabinet, and through

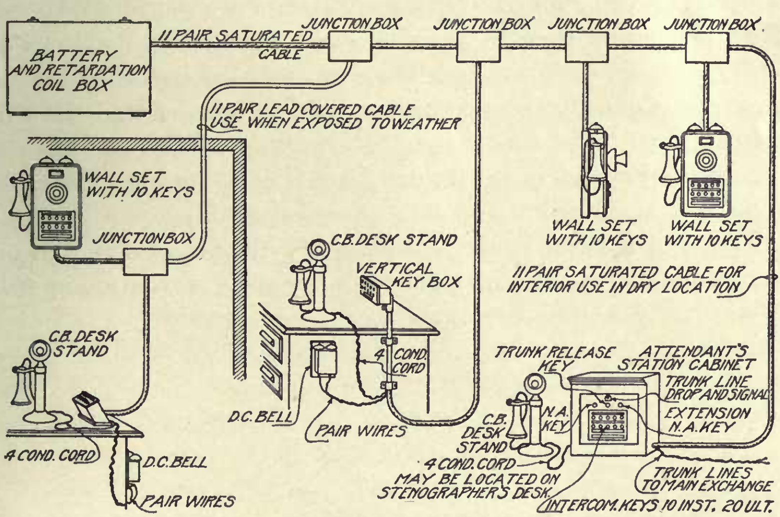


Fig. 451. Typical Arrangement of Intercommunicating System

an armature contact, give a signal on a low-pitched buzzer. This alarm buzzer operates only when the main exchange is ringing and, therefore, does not require that the drop shutter be restored immediately. An extra key may be provided for an extension night-alarm bell, for use where the attendant also does work in a room separate from that containing the attendant's station telephone equipment.

The attendant operator answers the main-line signal by pressing the proper trunk button, as designated by the operated drop on the attendant's cabinet. The answering of the trunk connects a locking relay across the circuit so that the attendant may call the desired party on the intercommunicating system without having to hold the trunk manually. The party desired is then notified which trunk to use and the attendant operator hangs up her receiver, no further attention being necessary on her part.

The trunk-holding relay is automatically released when the desired party (with the telephone receiver off the hook) depresses the proper trunk button, thus clearing the trunk line of all bridged apparatus and making the talking circuit the same as in the regular type of private branch-exchange switchboard.

The most convenient way of installing the wires of an intercommunicating system is to run a cable containing the proper number of pairs to provide for the ultimate number of stations to all the stations, tapping off from the conductors in the cable to the jacks or push buttons at each station. These tap connections are best made by means of junction boxes which contain terminals for all the conductors.

Such a junction box, with the through cable and the tap cable in place, is illustrated in Fig. 450. A schematic lay-out of the various parts of a Dean intercommunicating system, provided with an attendant's station and with trunks to a city office, is given in Fig. 451.

CHAPTER XXXVI

LONG-DISTANCE SWITCHING

Definitions. Telephone messages between communities are called long-distance messages. They are also called toll messages. Almost all long-distance traffic is handled by message-rate (measured-service) methods of charge. All measured-service messages are toll messages, whether they are completed within a given community or between communities. The term "long-distance," therefore, is more descriptive than the term "toll." The subject of local and long-distance measured service is treated exhaustively in a chapter of its own.

Some telephone-exchange operating companies call their own inter-city business "toll," and use the term "long-distance" for business carried between exchanges for them by another company. The distinction seems to be unwarranted.

Use of Repeating Coil. Most long-distance lines are magneto circuits. If they are switched to grounded circuits, repeating coils need to be inserted. Toll switching equipments contain means of inserting repeating coils in the connecting cords when required. Their use reduces the volume of transmitted speech, but often is essential even in connecting metallic circuit lines, as a quiet local metallic circuit may have a ground upon it which will cause excessive noises when a quiet long-distance line is connected to it.

Switching through Local Board. In the simplest form of long-distance switching, the lines terminate in switchboards with local lines and may be connected with each other and with the local lines through the regular cord circuits, if the equipment be of the magneto type. The waystations on such a line are equipped with magneto generators. These waystations may signal each other by bell ringing; the central office may call any waystation by ringing the proper signal and may supervise in a way all traffic on such lines by noting the calls for other stations than the supervising exchange.

Operators' Orders. *By Call Circuits.* Where the long-distance traffic between two communities is large, economy requires that the sending of signals by ringing over the line, waiting for an answer, and then reciting the details of the call, be improved upon. If the traffic is large and the distance between communities small, call circuits are established in the same way as between the switchboards in several manual central offices of an exchange. The long-distance operator handling the originating call passes the necessary details to the distant operator by telephone over the call circuit. Such circuits also are known as order circuits. They are accessible to originating operators at keys and are connected directly and permanently to the telephone sets of receiving operators. One call circuit can handle the orders for a large number of actual conversation circuits. The operator at the receiving end designates the conversation circuit which shall be used, the originating operator following that instruction.

By Telegraph. Where traffic and distance are large, conversation lines cost more than in the case last assumed. It then is of greater importance to use all the possible talking circuits for actual conversations in order that the revenue may be as high as possible. A phantom circuit good enough for call circuit purposes would be good enough for actual commercial messages, therefore, it is customary to furnish such originating and receiving operators with Morse telegraph sets. The lines are obtained by applying composite apparatus to the conversation circuits. Two Morse circuits can be had from each long-distance line without impairing any quality of that line except the ability to ring over it. As one Morse circuit can carry information enough between two operators to enable them to keep many telephone circuits busy, they do not need to ring upon the composited lines, so that nothing is lost while revenue is gained.

Two-Number Calls. In cases where the traffic between communities is large, where the rate is small, and where the conversations are short and more on the general order of local calls, it is usual to handle the switches exactly as local calls are trunked between central offices of the same exchange. That is, the subscriber's operator who answers the call trunks it, by the assistance of a call circuit and an incoming trunk operator. The subscriber's operator records only the numbers of the calling and called subscribers.

No long-distance operators at all assist in these connections. They are known as "two-number calls." The calling subscriber remains at his telephone until the conversation is finished.

Particular-Party-Calls. In cases where the traffic is smaller, and where the rate is large, it is customary to handle the calls through long-distance operators. The ticket records the particular party wished, and the calls are named "particular party" calls. In such connections the calling patron is allowed to hang up his receiver, after his call is recorded, and is called again when his correspondent is found and is ready to talk. This makes *all calls for conversations* outgoing ones. Only recording operators receive calls *from* patrons. Line operators make calls *to* patrons.

Trunking. Long-distance lines entering a city usually terminate in one office only, no matter how many offices the local exchange may have. It is possible to terminate these long-distance lines on a position of the multiple switchboard for local lines. For a variety of reasons this is not practiced except in special cases. The usual method is to terminate them in a special long-distance board and to provide trunk lines from this board to the one or more local switchboards of the exchange. In common-battery systems these toll trunks are so arranged that the called local subscriber receives transmitter current from the office nearest to him, yet is able to show the long-distance operator the position of his switch hook and is able to be called by the long-distance operator without the intervention of the switching operator in the local office, even though two repeating coils may be in the trunk circuit.

Through Ringing. There is a distinct traffic advantage in having the ringing of the subscriber under the control of the long-distance operator. The latter may call for the subscriber by stating her wish over the call circuit associated with the long-distance trunk. The connection having been made by the switching operator, the long-distance operator may withhold ringing the subscriber's bell until all is in readiness for the conversation.

High-Voltage Toll Trunks. In some systems, the long-distance trunks are further specialized by being enabled to furnish transmitter current to subscribers at a higher voltage than is used in local conversations. With a given construction of transmitters there is a critical maximum current which can be carried by the granular carbon of the instrument without excessive heating, consequent noises, and permanent damage. The shortest lines and the longest lines of an exchange district being served by a source of current common to all, the standard potential of this source must be such as to give the longest lines current enough without giving the shortest lines too much. The very longest local lines, however, do not receive current enough from the standard potential to give maximum efficiency when talking over long distances, though they get enough for local conversations. By providing a battery with a voltage twice that used for local conversations and connecting it into the current supply element of the toll trunk through non-inductive resistances, not too much current may be given to the shortest lines and considerably more than normal current to the longest lines.

Ticket Passing. When only one operator is necessary in a town, her duty being to switch both local and long-distance lines, she may write her own tickets and execute them entire. In larger communities with larger long-distance traffic, the duties need to be specialized. The subscribers' wants as to long-distance connections are given by themselves to recording long-distance operators, who write them on tickets and pass these to operators who get the parties together. The problem of ticket-passing becomes important and many mechanical carriers have been tried, culminating in the system which utilizes vacuum tubes. This is in some ways similar to vacuum or compressed-air tube systems for carrying cash in retail stores. The ticket is carried, however, without any enclosing case and the tubes are flat instead of round, *i. e.*, they are rectangular in section. By suitable means a vacuum is maintained in a large common tube having a tap to a box-like valve at each line operator's position. A ticket tube connects this valve with a distributing table at or near which the tickets are written. The tickets are of uniform size and are so made as to enable a flap to be bent up easily along one edge. The distributing operator has merely to insert the ticket, bent edge foremost, in the open end of the tube, whereupon the air pressure behind it will drive it through to its destination, near by or far away. The tickets travel thirty feet a second. The tube may be bent into almost any required form. The ticket, on arriving at a line operator's position, slides between two springs, breaking a shunt around a relay and allowing the latter to light the lamp.

Waystations. Waystations on long-distance lines may be equipped in several ways. Most of them have magneto sets and can ring each other. Some are equipped with common-battery sets and get all current for signaling and transmission from a terminal central office. In the latter case, there is the advantage that the ringers are in series with condensers, assisting greatly in tests for fault locations. Such tests are hindered by the presence of ringer bridges across the line, as in magneto practice. Condensers can be inserted in series with ringers of magneto sets if the testing advantage is valued highly enough. A disadvantage of the use of common-battery sets in waystations on long-distance lines is the lessened transmission volume of the stations farthest from the current source.

Center Checking. An operating advantage of common-battery sets on long-distance lines is that all calls are forced to be answered by the terminal station. Waystations can not call each other, as they have no calling means. With magneto sets, waystation agents sometimes call each other direct and neglect to record the call and to remit its price. When they can not call each other direct, the revenues of the company increase.

A traffic method which requires all calls from waystations to be made to a central switching office is called a center-checking system. It is so called because all checking for stations so switched is done at the central point instead of each waystation keeping its own records of calls sent and received. In such practice it is usual to bill each station once a month for the messages it sent. Where center checking is not practiced, the agent makes a report and sends a remittance. Center checking comes about naturally for waystations having no ringing equipment.

Center checking originated long before the invention of common-battery systems. It requires merely that no waystation shall have a generator which can ring a bell. The method most widely used is to equip the waystations with magneto generators which produce direct currents only; such a generator cannot operate a polarized ringer. It is not usual to produce the direct current by actually rectifying the alternating current, but merely by omitting half the impulses, sending to the line only alternate half-cycles of the current generated. Any drop or relay adapted to respond to regular ringing current will respond to this modified form of generator.

CHAPTER XXXVII

TELEPHONE TRAFFIC

The term "traffic," with reference to telephone service, has come to mean the gross transaction of communication between telephone users. This traffic may be expressed in whatever terms are found convenient for the particular phase considered.

Unit of Traffic. With reference to payment for local telephone service, the conversation is the unit of traffic. In the daily operations of telephone systems there are fewer conversations than there are connections and fewer connections than there are calls, because lines are found busy and all calls to subscribers are not answered.

For these reasons, in traffic inquiries which have to do with the amount of business which subscribers attempt to transact, the total traffic in a given time usually is considered as so many calls originated by the subscribers in the community. From this condition arises the term "originating calls."

For the reason that the purpose of the switching equipment in a central office is to make connections, the abilities of operators and of equipments frequently are measured in terms of connections per hour or per other unit of time.

For the reason that in charging for service all unavailing calls are omitted, the conversation is the unit of traffic.

Traffic Variations. Telephone-exchange traffic is subject to such general variations as are noted in the way a compass needle points north, the migrations of birds, the blowing of the trade winds, and other natural phenomena. There are variations in traffic which occur each day, others which change with the seasons, and still others which are related to holidays and other special commercial and social events. For instance, the day before Thanksgiving Day, in many regions, is the busiest telephone traffic day in the year.

The daily variations in telephone traffic are closely related to commercial activities and certain general features of this daily variation are common to all telephone systems everywhere. Fig. 452 is a typical graphic record of the traffic of a telephone exchange and represents what happens in almost every town or city. The total calls in this figure are not given as absolute units but would vary to adapt the figure to a particular case. The figure shows principally that the traffic in the night is light; that it rises to its maximum height somewhere between 10 o'clock A. M. and noon; that though it is never as high again during that day, the afternoon peak is over 80 per cent as great; and that two minor peaks appear about the dinner hour and after evening entertainments.

Busy-Hour Ratio. If the story told by Fig. 452 were to be turned into a table of calls per hour, the busiest hour of the day would be

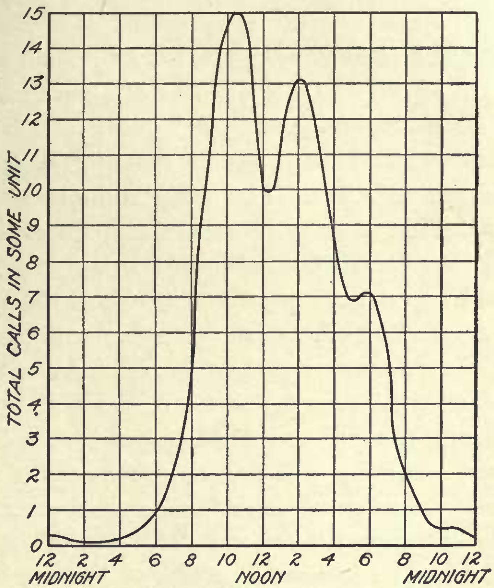


Fig. 452. Load Curve

found to correspond to the highest portion of the figure, and in that busiest hour of the day, if a number of selected days were to be compared, would be found a very constant traffic. The number of calls made, or the number of connections completed, in that particular hour, day by day, would be found to be much the same. The ratio of the number of units in that hour to the number of units in that entire day would be found to be practically the same ratio day by day. This ratio of busy hour to total day would be found to be much more nearly constant than the gross number of calls per hour or per day.

In a large, busy city, about one-eighth of the total daily calls are in some one hour; in a smaller, less active city, probably one-tenth are so congested. This is reasonable when one remembers that in the larger city the active business of the day begins later and ends earlier.

Importance of Traffic Study. A knowledge of the amount of traffic in an exchange, and its distribution as to time and as to the divisions of the exchange, is important for a number of reasons. Traffic knowledge is essential in order that the equipment may be designed and placed in the proper way and the total load distributed properly on that apparatus and its operators.

For example, in an office equipped with a manual multiple switchboard, the length of the switchboard is governed entirely by the number of operators who must work before it. It is mechanically possible to make a switchboard for ten thousand lines only 15 feet long, seating seven operators. The entire multiple of ten thousand lines could appear three times in such a switchboard. The seven operators could not handle the traffic we know would be originated by ten thousand lines, with any present system of charging for service. Even a rough knowledge of the probable traffic would enable us to approximate the number of operators needed and to equip each position, not only with access to the ten thousand lines to be called, but also with just enough keyboard equipment, serving as tools, and just enough answering jacks, serving as means of bringing the traffic to her. It is foreknowledge of traffic which enables a switchboard to fit the task it is to perform.

Rates of Calling. The rates of calling of different kinds of lines vary. The lines of business stations originate more calls than do the lines of residences. Some kinds of business originate more calls than others. Some kinds of business have a higher rate of calling in one season than in others. Flat-rate lines originate more calls than do message-rate lines. When a line changes from a flat rate to a message rate, the number of originating calls per day decreases. An operator's position, handling message-rate lines only, can serve more lines than if all of them were at flat rates. The number of message-rate or coin-prepayment lines which an operator's position can care for depends not only on the traffic but on the method of charging for service, whether by tickets or meters and upon the kind of meters; or it depends on the method of collecting the coins. In some regions, the rate of calling, on the introduction of a complete measured-service plan, has been reduced to one-fourth of what it was on the flat-rate plan.

In manual switchboards of early types, wherein the position of the subscriber's answering jack was fixed by his telephone number, the inequality of traffic became a serious problem. Most of the subscribers who first installed telephones when the exchange was small, retained their telephones and numbers; as their use of the telephone grew with their business, it was customary to find the positions answering the lower numbers much more busy than the positions answering the higher numbers, the latter belonging to later and usually less active business places.

Functions of Intermediate Distributing Frame. The intermediate distributing board was invented to meet these conditions of unequal traffic upon lines and of variations in traffic with changes of seasons and of charges. The intermediate distributing board enables a line to retain its number and its position in the multiple, but to keep its answering jack and lamp signal in any desired position. If a flat-rate subscriber changes to a message rate, his line may be moved to a message-rate position and be answered, in company with others like it, by an operator serving many more lines than she could serve if all of them were flat rate.

Methods of Traffic Study. The best way to learn traffic facts for the purposes of designing and operating equipment is to conduct systematic series of observations in all exchanges; to record them in company with all related facts; and to compare them from time to time, recording the results of the comparisons. Then when it is required to solve a new problem, the traffic data will enable the probable future conditions to be known with as great exactness as is possible in studies with relation to transportation or any other human activity.

There are three general ways of observing traffic. A record of originating calls is known as a "peg count," because the counting formerly was done by moving a peg from place to place in a series of

TABLE XIII

Calling Rates

Kind of Service	Calls per Day with Different Methods of Charge	
	Flat Rate	Message Rate
Residence	8	4
Business	12 to 20	8 to 14
Private Exchange Trunk	40	25
Hotel Exchange Trunk	50	30
Apartment House Trunk	30	18

holes. The simplest exact way is to provide each operator with a small mechanical counter, the key of which she can depress once for each call to be counted. A second way is to determine a ratio which exists, for the particular time and place, between the number of calls in a given period and the average number of cord circuits in use. Knowing this ratio, the cord circuits can be counted, the ratio applied, and the probable total known. The third method, which is applicable to offices having service meters on all lines, is to associate one master meter per position or group of lines with all the meters of that position or group, so that each time any service meter of that position is operated, the master meter will count one unit. This method applies to either manual or automatic equipments.

Representative Traffic Data. For purposes of comparison, the following are representative facts as to certain traffic conditions.

Calling Rates. The number of calls originated per day by different kinds of lines with different methods of charge are shown in Table XIII.

Operators' Loads. The abilities of subscribers' operators to switch these calls depend on the type of equipment used, on the kind of management exercised, and on the individual skill of operators. With manual multiple equipment of the common-battery type, and good management, the numbers of originating calls per busy hour given in Table XIV can be handled by an average operator. The number of calls per operator per busy hour depends upon the amount of trunking to other offices which that operator is required to do. In a small city, for example, where all the lines are handled by one switchboard, there is no local switching problem except to complete

TABLE XIV

Effect of Out-Trunking on Operator's Capacity

Per Cent Originating Calls Trunked to Other Offices	Capacity of Subscribers' Operator's Position in Calls per Busy Hour
0	240
10	230
30	200
50	185
75	170
90	165

the connection in the multiple before each position. In a large city, where wire economy and mechanical considerations compel the lines to be handled by a number of offices with manual equipment, some portion of the total originating load of each office must be trunked to others. Table XIV shows that an increase of 90 per cent in the amount of out-trunking has decreased the operator's ability to less than 70 per cent of the possible maximum.

Trunking Factor. In providing the system of trunks interconnecting the offices, whether the equipment be manual or automatic, it is essential to know not only how much traffic originates in each office, but how much of it will be trunked to each other office and how many trunks will be required. An interesting phase of telephone traffic studies is that it is possible to determine in advance the amount of traffic which can be completed directly in the multiple of that office and how much must be trunked elsewhere. Theoretical considerations would indicate that if the local multiple contains one-eighth of the total lines of the city, one-eighth of the calls originating in that office could be completed locally and seven-eighths would be trunked out. In almost all cases, however, it is found that more than the theoretical percentage of originating calls are for the neighborhood of that office and can be completed in the multiple. This results in the determination of a factor by which the theoretical out-trunking can be multiplied to determine the probable real out-trunking. In most cases, the ratio of actual to theoretical out-trunking is 75 per cent, or approximately that. In special cases, it may be far from 75 per cent.

Trunk Efficiency. The capacities of trunks vary with their methods of operation and with the number of trunks in a group.

TABLE XV

Messages per Trunk in Manual System

Number of Trunks in Group, Manual System	Messages per Trunk per Busy Hour
5	7
10	9
20	12
40	15
60	18

For example, in the manual system where trunk operators in distant offices are instructed over call circuits and make disconnections in response to lamp signals, such an incoming trunk operator can complete from 250 to 500 connections per busy hour. The actual ability depends upon the number of distant offices served by that operator and upon the amount of work she has to perform on each call.

The number of messages which can be handled by one trunk in the busy hour will depend upon the number of trunks in the group and upon the system employed. It appears that the ability of trunks in this regard is higher in the automatic system than in the manual system. For the latter, Table XV gives representative facts.

Some of the reasons for the higher efficiencies of trunks in the automatic system are not well defined, but unquestionably exist. They have to do partly with the prompter answering observable in automatic systems. The operation of calling being simple, a called subscriber seems to fear that unless he answers promptly the calling party will disconnect and perhaps may call a competitor. The introduction of machine-ringing on automatic lines, where existing in competition with manual ringing on manual lines, seems to encourage subscribers to answer even more promptly. The length of conversation in automatic systems seems to be shorter than in manual systems. Still more important, disconnection in automatic systems is instantaneous during all hours, whereas in manual systems it is less prompt in the busiest and least busy hours than in the hours of intermediate congestion. The practical results of trunk efficiencies in automatic systems are given in Table XVI.

Toll Traffic. Toll or long-distance traffic follows the general laws of local or exchange traffic. Conversations are of greater

TABLE XVI

Messages per Trunk in Automatic System

Number of Trunks in Group, Automatic System	Messages per Trunk per Busy Hour
5	15
10	22
20	28
40	32
60	34

average length in long-distance traffic. The long-distance line is held longer for an average conversation than is a local-exchange line. The local trunks which connect long-distance lines with exchange lines for conversation are held longer than are the actual long-distance trunks between cities. Knowing the probable traffic to be brought to the long-distance switching center by the long-distance trunks from exchange centers, the number of trunks required may be determined by knowing the capacity of each trunk. These trunk capacities vary with the method of handling the traffic and they vary as do local trunks with the number of trunks in a group. Table XVII illustrates this variation of capacity with sizes of groups.

TABLE XVII

Messages per Trunk in Long-Distance Groups

Number of Long-Distance Trunks in Group	Messages per Trunk per Busy Hour
5	2
10	3
20	3.2
40	3.5
60	4
100	4.6

Quality of Service. The quality of telephone service rendered by a particular equipment managed in a particular way depends on a great variety of elements. The handling of the traffic presented by patrons is a true manufacturing problem. The quality of the service rendered requires continuous testing in order that the management may know whether the service is reaching the standard; whether the standard is high enough; whether the cost of producing it can be reduced without lowering the quality; and whether the patrons are getting from it as much value as they might.

In manual systems, the quality of telephone service depends upon a number of elements. The following are some principal ones:

1. Prompt answering.
2. Prompt disconnection.
3. Freedom from errors in connecting with the called line.
4. Promptness in connecting with the called line.
5. Courtesy and the use of form.
6. Freedom from failure by busy lines and failure to answer.
7. Clear enunciation.
8. Team work.

Answering Time. There is an interrelation between these elements. Team work assists both answering and prompt disconnection. The quality of telephone service can not be measured alone in terms of prompt answering. Formerly telephone service was boasted of as being "three-second service" if most of the originating calls were answered in three seconds. Often such prompt answering reacts to prevent prompt disconnecting. Patient, systematic work is required to learn the real quality of the service.

As to answering, the clearest, truest statement concerning manual service is found by making test calls to each position, dividing them into groups of various numbers of whole seconds each, and comparing the percentage of these groups to the whole number of telephones to that position. For example, assume each of the calls to a given position to have been answered in ten seconds or less, in which

100 per cent are answered in ten seconds or less;
80 per cent in eight seconds or less
60 per cent in six seconds or less.

It is probable that a reasonably uniform manual service will show only a small percentage answered in three seconds or under. Such percentages may be drawn in the form of curves, so that at a glance one may learn efficiency in terms of prompt answering.

Disconnecting Time. Prompt disconnection was improved enormously by the introduction of relay manual boards. Just before the installation of relay boards in New York City, the average disconnecting time was over seventeen seconds. On the completion of an entire relay equipment, the average disconnecting time was found to be under three seconds. The introduction of relay manual apparatus has led subscribers to a larger traffic and to the making of calls which succeed each other very closely. A most important rule is, *that disconnect signals shall be given prompt attention either by the operator who made the connection, by an operator adjacent, or by a monitor who may be assisting;* and another, still more important one is, *that a flashing keyboard lamp indicating a recall shall be given precedence over all originating and all other disconnect signals.*

Accuracy and Promptness. Promptness and accuracy in connecting with the called line are vital, and yet a large percentage of errors in these elements might exist in an exchange having a very high average speed of answering the originating call. Indeed, it seems quite the rule that where the effort of the management is devoted toward securing and maintaining extreme speed of original answering, all the other elements suffer in due proportion.

Courtesy and Form. It goes without saying that operators should be courteous; but it is necessary to say it, and keep saying it in the most effective form, in order to prevent human nature under the most exasperating circumstances from lapsing a little from the standard, however high. The use of form assists both the operators and the subscribers, because in all matters of strict routine it is much easier to secure high speed and great accuracy by making as many as possible of the operations automatic. The use of the word "number" and other well-accepted formalities has assisted greatly in securing speed, clear understanding, and accurate performance. The simple expedient of spelling numbers by repeating the figures in a detached form—as "1-2-5" for 125—has taught subscribers the same expedient, and the percentage of possible error is materially reduced by going one step further and having the operator, in repeating, use always the opposite form from that spoken by the calling subscriber.

Busy and Don't Answer Calls. Notwithstanding the old impression of the public to the contrary, the operator has no control over the "busy line" and "don't answer" situation. It is, however, of high importance that the management should know, by the analysis of repeated and exhaustive tests of the service, to what extent these troubles are degrading it. In addition to improving the service by the elimination of busy reports, there is no means of increasing revenue which is so easy and so certain as that which comes from following up the tabulated results of busy calls.

Enunciation. It must be remembered that clear enunciation for telephone purposes is a matter wholly relative, and the ability of an operator in this regard can be determined only by a close analysis of many observations from the standpoint of a subscriber. A trick of speech rather than a pleasant voice and an easy address has made the answering ability of many an operator captivating to a group of satisfied subscribers.

Team Work. By team work is meant the ability of a group of operators, seated side by side, to work together as a unit in caring for the service brought to them by the answering jacks within their reach. In switchboards of the construction usual today, a call before any operator may be answered by her, or by the operator at either the right or the left of her position. In many exchanges this advantage is wholly overlooked. In the period of general re-design of central-office equipments about fourteen years ago, a switchboard was installed with mechanical visual signals and answering-jacks on a flat-top board, and an arrangement of operators such that the signal of any call was extremely prominent and in easy reach of each one of four or possibly five operators. Associated with the line signals within the reach of such a group was an auxiliary lamp signal which would light when a call was made by any of the lines so terminating. It was found that with this arrangement the calls were answered in a strictly even manner, special rushes being cared for by the joint efforts of the group rather than serving to swamp the operator who happened to be in charge of the particular section affected by the rush.

This principle has been tried out in so many ways that it is astonishing that it is not recognized as being a vital one. The whole matter is accomplished by impressing upon each operator that her duty is, *not* to answer the calls of a specific number of lines before her, but to answer, with such promptness as is possible, *any call which is within the reach of her answering equipment.*

Observation of Service. All that is required to be known concerning the form of address and courtesy may be learned by a close observation of the operators' work by the chief operators and monitors, and by the use of listening circuits permanently connected to the operators' sets. It is naturally necessary that the use of these listening circuits by the chief operator or her assistants must not be known to the operators at the times of use, even though they may know of the existence of such facilities.

With a well-designed and properly maintained automatic equipment, the eight elements of good manual service reduce themselves to only one or two. Freedom from failure by busy lines and failure to answer are service-qualities independent of the kind of switching apparatus. Too great a percentage of busy calls for a given line indicates that the telephone facilities for calls incoming to that subscriber are inadequate. The best condition would be for each subscriber to have lines enough so that none of them ever would be found busy. This is the condition the telephone company tries to establish between its various offices.

In manual practice it is possible to keep such records as will enable the traffic department to know when the lines to a subscriber are insufficient for the traffic trying to reach him. As soon as such facts are known, they can be laid before the subscriber so that he may arrange for additional incoming lines. In automatic practice this is not so simple, as the source and destination of traffic in general is not so clearly known to the traffic department. Automatic recorders of busy calls are necessary to enable the facts to be tabulated.

CHAPTER XXXVIII

MEASURED SERVICE

In the commercial relation between the public and a telephone system, the commodity which is produced by the latter and consumed by the former is telephone service. Users often consider that payment is made for rental of telephone apparatus and to some persons the payment per month seems large for the rental of a mere telephone which could be bought outright for a few dollars.

The telephone instrument is but a small part of the physical property used by a patron of a telephone system. Even the *entire* group of property elements used by a patron in receiving telephone service represents much less than what really is his proportion of the service-rendering effort. What the patron receives is service and its value during a time depends largely on how much of it he uses in that time, and less on the number of telephones he can call.

The cost of telephone service varies as the amount of use. It is just, therefore, that the selling price should vary as the amount of use.

Rates. There are two general methods of charging for telephone service and of naming rates for this charge. These are called flat rates and measured-service rates. The latter are also known as message rates, because the message or conversation is the unit. Flat rates are those which are also known as rentals. The service furnished under flat rates is also known as unlimited service, for the reason that under it a patron pays the same amount each month and is entitled to hold as many conversations—send as many messages and make as many calls—as he wishes, without any additional payment. In the measured-service plan, the amount of payment in a month varies in some way with the amount of use, depending on the plan adopted. The patron may pay a fixed base amount per month, entitling him to have equipment for telephone service and to receive messages, but being required to pay, in addition to this base amount, a sum which is determined by the number of messages which he sends. Or he may pay a base amount per month and be entitled to have the equipment, to receive calls, and to send a certain number of messages, paying specifically in addition only for messages exceeding that certain number.

Whether flat rates or measured-service rates are practiced, the general tendency is to establish lower rates for service in homes than in business places. This is another recognition of the justice of graduating the rates in accordance with the amount of use.

Units of Charging. While both the flat-rate and the measured-rate methods of charging for unlimited and measured service are practiced in local exchanges, long-distance service universally is sold at message rates. The unit of message rates in long-distance service is time. The charge for a message between two points joined by long-distance lines usually is a certain sum for a conversation three minutes long plus a certain sum for each additional minute or fraction of a minute. In local service, the message-rate time charge per message takes less account of the time unit. The conversation is almost universally the unit in exchanges. Some managements restrict messages of multi-party lines to five minutes per conversation, because of the desire to avoid withholding the line from other parties upon it for too long periods. Service sold at public stations similarly is restricted as to time, even though the message be local to the exchange. Three to five minutes local conversation is sold generally for five cents in the United States. The time of the average local message, counting actual conversation time only, is one hundred seconds.

Toll Service. *Long Haul.* In long-distance service, there are two general methods of handling traffic, as to the relations between the calling and the called stations. For the greater distances, as between cities not closely related because not belonging to one general community, the calling patron calls a particular person and pays nothing unless he holds conversation with that person. In this method, the operator records the name of the person called for; the name, telephone number, or both, of the person calling; the names of the towns where the message originated and ended; the date, the time conversation began, and the length of time it lasted.

Short Haul. Where towns are closely related in commercial and social ways and where the traffic is large and approaches local service in character, and yet where conversations between them are charged at different rates than are local calls within them, a more rapid system of toll charging than that just described is of advantage. In these conditions, patrons are not sold a service which allows a particular party to be named and found, nor is the identity of the calling person required. The operator needs to know merely of these calls that they originate at a certain telephone and are for a certain other. The facts she must record are fewer and her work is simpler. Therefore, the cost of such switching is less than for true long-distance calls and it can be learned by careful auditing just when traffic between points becomes great enough to warrant switching them in this way. Such switching, for example, exists between New York and Brooklyn, between Chicago and suburbs around it which have names of their own but really are part of the community of Chicago, and between San Francisco and other cities which cluster around San Francisco Bay.

Calls of the "long-haul" class are known as "particular person" or "particular party" calls, while "short-haul" calls are known as "two-number" long-distance calls. It is customary to handle particular party calls on long-distance switchboards and to handle two-number calls in manual systems on subscribers' switchboards exactly like local calls, except that the two number calls are ticketed. It is customary in automatic systems to handle two-number calls by means of the regular automatic equipment plus ticketing by a suburban or two-number operator.

Timing Toll Connections. It formerly was customary to measure the time of long-distance conversations by noting on the ticket the time of its beginning and the time of its ending, the operator reading the time from a clock. For human and physical reasons, such timing seems not to be considered infallible by the patron who pays the charge, and in cases of dispute concerning overtime charges so timed, telephone companies find it wisest to make concessions. The physical cause of error in reading time from a clock is that of parallax; that is, the error which arises from the fact that the minute hand of a clock is some distance from the surface of the dial so that one can "look under it." On an ordinary clock having a large face and its minute hand pointing upward or downward, five people standing in a row could read five different times from it at the same instant. The middle person might see the minute hand pointing at 6, indicating the time to be half-past something; whereas, person No. 1 and person No. 5 in the row might read the time respectively 29 and 31 minutes past something. Operators far to the right or to the left of a clock will get different readings, and an operator below a clock will get different kinds of readings at different times and correct readings at few times.

Timing Machines:—Machines which record time directly on long-distance tickets are of value and machines which automatically compute the time elapsing during a conversation are of much greater value. The calculagraph is a machine of the latter class. The

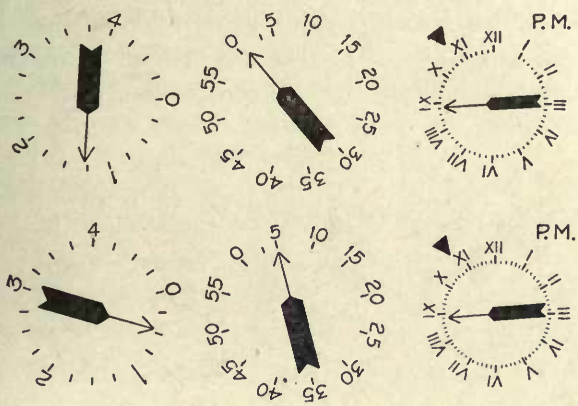


Fig. 453. Calculagraph Records

use of some such machine uniformly reduces controversy as to time which really elapsed. Parallax errors are avoided. The record possesses a dignity which carries conviction.

Calculagraph records are shown in Fig. 453. In the one shown in the upper portion of this figure, the conversation began at 10.44 P. M. This is shown by the right-hand dial of the three which constitute the record. The minutes past 10 o'clock are shown by the hand within the dial and the hour 10 is shown by the triangular mark just outside the dial between X and XI.

The duration of the conversation is shown by the middle and the left-hand dials. The figures on both these dials indicate minutes. The middle dial indicates roughly that the conversation lasted for a time between 0 and 5 minutes. The left-hand dial indicates with greater exactness that the conversation lasted one and one-quarter minutes.

The hand of the left-hand dial makes one revolution in five minutes; of the middle dial, one revolution in an hour. The middle dial tells how many full periods of five minutes have elapsed and the left-hand dial shows the excess over the five-minute interval.

The lower portion of Fig. 453 is a similar record beginning at the same time of day, but lasting about five and one-half minutes. As before, the readings of the two dials are added to get the elapsed time.

The right-hand dial, showing merely time of day, stands still while its hands revolve. The dies which print the dials and hands of the middle and the left-hand records rotate together. Examining the machine, one finds that the hands of these dials always

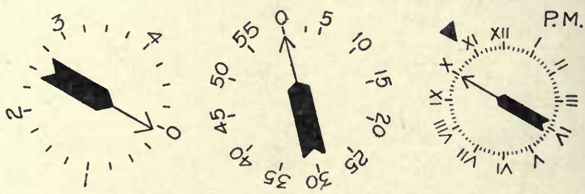


Fig. 454. Relative Position of Hands and Dials

point to zero. The middle dial and hand make one complete revolution in an hour; the left-hand dial and hand, one in five minutes. In making the records, the dials are printed at the beginning and the hands at the end of the conversation. Therefore, the hands will have moved forward during the conversation—still pointing to zero in both cases—but when printed the hands will point to some other place than they were pointing when the dials were printed. In this way, their angular distances truly indicate the lapse of time. Fig. 454 shows the relative position of the hands and dials within the machine at all times. It will be noted that the arrow of the left-hand dial does not point exactly to zero. This is due to the fact that the dials and hands are printed by separate operations and cannot be printed simultaneously.

Another method of timing toll connections has been developed by the Monarch Telephone Manufacturing Company. This employs a master clock of great accuracy, which may be mounted on the wall anywhere in the building or another building if desired. A circuit leads from this clock to a time-stamp device on the operator's key shelf, and the clock closes this circuit every quarter minute. The impulses thus sent over the circuit energize the magnet of the time stamp, which steps a train of printing wheels around so as always to keep them set in such position as to properly print the correct time on a ticket whenever the head of the stamp is moved by the operator into contact with the ticket. A large number of such stamps may be operated from the same master clock. By printing the starting time of a connection below the finishing time the computation of lapsed time becomes a matter of subtraction. A typical toll ticket with the beginning and ending time printed by the time stamp in the upper left-hand corner and the elapsed time recorded by hand in the upper right-hand corner is shown in Fig. 455. It is seen that this stamp records in the order mentioned the month, the day, the hour, the minute and quarter minute, the A. M. and P. M. division of the day, and the year.

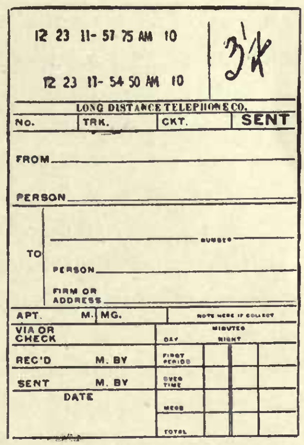


Fig. 455. Toll Ticket Used with Monarch System

An interesting feature of this system is that the same master clock may be made in a similar manner to actuate secondary clocks placed at subscribers' stations, the impulses being sent over wires in the same cables as those containing the subscribers' lines. This system, therefore, serves not only as a means for timing the toll tickets and operating time stamps wherever they are required in the business of the telephone company, but also to supply a general clock and time-stamp service to the patrons of the telephone company as a "by-product" of the general telephone business.

Exchange service is measured in terms of conversations without much regard to their length. The payment for the service may be made at the time it is received, as in public stations and at telephones equipped with coin prepayment devices; or the calls from a telephone may be recorded and collection for them made at agreed intervals. In the prepayment method the price per call is uniform. In the deferred payment method the calls are recorded as they are made, their number summed up at intervals, and the amount due determined by the price per call. The price per call may vary with the number of calls sold. A large user may have a lower rate per call than a small user.

Local Service. *Ticket Method.* Measured local service sometimes is recorded by means of tickets, similarly to the described method of charging long-distance calls, except that the time of day and the duration of conversation are not so important. Where local ticketing is practiced, it is usual to write on the ticket only the number of the calling telephone and the date, and to pass into the records only those tickets which represent actual conversations, keeping out tickets representing calls for busy lines and calls which were not answered.

Meter Method. The requirements of speed in good local service are opposed to the ticketing method. Where measured service is supplied to a substantial proportion of the lines of a large exchange, electro-mechanical service meters are attached to the lines. These service meters register as a consequence of some act on the part of the switchboard operator, or may be caused to register by the answering of the called subscriber.

In manual practice, meters of the type shown in Fig. 456 are associated with the lines as in Fig. 457. The meters are mounted separately from the switchboard, needing only to be connected to the test-strand of the line by cabled wires. If desired, the meter may be mounted on racks in quarters especially devoted to them, and the cases in which the racks are mounted may be kept locked. In such an arrangement the meters are read from time to time through the glass doors of the cases.

Fig. 456. Connection Meter

The meters are caused to operate by pressure on the meter key MK, associated with the answering cord as in Fig. 458. This increases the normal potential to 30 volts. When the armature of the meter has made a part of its stroke, it closes a contact which places its 40-ohm winding in shunt with its 500-ohm winding, thus furnishing ample power for turning the meter wheels.

Such meters are in common use in large exchanges, notable examples being the cities of New York and London. In London, there is a zone within which the price per call is one penny and between which and other zones the price is twopence. Calls within the zone either are completed by the answering operator directly in the multiple before her or are trunked to other offices in that zone. Calls for points outside of that zone are trunked to other

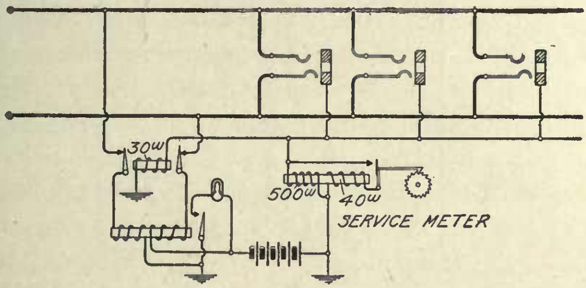


Fig. 457. Western Electric Line Circuit and Service Meter

offices and in giving the order the operator finds that the call circuit key lights a special signal lamp before her. This reminds her that the call is at a twopence price, so in recording it she presses the meter key twice. This counts two units on the meter and the units are billed at a penny each.

In automatic systems it is not possible to operate a meter system in which the operator will press a key for each call to be charged, because there is no operator. In such systems—a notable example being the measured-service automatic system in San Francisco—the meter registers only upon the answering of the called subscriber. Calls for lines found busy and calls which are not answered do not register. Calls for long-distance recording operators, two-number ticket operators, information, complaint, and other company departments are not registered. In the Chinatown quarter of San Francisco, where most calls begin and end in the neighborhood, service is sold at an unlimited flat rate for neighborhood calls and at a message rate for other calls. The meter system recognizes this condition and does not register calls *from* Chinese subscribers *for* Chinese subscribers, though it does register calls from Chinese subscribers to Caucasian subscribers. The nature of the system is such as to enable it to discriminate as to races, localities, or other peculiarities as may be desired.

In the manual meter circuits of Figs. 457 and 458, the meter windings have no relation to the line conductors. In the automatic arrangement just described, there are meter windings in the line during times of calling, but none in the line during times of con-

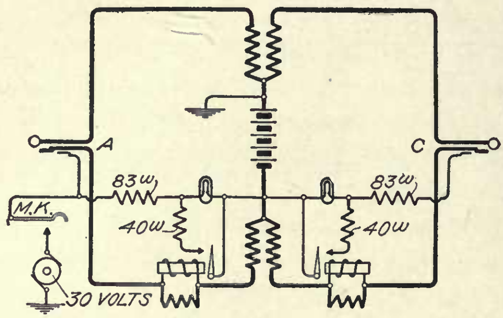


Fig. 458. Western Electric Cord Circuit and Service Meter Key

versation. The balance of the line, therefore, is undisturbed at all times wherein balance is of any importance.

In both systems just described, the meters of all lines are in their respective central offices. Meters for use at subscribers' stations have been devised and there is no fundamental reason why the record might not be made at the subscriber's station instead of, or in addition to, a central-office record. Experience has shown that confidence in a meter system can be secured if the meters be positive, accurate, and reliable. The labor of reading the meters is much less when they are kept in central offices. Subscribers may have access to them if they wish.

Prepayment Method. Prepayment measured-service mechanisms permit a coin or token to be dropped into a machine at the subscriber's telephone at the time the conversation is held. A variety of forms of telephone coin collectors are in use, their operations being fundamentally either electrical or mechanical.

Electrically operated coin collectors require either that the coin be dropped into the machine in order to enable the central office to be signaled in manual systems, or the switches to be operated in automatic systems, or they require that the coin be dropped into the machine after calling, but before the conversation is permitted.

Western Electric Company coin collectors, shown in Fig. 459, may be operated in either way in connection with manual systems. The usual way is to require the coin to be dropped before the central-office line lamp can glow. The operator then rings the called subscriber and upon his answering places a sufficient potential upon the calling line to operate the polarized relay and to drop the coin into the cash box. If the called subscriber does not answer or his line is busy, potential is placed on the calling line, moving the polarized relay in the other direction and dropping the coin into a return chute so that the subscriber may take it. If it is preferred that the coin be paid only on the request of the operator, the return feature need not be provided.

In both forms of operation, the Western Electric coin collector is adapted to bridge its polarized relay between one limb of the line and ground during the time a coin rests on the pins, as shown in Fig. 459. When no coin is on the pins—*i. e.*, before calling and after the called station responds—the relay is not so bridged.

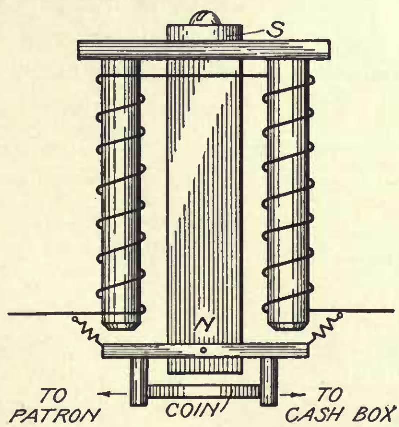


Fig. 459. Principle of Western Electric Coin Collector

The armature of the relay responds only to a high potential and this is applied by the operator. If the coin is to be taken by the company, one polarity is sent; if it is to be returned to the patron, the other polarity is sent. These polarities are applied to a limb of the line proper. It will be recalled that pressures to actuate service meters are applied to the test-strand. If wished, keys may be arranged so as to apply 30 volts to the test-strand and the collecting potential to the line at the same operation. This enables the service meter to count the tokens placed in the cash box of the coin collector, and serves as a valuable check.

In automatic systems, in one arrangement, coin collectors are arranged so that no impulses can be sent unless a coin has been deposited, the coin automatically passing to the cash box when the called subscriber answers, or to the patron if it is not answered. In another arrangement, calls are made exactly as in unlimited service, but a coin must be deposited before a conversation can be held. The calling person can hear the called party speak and may speak himself but can not be heard until the coin is deposited. No coin-return mechanism is required in this method.

Coin collectors of these types usually are adapted to receive only one kind of coin, these, in the United States, being either nickels or dimes. For long-distance service, where the charges vary, it is necessary to signal to an operator just what coins are paid. It is uniformly customary to send these signals by sound, the collector being so arranged that the coins strike gongs. In coin collectors of the Gray Telephone Paystation Company, the coins strike these gongs by their own weight in falling through chutes. In coin collectors of the Baird Electric Company, the power for the signals is provided by hand power, a lever being pulled for each coin deposited. Both methods are in wide use.

CHAPTER XXXIX

PHANTOM, SIMPLEX, AND COMPOSITE CIRCUITS

Definitions. Phantom circuits are arrangements of telephone wires whereby more working, non-interfering telephone lines exist than there are sets of actual wires. When four wires are arranged to provide three metallic circuits for telephone purposes, two of the lines are physical circuits and one is a phantom circuit.

Simplex and composite circuits are arrangements of wires whereby telephony and telegraphy can take place at the same time over the same wires without interference.

Phantom. In Fig. 460 four wires join two offices. *RR* are repeating coils, designed for efficient transforming of both talking

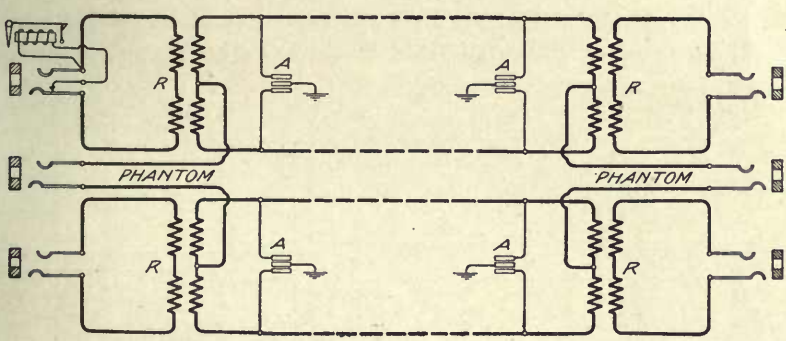


Fig. 460. Phantom Circuit

and ringing currents. The devices marked *A* in this and the following figures are air-gap arresters. Currents from the telephones connected to either physical pair of wires pass, at any instant, in opposite directions in the two wires of the pair. The phantom circuit uses one of the physical pairs as a *wire* of its line. It does this by tapping the middle point of the line side of each of the repeating coils. The impedance of the repeating-coil winding is lowered because, all the windings being on the same core, the phantom line currents pass from the middle to the outer connections so as to neutralize each other's influence. The currents of the phantom circuit, unlike those of the physical circuits, are *in the same direction* in both wires of a pair at any instant. Their potentials, therefore, are equal and simultaneous.

A phantom circuit is formed most simply when both physical lines end in the same two offices. If one physical line is longer than

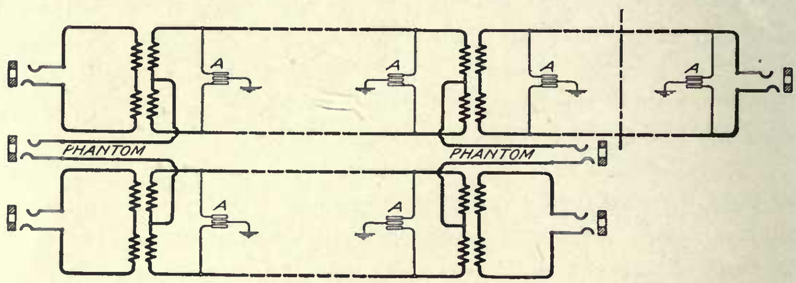


Fig. 461. Phantom from Two Physical Circuits of Unequal Length

the other, a phantom circuit may be formed as in Fig. 461, wherein the repeating coil is inserted in the longer line where it passes through a terminal station of the shorter.

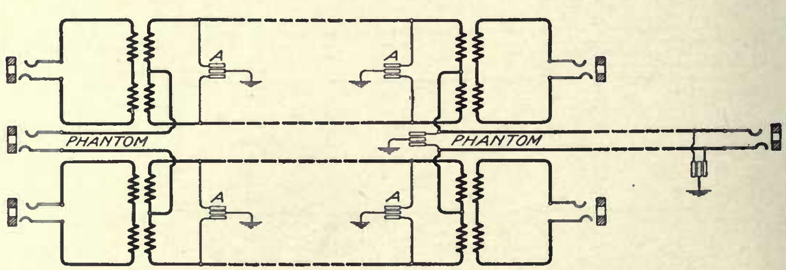


Fig. 462. Phantom Extended by Physical Circuit

A circuit may be built up by adding a physical circuit to a phantom. A circuit may be made up of two or more phantom circuits, joined by physical ones. In Fig. 462 a phantom circuit is extended by the use of a physical circuit, while in Fig. 463, two phantom circuits are joined by placing between them a physical circuit.

Transpositions. In phantom circuits formed merely by inserting repeating coils in physical circuits and doing nothing else, an exact balance of the sides of the phantom circuit is lacking. The

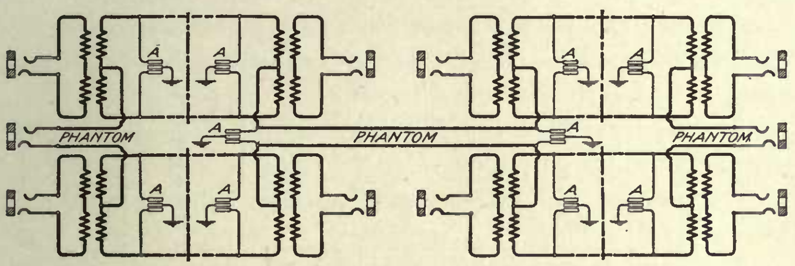


Fig. 463. Two Phantoms Joined by Physical Circuit

resistances, insulations, and capacities to earth of the sides may be equal, but the exposures to adjacent telephone and telegraph circuits and to power circuits will not be equal unless the phantom circuits are transposed.

To transpose a set of lines of two physical wires each, is not complicated, though it must be done with care and in accordance

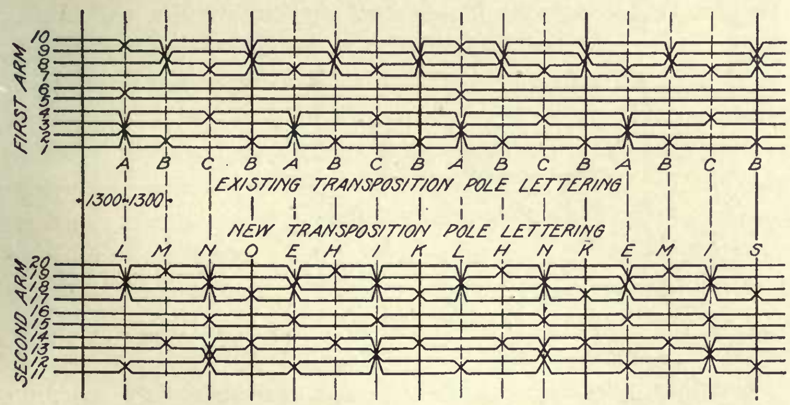


Fig. 464. Transposition of Phantom Circuits

with a definite, foreknown plan. Transposing phantom circuits is less simple, however, as four wires per circuit have to be transposed, instead of two.

In Fig. 464, the general spacing of transposition sections is the usual one, 1,300 feet, of the *ABCB* system widely in use. The pole circuit, on pins *5* and *6* of the upper arm, is transposed once each two miles. The pole circuit of the second arm transposes either once or twice a mile. But neither pole circuit differs in transposition from any other regular scheme except in the frequency of transposition. All the other wires of each arm, however, are so arranged that each wire on either side of the pole circuit moves from pin to pin at section-ends, till it has completed a cycle of changes over all four of the pins on its side. In doing so, each phantom circuit is transposed with proper regard to each of the other three on that twenty-wire line.

The "new transposition" lettering in Fig. 464 is for the purpose of identifying the exact scheme of wiring each transposition pole. The complication of wiring at each transposition pole is increased by the adoption of phantom circuits. Maintenance of all the circuits is made more costly and less easy unless the work at points of transposition is done with care and skill. Phantom circuits, to be always successful, require that the physical circuits be balanced and kept so.

Transmission over Phantom Circuits. Under proper conditions phantom circuits are better than physical circuits, and in this respect it may be noted that some long-distance operating companies instruct their operators always to give preference to phantom circuits, because of the better transmission over them. The use of phantom circuits is confined almost wholly to open-wire circuits; and while the capacity of the phantom circuit is somewhat greater than that of the physical circuit, its resistance is considerably smaller. In the actual wire the phantom loop is only half the resistance of either of the physical lines from which it is made, for it contains twice as much copper. The resistance of the repeating coils, however, is to be added.

Simplex. Simplex telegraph circuits are made from metallic circuit telephone lines, as shown in Fig. 465. The principle is identical with that of phantom telephone circuits. The potentials placed on the telephone line by the telegraph operations are equal and simultaneous. They cause no current to flow *around* the telephone loop, only *along* it. If all qualities of the loop are balanced, the telephones will not overhear the telegraph impulses. In the figure, *AA* are arresters, as before, *GG* are Morse relays; a 2-microfarad condenser is shunted around the contact of each Morse key *F* to quench the noises due to the sudden changes on opening the keys between dots and dashes.

A simplex arrangement even more simple substitutes impedance coils for the repeating coils of Fig. 465. The operation of

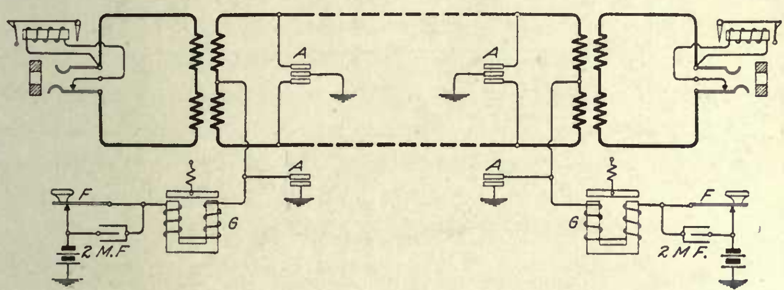


Fig. 465. Simplex Telegraph Circuit

the Morse circuit is the same. An advantage of such a circuit, as shown in Fig. 466, is that the telephone circuit does not suffer from the two repeating-coil losses in series. A disadvantage is, that

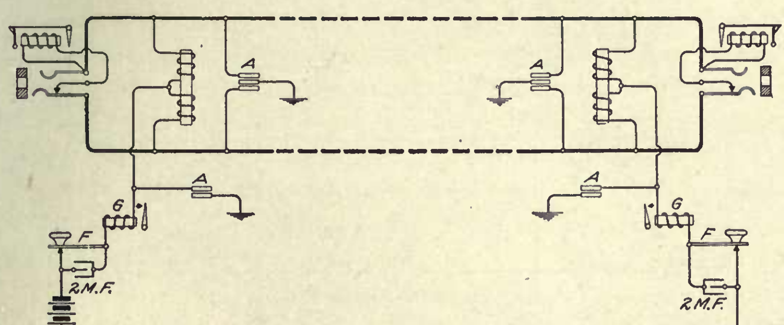


Fig. 466. Simplex Telegraph Circuit

in ringing on such a line with a grounded generator, the Morse relays are caused to chatter.

The circuit of Fig. 465 may be made to fit the condition of a through telephone line and a way telegraph station. The midway Morse apparatus of Fig. 467 is looped in by a combination of impedance coils and condensers. The plans of Figs. 465 and 466 here are combined, with the further idea of stopping direct and passing alternating currents, as is so well accomplished by the use of condensers.

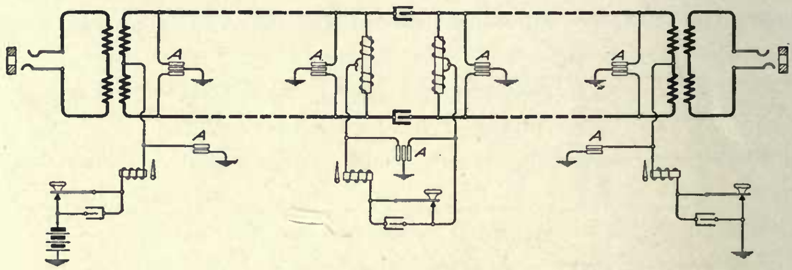


Fig. 467. Simplex Circuit with Waystation

Composite. Composite circuits depend on another principle than that of producing equal and simultaneous potentials on the two wires of the telephone loop. The opposition of impedance coils to alternating currents and of condensers to direct currents are the fundamentals. The early work in this art was done by Van Rysselberghe, of Belgium. In Fig. 468, one telephone circuit

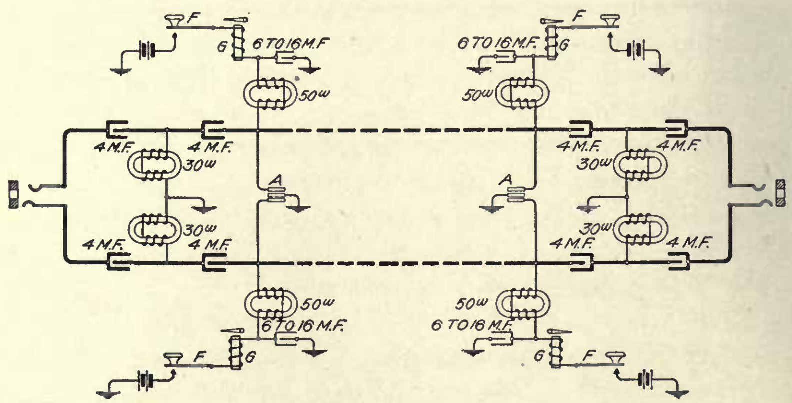


Fig. 468. Composite Circuit

forms two Morse circuits, two wires carrying three services. Each Morse circuit will be seen to include, serially, two 50-ohm impedance coils, and to have shunts through condensers to ground. The 50-

ohm coils are connected differentially, offering low consequent impedance to Morse impulses, whose frequency of interruption is not great. As the impedance coils are large, have cores of considerable length, and are wound with two separate though serially connected windings each, their impedance to voice currents is great. They act as though they were not connected differentially, so far as voice currents are concerned.

Because of the condensers serially in the telephone line, voice currents can pass through it, but direct currents can not. Impulses due to discharges of cores, coils, and capacities in the Morse circuit *could* make sounds in the telephones, but these are choked out, or led to earth by the 30-ohm impedance coils and the heavy Morse condensers.

Ringing. Ringing over simplex circuits is done in the way usual where no telegraph service is added. Both telegraphy and telephony over simplex circuits follow their usual practice in the way of calling and conversing. In composite working, however, ringing by usual methods either is impossible because of heavy grounds and shunts, or if it is possible to get ringing signals through at all, the relays of the Morse apparatus will chatter, interfering with the proper use of the telegraph portion of the service.

It is customary, therefore, either to equip composite circuits with special signaling devices by which high-frequency currents pass over the telephone circuits, operating relays which in turn operate local ringing signals; or to refrain from ringing on composite circuits and to transmit orders for connections by telegraph. The latter is wholly satisfactory over composite lines between points having heavy telegraph traffic, and it is between such points as these that composite practice is most general.

Phantoms from Simplex and Composite Circuits. Phantom and simplex principles are identical, and by adding the composite principle, two simplex circuits may have a phantom superadded, as in Fig. 469. Similarly, as in Fig. 470, two composite circuits can be phantomed. This case gives seven distinct services over four wires: three telephone loops—two physical and one phantom—and four Morse lines.

Railway Composite. The foregoing are problems of making telegraphy a by-product of telephony. With so many telegraph

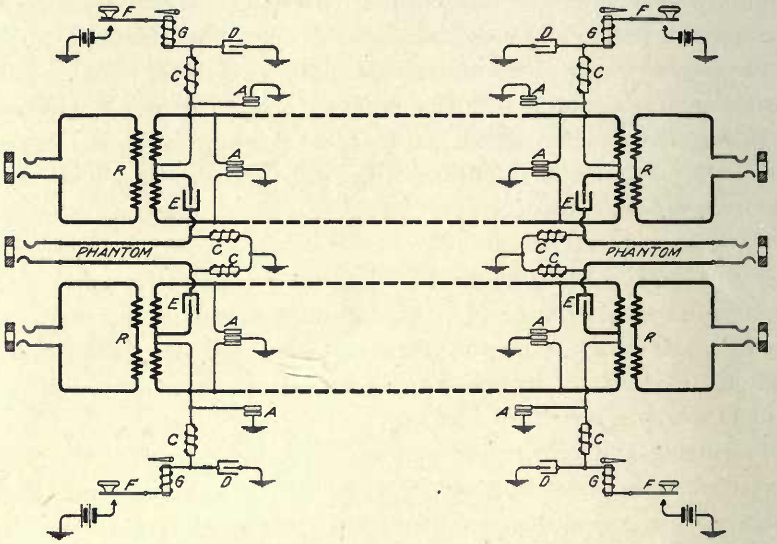


Fig. 469. Phantom of Two Simplex Circuits

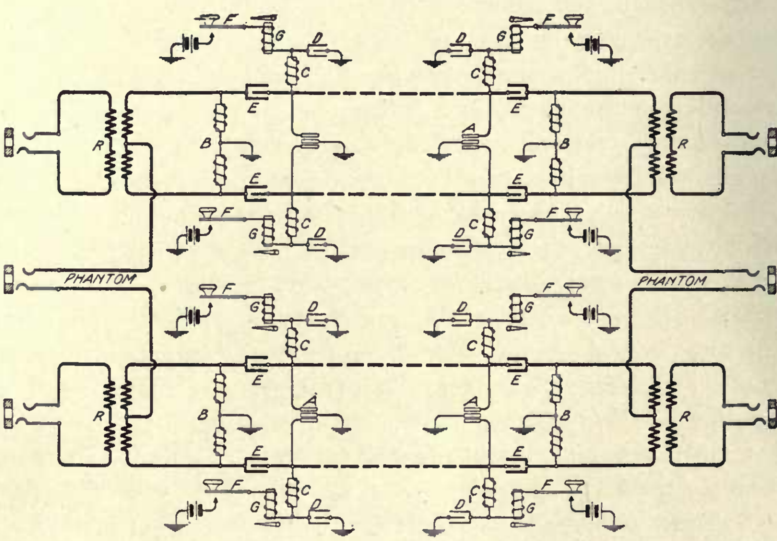


Fig. 470. Phantom of Two Composite Circuits

wires on poles over the country, it has seemed a pity not to turn the thing around and provide for telephony as a by-product of telegraphy. This has been accomplished, and the result is called a railway composite system. For the reason that the telegraph circuits are not in pairs, accurately matched one wire against another, and are not always uniform as to material, it has not been possible to secure as good telephone circuits from telegraph wires as telegraph circuits from telephone wires.

Practical results are secured by adaptation of the original principle of different frequencies. A study of Fig. 468 shows that over such a composite circuit the usual method of ringing from station to station over the telephone circuit by an alternating current of a frequency of about sixteen per second is practically impossible. This is because of the heavy short-circuit provided by the two 30-ohm choke coils at each of the stations, the heavy shunt of the large condensers, and the grounding through the 50-ohm choke coils. If high-frequency speech currents can pass over these circuits with a very small loss, other high-frequency circuits should find a good path. There are many easy ways of making such currents, but formerly none very simple for receiving them. Fig 471 shows one simple observer of such high-frequency currents, it being merely an adaptation of the familiar polarized ringer used in every subscriber's telephone. In either position of the armature it makes contact with one or the other of two studs connected to the battery, so that in all times of rest the relay *A* is energized When a high-frequency current passes through this polarized relay, however, there is enough time in which the armature is out of contact with either stud to reduce the total energy through the relay *A* and allow its armature to fall away, ringing a vibrating bell or giving some other signal.

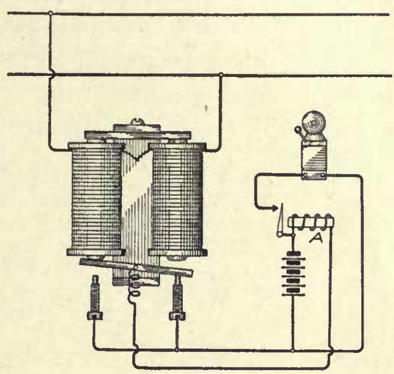


Fig. 471. Ringing Device for Composite Circuits

Fig. 472 shows a form of apparatus for producing the high-frequency current necessary for signaling. It is evident that if a magneto generator, such as is used in ordinary magneto telephones, could be made to drive its armature fast enough, it also might furnish the high-frequency current necessary for signaling through condensers and past heavy impedances.

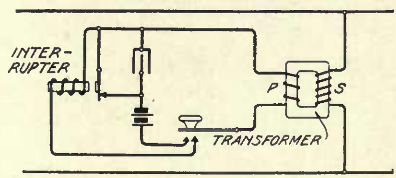


Fig. 472. Ringing Current Device

Applying these principles of high-frequency signals sent and received to a single-wire telegraph circuit, the arrangement shown in Fig. 473 results, this being a type of railway composite circuit. The principal points of interest herein are the insertion of impedances in series with the telegraph lines, the shunting of the telegraph relays by small condensers, the further shunting of the whole telegraph mechanism of a station by another condenser, and thus keeping out of the line circuit changes in current values which would be heard in the telephones if violent, and might be inaudible if otherwise.

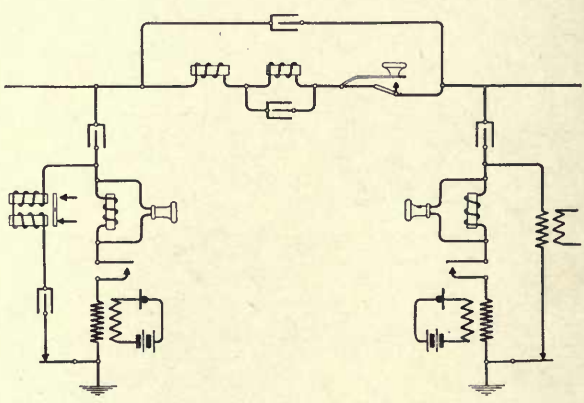


Fig. 473. Railway Composite Circuit

A further interesting element is the very heavy shunting of the telephone receiver by means of an inductive coil. This shunt is applied for by-path purposes so that heavy disturbing currents may be kept out of the receiver while a sufficient amount of voice current is diverted through the receiver It is well to have the inductance of this shunt made adjustable by providing a movable iron core for the shunt winding. When the core is drawn out of the coil, its impedance is diminished because the inductance is diminished. This reduces the amount of disturbing noise in the receiver. The core should be withdrawn as little as the amount of disturbance permits, as this also diminishes the loudness of the received speech.

Because the signaling over lines equipped with this form of composite working results in the ringing of a bell by means of local current, it is of particular advantage in cases where the bell needs to ring loudly. Switch stations, crossings, and similar places where the attendant is not constantly near the telephone can be equipped with this type of composite apparatus and it so offers a valuable substitute for regular railway telegraph equipment, with which the attendant may not be familiar. The success of the local bell-ringing arrangement, however, depends on accurate relay adjustment and on the maintenance of a primary battery. The drain on the ringing battery is greater than on the talking battery.

A good substitute for the bell signal on railway composite circuits is a telephone receiver responding directly to high-frequency currents over the line. The receiver is designed specially for the purpose and is known as a "howler." Its signal can be easily heard through a large room. The condenser in series with it is of small capacity, limiting the drain upon the line. Usually the howler is detached by the switch hook during conversation from a station.

Railway Composite Set. The circuit of a set utilizing such an arrangement together with other details of a complete railway composite set is shown in Fig. 474. The drawing is arranged thus, in the hope of simplifying the understanding of its principles. It will be seen that the induction coil serves as an interrupter as well as for transmission. All of the contacts are shown in the position they have during conversation. The letters *Hc1*, *Hc 2*, etc., and *Kc 1*, *Kc 2*, etc., refer to hook contacts and key contacts, respectively, of the numbers given. The arrangements of the hook and key springs are shown at the right of the figure. *RR* represent impedance coils connected serially in the line and placed at terminal stations. The composite telephone sets are bridged from the line to ground at any points between the terminal impedance coils.

The direct currents of telegraphy are prevented from passing to ground through the telephone set during conversation by the 2-

microfarad condenser which is in series with the receiver. They are prevented from passing to ground through the telephone set when the receiver is on the hook by a .05 microfarad condenser in series with the howler. The alternating currents of speech and interrupter signaling are kept from passing to ground at terminals by the impedance coils.

Signals are sent from the set by pressing the key *K*. This operates the vibrator by closing contacts *Kc 6* and *Kc 7*. The howler is cut off and the receiver is short-circuited by the same operation of the key. The impedance of the coil *I* is changed by moving its adjustable core.

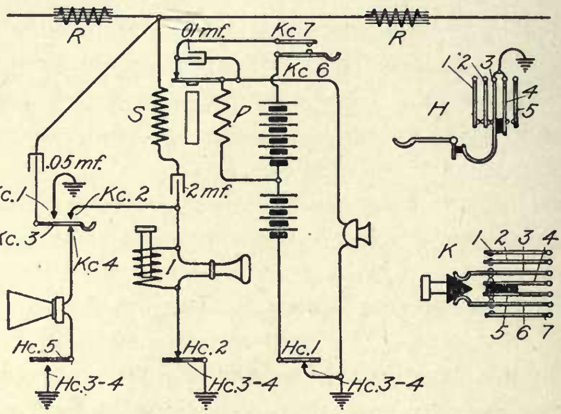


Fig. 474. Railway Composite Set

Applications. A chief use of composite and simplex circuits is for ticket wire purposes. These are circuits over which long-distance operators instruct each other as to connecting and disconnecting lines, the routing of calls, and the making of appointments. One such wire will care for all the business of many long-distance trunks. The public also absorbs the telegraph product of telephone lines. Such telegraph service is leased to brokers, manufacturers, merchants, and newspapers. Railway companies use portable telephone adjuncts to telegraph circuits on trains for service from stations not able to support telegraph attendants, and in a limited degree for the dispatching of trains. Telephone train dispatching, however, merits better equipment than a railway composite system affords.

CHAPTER XL

*TELEPHONE TRAIN DISPATCHING

It has been only within the past few years that the telephone has begun to replace the telegraph for handling train movements. The telegraph and the railroads have grown up together in this country since 1850, and in view of the excellent results that the telegraph has given in train dispatching and of the close alliance that has always naturally existed between the railway and the telegraph, it has been difficult for the telephone, which came much later, to enter the field.

Rapid Growth. The telephone has been in general use among the railroads for many years, but only on a few short lines has it been used for dispatching trains. In these cases the ordinary magneto circuit and instruments have been employed, differing in no respect from those used in commercial service at the present time. Code ringing was used and the number of stations on a circuit was limited by the same causes that limit the telephones on commercial party lines at present.

The present type of telephone dispatching systems, however, differs essentially from the systems used in commercial work, and is, in fact, a highly specialized party-line system, arranged for selective ringing and *many stations.* The first of the present type was installed by the New York Central and Hudson River Railroad in October, 1907, between Albany and Fonda, New York, a distance of 40 miles. This section of the road is on them ain line and has four tracks controlled by block signals.

The Chicago, Burlington, and Quincy Railroad was the second to install train-dispatching circuits. In December, 1907, a portion of the main line from Aurora to Mendota, Illinois, a distance of 46 miles, was equipped. This was followed in quick succession by various

*We wish particularly to acknowledge the courtesy of the Western Electric Company in their generous assistance in the preparation of this chapter.

other circuits ranging, in general, in lengths over 100 miles. At the present time there are over 20 train-dispatching circuits on the Chicago, Burlington, and Quincy Railroad covering 125 miles of double track, 28 miles of multi-track, and 1,381 miles of single track, and connecting with 286 stations.

Other railroads entered this field in quick order after the initial installations, and at the present time nearly every large railroad system in the United States is equipped with several telephone train-dispatching circuits and all of these seem to be extending their systems.

In 1910, several railroads, including the Delaware, Lackawanna, and Western, had their total mileage equipped with telephone dispatching circuits. The Atchison, Topeka, and Santa Fe Railroad is equipping its whole system as rapidly as possible and already is the largest user of this equipment in this country. From latest information, over 55 railroads have entered this field, with the result that the telephone is now in use in railroad service on over 29,000 miles of line.

Causes of Its Introduction. The reasons leading to the introduction of the telephone into the dispatching field were of this nature: First, and most important, was the enactment of State and Federal Laws limiting to nine hours the working day of railroad employes transmitting or receiving orders pertaining to the movement of trains. The second, which is directly dependent upon the first, was the inability of the railroads to obtain the additional number of telegraph operators which were required under the provisions of the new laws. It was estimated that 15,000 additional operators would be required to maintain service in the same fashion after the new laws went into effect in 1907. The increased annual expense occasioned by the employment of these additional operators was roughly estimated at $10,000,000. A third reason is found in the decreased efficiency of the average railway and commercial telegraph operator. There is a very general complaint among the railroads today regarding this particular point, and many of them welcome the telephone, because, if for no other reason, it renders them independent of the telegrapher. What has occasioned this decrease in efficiency it is not easy to say, but there is a strong tendency to lay it, in part, to the attitude of the telegraphers' organization toward the student operator. It is a fact, too, that the limits which these organizations have placed on student operators were directly responsible for the lack of available men when they were needed.

Advantages. In making this radical change, railroad officials were most cautious, and yet we know of no case where the introduction of the telephone has been followed by its abandonment, the tendency having been in all cases toward further installations and more equipment of the modern type. The reasons for this are clear, for where the telephone is used it does not require a highly spec alized man as station operator and consequently a much broader field is open to the railroads from which to draw operators. This, we think, is the most far-reaching advantage.

The telephone method also is faster. On an ordinary train-dispatching circuit it now requires from 0.1 of a second to 5 seconds to call any station. In case a plurality of calls is desired, the dispatcher calls one station after another, getting the answer from one while the next is being called, and so on. By speaking into a telephone many more words may be transmitted in a given time than by Morse telegraphy. It is possible to send fifty words a minute by Morse, but such speed is exceptional. Less than half that is the rule. The gain in high speed, therefore, which is obtained is obvious and it has been found that this is a most important feature on busy divisions. It is true that in the issuance of "orders," the speed, in telephonic train dispatching, is limited to that required to write the words in longhand. But all directions of a collateral character, the receipt of important information, and the instantaneous descriptions of emergency situations can be given and received at a speed limited only by that of human speech.

The dispatcher is also brought into a closer personal relation with the station men and trainmen, and this feature of direct personal communication has been found to be of importance in bringing about a higher degree of co-operation and better discipline in the service.

Telephone dispatching has features peculiar to itself which are important in improving the class of service. One of these is the "answer-back" automatically given to the dispatcher by the way-station bell. This informs the dispatcher whether or not the bell at the station rang, and excuses by the operators that it did not, are eliminated.

Anyone can answer a telephone call in an emergency. The station operator is frequently agent also, and his duties often take him out of hearing of the telegraph sounder. The selector bell used with the telephone can be heard for a distance of several hundred feet. In addition, it is quite likely that anyone in the neighborhood would recognize that the station was wanted and either notify the operator or answer the call.

In cases of emergency the train crews can get into direct communication with the dispatcher immediately, by means of portable telephone sets which are carried on the trains. It is a well-known fact that every minute a main line is blocked by a wreck can be reckoned as great loss to the railroad.

It is also possible to install siding telephone sets located either in booths or on poles along the right-of-way. These are in general service today at sidings, crossings, drawbridges, water tanks, and such places, where it may be essential for a train crew to reach the nearest waystation to give or receive information.

The advantage of these siding sets is coming more and more to be realized. With the telegraph method of dispatching, a train is ordered to pass another train at a certain siding, let us say. It reaches this point, and to use a railroad expression, "goes into the hole." Now, if anything happens to the second train whereby it is delayed, the first train remains tied up at that siding without the possibility of either reaching the dispatcher or being reached by him. With the telephone station at the siding, which requires no operator, this is avoided. If a train finds itself waiting too long, the conductor goes to the siding telephone and talks to the dispatcher, possibly getting orders which will advance him many miles that would otherwise have been lost.

It is no longer necessary for a waystation operator to call the dispatcher. When one of these operators wishes to talk to the dispatcher, he merely takes his telephone receiver off the hook, presses a button, and speaks to the dispatcher.

With the telephone it is a simple matter to arrange for provision so that the chief dispatcher, the superintendent, or any other official may listen in at will upon a train circuit to observe the character of the service. The fact that this can be done and that the operators know it can be done has a very strong tendency to improve the discipline.

The dispatchers are so relieved, by the elimination of the strain of continuous telegraphing, and can handle their work so much more quickly with the telephone, that in many cases it has been found possible to increase the length of their divisions from 30 to 50 per cent.

Railroad Conditions. One of the main reasons that delayed the telephone for so many years in its entrance to the dispatching field is that the conditions in this field are like nothing which has yet been met with in commercial telephony. There was no system developed for meeting them, although the elements were at hand. A railroad is divided up into a number of divisions or dispatchers' districts of varying lengths. These lengths are dependent on the density of the traffic over the division. In some cases a dispatcher will handle not more than 25 miles of line. In other cases this district may be 300 miles long. Over the length of one of these divisions the telephone circuit extends, and this circuit may have upon it 5 or 50 stations, *all of which may be required to listen upon the line at the same time.*

It will be seen from this that the telephone dispatching circuit partakes somewhat of the nature of a long-distance commercial circuit in its length, and it also resembles a rural line in that it has a large number of telephones upon it. Regarding three other characteristics, namely, that many of these stations may be required to be in on the circuit simultaneously, that they must all be signaled selectively, and that it must also be possible to talk and signal on the circuit simultaneously, a telephone train-dispatching circuit resembles nothing in the commercial field. These requirements are the ones which have necessitated the development of special equipment.

Transmitting Orders. The method of giving orders is the same as that followed with the telegraph, with one important exception. When the dispatcher transmits a train order by telephone, he writes out the order as he speaks it into his transmitter. In this way the speed at which the order is given is regulated so that everyone receiving it can easily get it all down, and a copy of the transmitted order is retained by the dispatcher. All figures and proper names are spelled out. Then after an order has been given, it is repeated to the dispatcher by each man receiving it, and he underlines each word as it comes in. This is now done so rapidly that a man can repeat an order more quickly than the dispatcher can underline. The doubt as to the accuracy with which it is possible to transmit information by telephone has been dispelled by this method of procedure, and the safety of telephone dispatching has been fully established.

Apparatus. The apparatus which is employed at waystations may be divided into two groups—the selector equipment and the telephone equipment. The selector is an electro-mechanical device for ringing a bell at a waystation when the dispatcher operates a key corresponding to that station. At first, as in telegraphy, the selector magnets were connected in series in the line, but today all systems bridge the selectors across the telephone circuit in the same way and for the same reasons that it is done in bridging party-line work. There are at the present time three types of selectors in general use, and the mileage operated by means of these is probably considerably over 95 per cent of the total mileage so operated in the country.

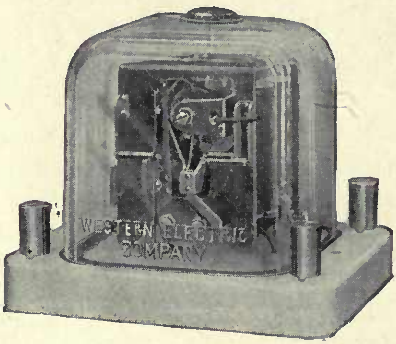


Fig. 475. Western Electric Selector

The Western Electric Selector. This selector is the latest and perhaps the simplest. Fig. 475 shows it with its glass dust-proof cover on, and Fig. 476 shows it with the cover removed. This selector is adapted for operating at high speed, stations being called at the rate of ten per second.

The operating mechanism, which is mounted on the front of the selector so as to be readily accessible, works on the central-energy principle—the battery for its operation, as well as for the operation of the bell used in connection with it, both being located at the dispatcher's office. The bell battery may, however, be placed at the waystation if this is desired.

The selector consists of two electromagnets which are bridged in series across the telephone circuit and are of very high impedance. It is possible to place as many of these selectors as may be desired across a circuit without seriously affecting the telephonic transmission. Direct-current impulses sent out by the dispatcher operate these magnets, one of which is slow and the other quick-acting. The first impulse sent out is a long impulse and pulls up both arma-

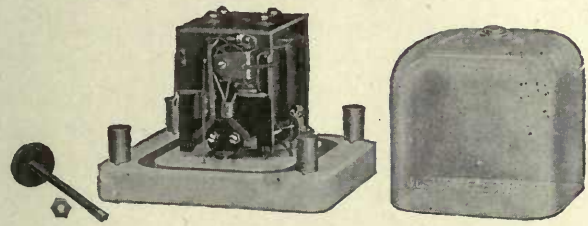


Fig. 476. Western Electric Selector

tures, thereby causing the pawls above and below the small ratchet wheel, shown in Fig 476, to engage with this wheel. The remaining impulses operate the quick-acting magnet and step the wheel

Fig. 477. Dispatcher's Keys

around the proper number of teeth, but do not affect the slow-acting magnet which remains held up by them. The pawl connected to the slow-acting magnet merely serves to prevent the ratchet wheel from turning back. Attached to the ratchet wheel is a contact whose position can be varied in relation to the stationary contact on the left of the selector with which this engages. This contact is set so that when the wheel has been rotated the desired number of teeth, the two contacts will make and the bell be rung. Any selector may thus be adjusted for any station, and the selectors are thus interchangeable. When the current is removed from the line at the dispatcher's office, the armatures fall back and everything is restored to normal. An "answer-back" signal is provided with this selector dependent upon the operation of the bell. When the selector at a

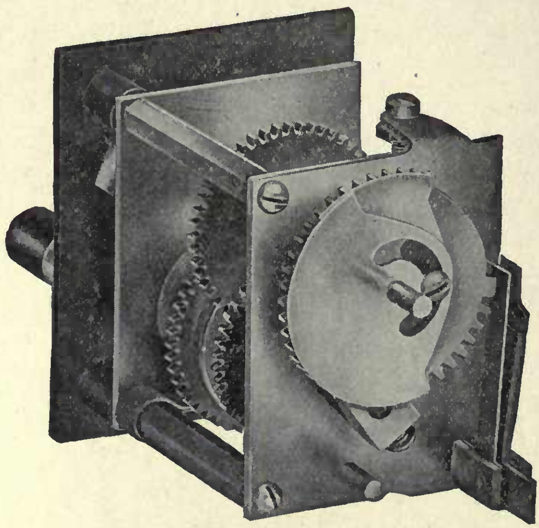


Fig. 478. Dispatcher's Key Mechanism

station operates, the bell normally rings for a few seconds. The dispatcher, however, can hold this ring for any length of time desired.

The keys employed at the dispatcher's office for operating selectors are shown in Fig. 477. There is one key for each way-station on the line and the dispatcher calls any station by merely giving the corresponding key a quarter turn to the right. Fig. 478 shows the mechanism of one of these keys and the means employed for sending out current impulses over the circuit. The key is adjustable and may be arranged for any station desired by means of the movable cams shown on the rear in Fig. 478, these cams, when occupying different positions, serving to cover different numbers of the teeth of the impulse wheel which operate the impulse contacts.

The Gill Selector. The second type of selector in extensive use throughout the country today is known as the Gill, after its inventor. It is manufactured for both local-battery and central-energy types, the latter being the latest development of this selector. With the local-battery type, the waystation bell rings until stopped by the dispatcher. With the central-energy type it rings a definite length of time and can be held for a longer period as is the case with the Western Electric selector. The selector is operated by combinations of direct-current impulses which are sent out over the line by keys in the dispatcher's office.

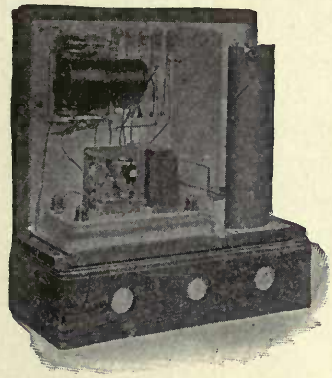


Fig. 479. Gill Selector

The dispatcher has a key cabinet, and calls in the same way as already described, but these keys instead of sending a series of quick impulses, send a succession of impulses with intervals between corresponding to the particular arrangement of teeth in the corresponding waystation selector wheel. Each key, therefore, belongs definitely with a certain selector and can be used in connection with no other.

A concrete example may make this clearer. The dispatcher may operate key No. 1421. This key starts a clockwork mechanism which impresses at regular intervals, on the telephone line, direct-current impulses, with intervals between as follows: 1-4-2-1. There is on the line one selector corresponding to this combination and it alone, of all the selectors on the circuit, will step its wheel clear around so that contact is made and the bell is rung. In all the others, the pawls will have slipped out at some point of the revolution and the wheels will have returned to their normal positions.

The Gill selector is shown in Fig. 479. It contains a double-wound relay which is bridged across the telephone circuit and operates the selector. This relay has a resistance of 4,500 ohms and a high impedance, and operates the selector mechanism which is a special modification of the ratchet and pawl principle. The essential features of this selector are the "step-up" selector wheel and a time wheel, normally held at the bottom of an inclined track.

The operation of the selector magnet pushes the time wheel up the track and allows it to roll down. If the magnet is operated rapidly, the wheel does not get clear down before being pushed back again. A small pin on the side of the pawl, engaging the selector wheel normally, opposes the selector wheel teeth near their outer points. When the time wheel rolls to the bottom of the track, however, the pawl is allowed to drop to the bottom of the tooth. Some of the teeth on the selector wheel are formed so that they will effectually engage with the pawl only when the latter is in normal position, while others will engage only while the pawl is at the bottom position; thus innumerable combinations can be made which will respond to certain combinations of rapid impulses with intervals between. The correct combination of impulses and intervals steps

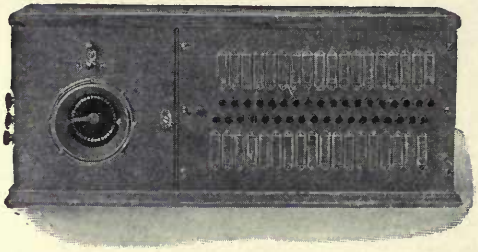


Fig. 480. Cummings-Wray Dispatcher's Sender

the selector wheel clear around so that a contact is made. The selector wheels at all other stations fail to reach their contact position because at some point or points in their revolution the pawls have slipped out, allowing the selector wheels to return "home."

The "answer-back" is provided in this selector by means of a few inductive turns of the bell circuit which are wound on the selector relay. The operation of the bell through these turns induces an alternating current in the selector winding which flows out on the line and is heard as a distinctive buzzing noise by the dispatcher.

The Cummings-Wray Selector. Both of the selectors already described are of a type known as the *individual-call* selectors, meaning that only one station at a time can be called. If a plurality of calls is desired, the dispatcher calls one station after another. The third type of selector in use today is of a type known as the *multiple-call*, in which the dispatcher can call simultaneously as many stations as he desires.

The Cummings-Wray selector and that of the Kellogg Switchboard and Supply Company are of this type and operate on the principle of synchronous clocks. When the dispatcher wishes to put through a call, he throws the keys of all the stations that he desires and then operates a starting key. The bells at all these stations are rung by one operation.

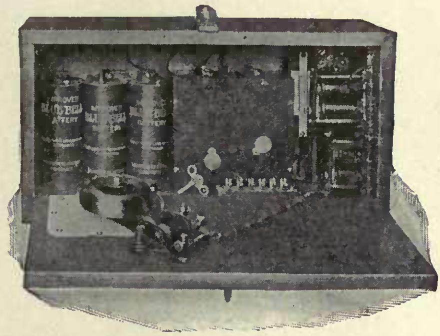


Fig. 481. Cummings-Wray Selector

The dispatcher's sending equipment of the Cummings-Wray system is shown in Fig. 480, and the waystation selector in Fig. 481. It is necessary with this system for the clocks at all stations to be wound every eight days.

In the dispatcher's master sender the clock-work mechanism operates a contact arm which shows on the face of the sender in Fig. 480. There is one contact for every station on the line. The clock at this office and the clocks at all the waystation offices start together, and it is by this means that the stations are signaled, as will be described later, when the detailed operation of the circuits is taken up.

Telephone Equipment. Of no less importance than the selective devices is the telephone apparatus. That which is here illustrated is the product of the Western Electric Company, to whom we are indebted for all the illustrations in this chapter.

Dispatcher's Transmitter. The dispatcher, in most cases, uses the chest transmitter similar to that employed by switchboard operators in every-day service. He is connected at all times to the telephone circuit, and for this reason equipment easy for him to wear is essential. In very noisy locations he is equipped with a double head receiver. On account of the dispatcher being connected across the line permanently and of his being required to talk a large part of the time, there is a severe drain on the transmitter battery. For this reason storage batteries are generally used.

Fig. 482. Waystation Desk Telephone

Waystation Telephones. At the waystations various types of telephone equipment may be used. Perhaps the most common is the familiar desk stand shown in Fig. 482, which, for railroad service, is arranged with a special hook-switch lever for use with a head receiver.

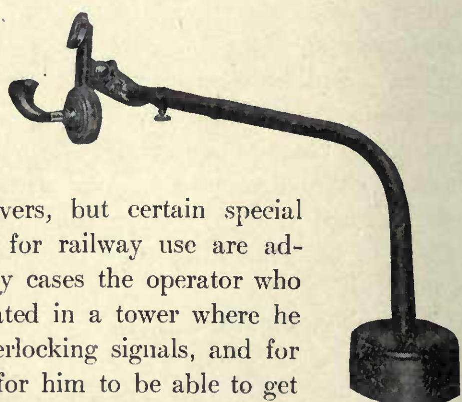


Fig. 483. Telephone Arm

Often some of the familiar swinging-arm telephone supports are used, in connection with head receivers, but certain special types developed particularly for railway use are advantageous, because in many cases the operator who handles train orders is located in a tower where he must also attend to the interlocking signals, and for such service it is necessary for him to be able to get away from the telephone and back to it quickly. The Western Electric telephone arm developed for this use is shown in Fig. 483. In this the transmitter and the receiver are so disposed as to conform approximately to the shape of the operator's head. When the arm is thrown back out of the way it opens the transmitter circuit by means of a commutator in its base.

Siding Telephones. Two types of sets are employed for siding purposes. The first is an ordinary magneto wall instrument, which embodies the special apparatus and circuit features employed in the standard waystation sets. These are used only where it is possible to

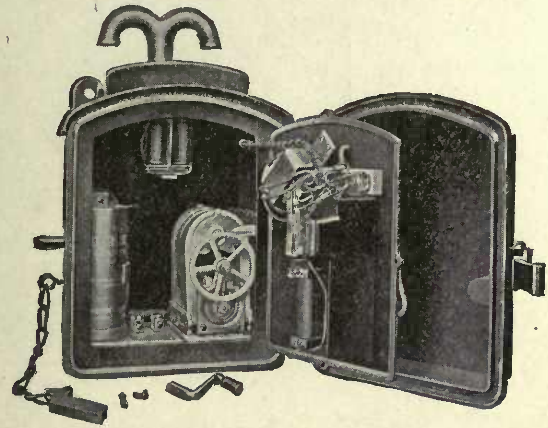


Fig. 484. Weather-Proof Telephone Set

locate them indoors or in booths along the line. These sets are permanently connected to the train wire, and since the chances are small that more than one of them will be in use at a time, they are rung by the dispatcher, by means of a regular hand generator, when it is necessary for him to signal a switching.

In certain cases it is not feasible to locate these siding telephone sets indoors, and to meet these conditions an iron weather-proof set is employed, as shown in Figs. 484 and 485. The apparatus in this set is treated with a moisture-proofing compound, and the casing itself is impervious to weather conditions.

Fig. 485. Weather-Proof Telephone Set

Portable Train Sets. Portable telephone sets are being carried regularly on wrecking trains and their use is coming into more and more general acceptance on freight and passenger trains. Fig. 486 shows one of these sets equipped with a five-bar generator for calling

Fig. 486. Portable Telephone Set

the dispatcher. Fig. 487 shows a small set without generator for conductors' and inspectors' use on lines where the dispatcher is at all times connected in the circuit.

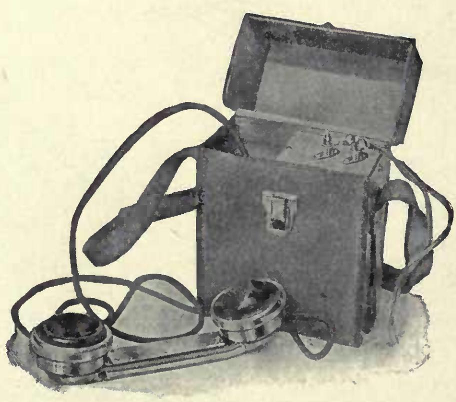


Fig. 487. Portable Telephone Set

These sets are connected to the telephone circuit at any point on the line by means of a light portable pole arranged with terminals at its outer extremity for hooking over the line wires, and with flexible conducting cords leading to the portable set. The use of these sets among officials on their private cars, among construction and bridge gangs working on the line, and among telephone inspectors and repairmen for reporting trouble, is becoming more and more general.

Western Electric Circuits. As already stated, a telephone train-dispatching circuit may be from 25 to 300 miles in length, and upon this may be as many stations as can be handled by one dispatcher. The largest known number of stations upon an existing circuit of this character is 65.

Dispatcher's Circuit Arrangement. The circuits of the dispatcher's station in the Western Electric system are shown in Fig. 488, the operation of which is briefly as follows: When the dispatcher wishes to call any particular station, he gives the key corresponding to that station a quarter turn. This sends out a series of rapid

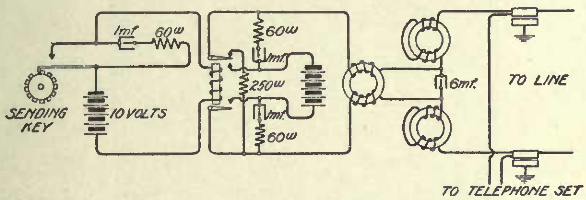


Fig. 488. Dispatcher's Station—Western Electric System

direct-current impulses on the telephone line through the contact of a special telegraph relay which is operated by the key in a local circuit. The telegraph relay is equipped with spark-eliminating condensers around its contacts and is of heavy construction throughout in order to carry properly the sending current.

Voltage. The voltage of the sending battery is dependent on the length of the line and the number of stations upon it. It ranges from 100 to 300 volts in most cases. When higher voltages are required in order successfully to operate the circuit, it is generally customary to install a telegraph repeater circuit at the center of the line, in order to keep the voltage within safe limits. One reason for limiting the voltage employed is that the condensers used in the circuit will not stand much higher potentials without danger of burning out. It is also possible to halve the voltage by placing the dispatcher in the center of the line, from which position he may signal in two directions instead of from one end.

Simultaneous Talking and Signaling. Retardation coils and condensers will be noticed in series with the circuit through which the signaling current must pass before going out on the line. These are for the purpose of absorbing the noise which is caused by high-voltage battery, thus enabling the dispatcher to talk and signal simultaneously. The 250-ohm resistance connected across the circuit through one back contact of the telegraph relay absorbs the discharge of the 6-microfarad condenser.

Waystation Circuit. The complete selector set for the waystations is shown in Fig. 489, and the wiring diagram of its apparatus in Fig. 490. The first impulse sent out by the key in the dispatcher's office is a long direct-current impulse, the first tooth being three or four times as wide as the other teeth. This impulse operates both magnets of the selector and attracts their armatures, which, in turn, cause two pawls to engage with the ratchet wheel, while the remaining quick impulses operate the "stepping-up" pawl and rotate the wheel the requisite number of teeth. Retardation coils are placed in series with the selector in order to choke back any lightning discharges which might come in over the line. The selector contact, when operated, closes a bell circuit, and it will be noted that both the selector and the bell are operated from battery current coming over the main line through variable resistances. There are, of course, a number of selectors bridged across the circuit, and the variable resistance at each station is so adjusted as to give each

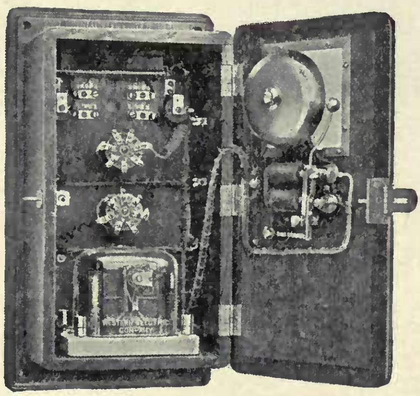


Fig. 489. Selector Set—Western Electric System

approximately 10 milliamperes, which allows a large factor of safety for line leakage in wet weather. The drop across the coils at 10 milliamperes is 38 volts. If these coils were not employed, it is clear

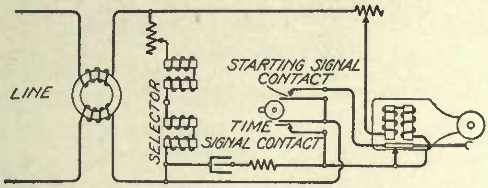


Fig. 490. Selector Set—Western Electric System

that the selectors nearer the dispatcher would get most of the current and those further away very little.

A time-signal contact is also indicated on the selector-circuit diagram of Fig. 490. This is common to all offices and may be operated by a special key in the dispatcher's office, thereby enabling him to send out time signals over the telephone circuit.

Gill Circuits. The circuit arrangement for the dispatcher's outfit of the Gill system is shown in Fig. 491. This is similar to that of the Western Electric system just described. The method of operation also is similar, the mechanical means of accomplishing

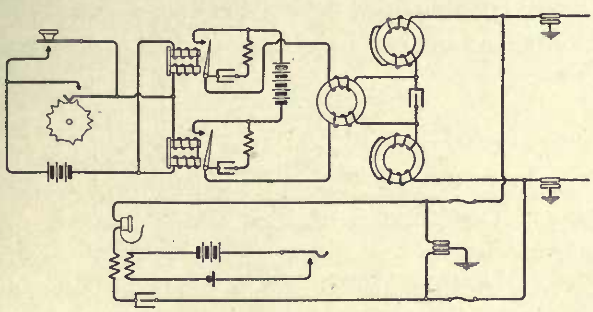


Fig. 491. Gill Dispatcher's Station

the selection being the main point of difference. In Fig. 492 the wiring of the Gill selector at a waystation for local-battery service is shown. The selector contact closes the bell circuit in the station and a few windings of this circuit are located on the selector magnets, as shown. These provide the "answer-back" by inductive means.

Fig. 493 shows the wiring of the waystation, central-energy Gill selector. In this case, the local battery for the operation of the bell is omitted and the bell is rung, as is the case of the Western Electric selector, by the main sending battery in the dispatcher's office.

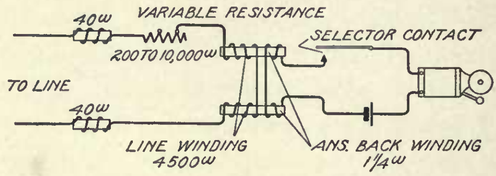


Fig. 492. Gill Selector—Local Battery

The sending keys of these two types of circuits differ, in that with the local-battery selector the key contact is open after the selector has operated, and the ringing of the bell must be stopped by the dispatcher pressing a button or calling another station. Either of these operations sends out a new current impulse which releases the selector and opens its circuit.

With the central-energy selector, however, the contacts of the sending key at the dispatcher's office remain closed after operation for a definite length of time. This is obviously necessary in order that battery may be kept on the line for the operation of the bell. In this case the contacts remain closed during a certain portion of the revolution of the key, and the bell stops ringing when that portion of the

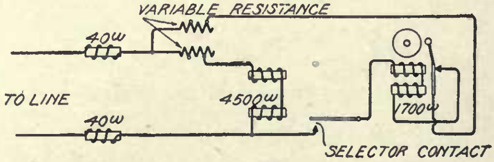


Fig. 493. Gill Selector—Central Energy

revolution is completed. If, however, the dispatcher desires to give any station a longer ring, he may do so by keeping the key contacts closed through an auxiliary strap key as soon as he hears the "answer-back" signal from the called station.

Cummings-Wray Circuits. The Cummings-Wray system, as previously stated, is of the multiple-call type, operating with synchronous clocks. Instead of operating one key after another in order to call a number of stations, all the keys are operated at once and a starting key sets the mechanism in motion which calls all these stations with one operation. Fig. 494 shows the circuit arrangement of this system.

In order to ring one or more stations, the dispatcher presses the corresponding key or keys and then operates the starting key. This starting key maintains its contact for an appreciable length of time to allow the clock mechanism to get under way and get clear of the releasing magnet clutch. Closing the starting key operates the clock-releasing magnet and also operates the two telegraph-line relays. These send out an impulse of battery on the line operating

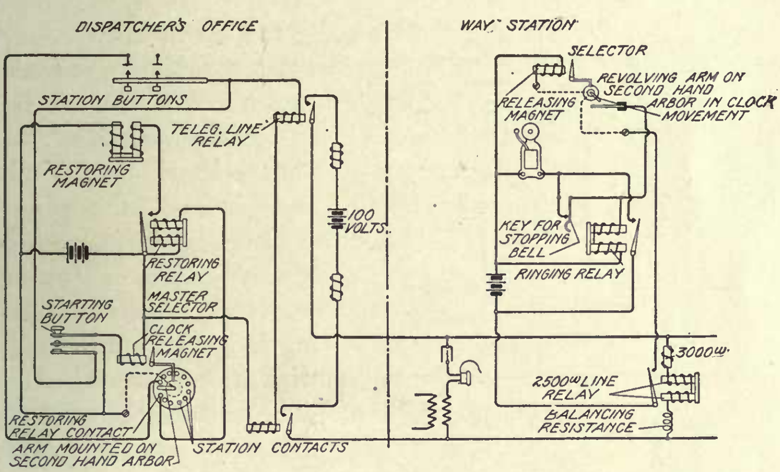


Fig. 494. Cummings-Wray System

the bridged 2,500-ohm line relays and, in turn, the selector releasing magnets; thus, all the waystation clocks start in unison with the master clock. The second hand arbor of each clock carries an arm, which at each waystation is set at a different angle with the normal position than that at any other station. Each of these arms makes contact precisely at the moment the master-clock arm is passing over the contact corresponding to that station.

If, now, a given station key is pressed in the master sender, the telegraph-line relays will again operate when the master-clock arm reaches that point, sending out another impulse of battery over the line. The selector contact at the waystation is closed at this moment;

therefore, the closing of the relay contact operates the ringing relay through a local circuit, as shown. The ringing relay is immediately locked through its own contact, thus maintaining the bell circuit closed until it is opened by the key and the ringing is stopped.

As the master-clock arm passes the last point on the contact dial, the current flows through the restoring relay operating the restoring magnet which releases all the keys. A push button is provided by means of which the keys may be manually released, if desired. This is used in case the dispatcher presses a key by mistake. Retardation coils and variable resistances are provided at the waystation just as with the other selector systems which have been described and for the same reasons.

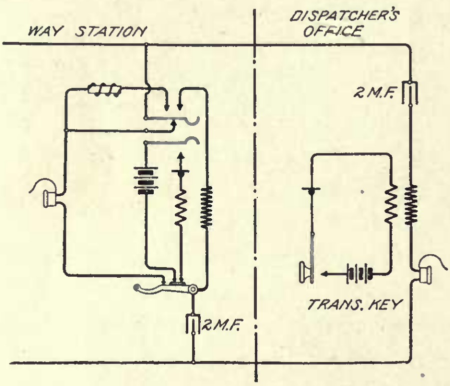


Fig. 495. Telephone Circuits

The circuits of the operator's telephone equipment shown in Fig. 495, are also bridged across the line. This apparatus is of high impedance and of a special design adapted to railroad service. There may be any number of telephones listening in upon a railroad train wire at the same time, and often a dispatcher calls in five or six at once to give orders. These conditions have necessitated the special circuit arrangement shown in Fig. 495.

The receivers used at the waystations are of high impedance and are normally connected, through the hook switch, directly across the line in series with a condenser. When the operator, at a waystation wishes to talk, however, he presses the key shown. This puts the receiver across the line in series with the retardation coil and in parallel with the secondary of the induction coil. It closes the transmitter battery circuit at the same time through the primary of the induction coil.

The retardation coil is for the purpose of preventing excessive side tone, and it also increases the impedance of the receiver circuit, which is a shunt on the induction coil. This latter coil, however, is of a special design which permits just enough current to flow through the receiver to allow the dispatcher to interrupt a way-station operator when he is talking.

The key used to close the transmitter battery is operated by hand and is of a non-locking type. In some cases, where the operators are very busy, a foot switch is used in place of this key. The use of such a key or switch in practical operation has been found perfectly satisfactory, and it takes the operators but a short time to become used to it.

The circuits of the dispatcher's office are similarly arranged, Fig. 495, being designed especially to facilitate their operation. In other words, as the dispatcher is doing most of the work on the circuit, his receiver is of a low-impedance type, which gives him slightly better transmission than the way-stations obtain. The key in his transmitter circuit is of the locking type, so that he does not have to hold it in while talking. This is for the reason that the dispatcher does most of the talking on this circuit. Foot switches are also employed in some cases by the dispatchers.

Fig. 496. Test Board

Test Boards. It is becoming quite a general practice among the railroads to install more than one telephone circuit along their rights-of-way. In many cases in addition to the train wire, a message circuit is also equipped, and quite frequently a block wire also operated by telephone, parallels these two. It is desirable on these circuits to be able to make simple tests and also to be able to patch one circuit with another in cases of emergency.

Test boards have been designed for facilitating this work. These consist of simple plug and jack boxes, the general appearance of which is shown in Fig. 496. The circuit arrangement of one of these is shown in Fig. 497. Each wire comes into an individual jack as will be noted on one side of the board, and passes through the inside contact of this jack, out through a similar jack on the opposite side. The selector and telephone set at an office are taken off these inside contacts through a key, as shown. The outside contacts of this key are wired across two pairs of cords. Now, assume the train wire comes in on jacks *1* and *3*, and the message wire on jacks *9* and *11*. In case of an accident to the train wire between two stations, it is desirable to patch this connection with a message wire in order to keep the all-important train wire working. The dispatcher instructs the operator at the last station which he can obtain, to insert plugs *1* and *2* in jacks *1* and *10*, and plugs *3* and *4* in jacks *3* and *12*, at the same time throwing the left-hand key. Then, obtaining an operator beyond the break by any available means, he instructs

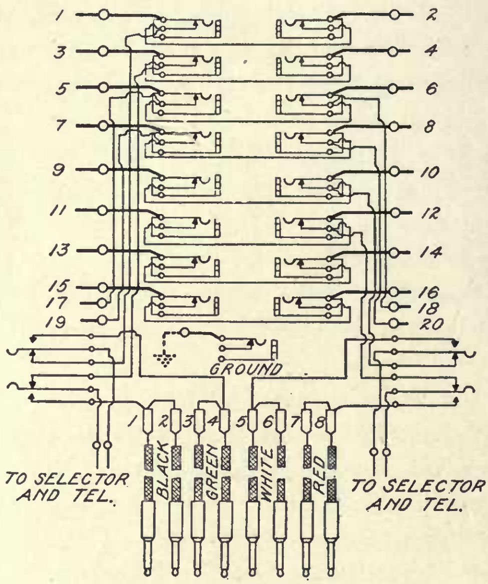


Fig. 497. Circuits of Test Board

him likewise to insert plugs *1* and *2* in jacks *9* and *2*, and plugs *3* and *4* in jacks *11* and *4*, similarly throwing the left-hand key. By tracing this out, it will be observed that the train wire is patched over the disabled section by means of the message circuit, and that the selector and the telephone equipment are cut over on to the patched connections; in other words, bridged across the patching cords.

It will also be seen that with this board it is possible to open any circuit merely by plugging into a jack. Two wires can be short-circuited or a loop made by plugging two cords of corresponding colors into the two jacks. A ground jack is provided for grounding any wire. In this way, a very flexible arrangement of circuits is obtained, and it is possible to make any of the simple tests which are all that are usually required on this type of circuit.

Blocking Sets. As was just mentioned, quite frequently in addition to train wires and message circuits, block wires are also operated by telephone. In some cases separate telephone instruments are used for the blocking service, but in others the same man handles all three circuits over the same telephone. The block wire is generally a converted telegraph wire between stations, usually of iron and usually grounded. It seldom ranges in length over six miles.

Where the block wires are operated as individual units with their own instruments, it is unnecessary to have any auxiliary apparatus to be used in connection with them. Where, however, they are operated as part of a system and the same telephone is used on these that is used on the train wire and message wire, additional apparatus, called a blocking set, is required. This blocking set, shown in Figs. 498 and 499, was developed especially for this service by the Western Electric Company. As will be noted, a repeating coil at the top and a key on the front of the set are wired in connection with a pair of train wire cords. This repeating coil is for use in connecting a grounded circuit to a metallic circuit, as, for instance, connecting a block wire to the train wire, and is, of

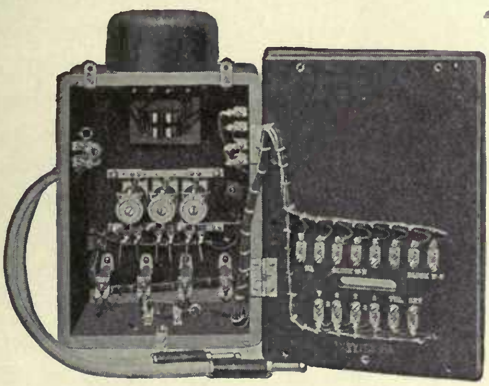


Fig. 498. Blocking Set

course, for the purpose of eliminating noise. Below the key are three combined jacks and signals. One block wire comes into each of these and a private line may be brought into the middle one. When the next block rings up, a visual signal is displayed which operates a bell in the office by means of a local circuit. The operator answers by plugging the telephone cord extending from the bottom of the set into the proper jack. This automatically restores the signal and stops the bell.

Below these signals appear four jacks. One is wired across the train wire; one across the message wire; and the other two are bridged across the two pairs of patching cords on each side of the set. The operator answers a call on any circuit by plugging his telephone cord into the proper jack.

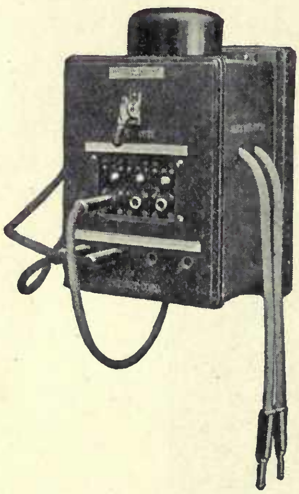


Fig. 499. Blocking Set

If a waystation is not kept open in the evening, or the operator leaves it for any reason and locks up, he can connect two blocks together by means of the block-wire cords. These are arranged simply for connecting two grounded circuits together and serve to join two adjacent blocks, thereby eliminating one station. A jack is wired across these cords, so that the waystation operator can listen in on the connection if he so desires.

In some cases not only are the telephone circuits brought into the test board, but also two telegraph wires are looped through this board before going to the peg switchboard. This is becoming quite a frequent practice and, in times of great emergency, enables patches to be made to the telegraph wires as well as to the telephone wires.

Dispatching on Electric Railways. As interurban electric railways are becoming more extended, and as their traffic is becoming heavier, they approximate more closely to steam methods of operation. It is not unusual for an electric railway to dispatch its cars exactly as in the case of a steam road. There is a tendency, however, in this class of work, toward slightly different methods, and these will be briefly outlined.

On those electric railways where the traffic is not especially heavy, an ordinary magneto telephone line is frequently employed with standard magneto instruments. In some cases the telephone sets are placed in waiting rooms or booths along the line of the road. In other cases it is not feasible to locate the telephone indoors and then iron weatherproof sets, such as are shown in Figs. 484 and 485, are mounted directly on the poles along the line of railway. With a line of this character there is usually some central point from which orders are issued and the trainmen call this number when arriving at sidings or wherever they may need to do so.

Another method of installing a telephone system upon electric railways is as follows: Instead of instruments being mounted in booths or on poles along the line, portable telephone sets are carried on the cars and jacks are located at regular intervals along the right-of-way on the poles. The crew of the car wishing to get in touch with the central office or the dispatcher, plugs into one of these jacks and uses the portable telephone set. At indoor stations, in offices or buildings belonging to the railroad, the regular magneto sets may be employed, as in the first case outlined.

On electric railway systems where the traffic is heavy, the train or car movements may be handled by a dispatcher just as on the steam railroad. There is usually one difference, however. On a steam road, the operators who give the train crews their orders and manipulate the semaphore signals are located at regular intervals in the different waystations. No such operators are usually found on electric railways, except, perhaps, at very important points, and, therefore, it is necessary for the dispatcher to be able to signal cars at any point and to get into communication with the crews of these cars. He does this by means of semaphores operated by telephone selectors over the telephone line. The telephone circuit may be equipped with any number of selectors desired, and the dispatcher can operate any particular one without operating any other one on the circuit. Each selector, when operated, closes a pair of contacts. This completes a local circuit which throws the semaphore arm to the "danger" position, at the same time giving the dispatcher a distinctive buzz in his ear, which informs him that the arm has actually moved to this position. He can get this signal only by the operation of the arm.

Each semaphore is located adjacent to a telephone booth in which is also placed the restoring lever, by means of which the semaphore is set in the "clear" position by the crew of the car which has been signaled. The wall-type telephone set is usually employed for this class of service, but if desired, desk stands or any of the various transmitter arms may be used.

It is necessary for the crew of the car which first approaches a semaphore set at "danger," to get out, communicate with the dispatcher, and restore the signal to the "clear" position. The dispatcher can not restore the signal. The signal is set only in order that the train crew may get into telephonic communication with the dispatcher, and in order to do this, it is necessary for them to go into the booth in any case.

CHAPTER XLI

TYPES OF TELEPHONE LINES

Telephone lines may be underground or overhead. If the latter, they are called *aërial lines.* Wherever placed, the lines must be insulated from each other and from other things, such as the earth. If aërial, the lines either are of bare wire supported by solid insulators, or they are of wire insulated throughout its length by some covering. That covering in the present practice is principally of rubber, gutta-percha, or dry paper.

The mechanical conditions of practice require bare aërial wires to be borne by poles or other supports 100 to 200 feet apart; to be spaced 8 to 12 inches apart; to be stretched tightly enough not to be swung together by winds, and to be strong enough to bear their own weight plus wind pressure and a load of ice. These dimensions cause the total space occupied by a line of several hundred wires to be great.

The electrical conditions of practice require of exchange (city) lines that the loop resistance be not over about 500 ohms and the mutual capacity not over about .3 microfarad. These conditions are not so severe as to require large wires far apart. Open wires on poles must be larger and farther apart for mechanical reasons than they need to be for electrical reasons. Small wires close together are good enough for exchange lines if they do not have to be strung on poles as bare wires.

The solution for these requirements is the telephone cable. Many wires can be put in a small space if cabled. Cables may be supported by poles, buildings, or fences, or may be laid in the earth or in water. There is no difference between the electrical operations of cables in the earth, in the water, and in the air.

Cabled wires have the advantage that they are less likely to individual insulation and continuity troubles than are open wires. Insulation troubles, when they do happen to cable wires, usually affect more circuits than in open-wire construction; cabled wires have higher mutual capacity than open wires; these are disadvantages. Cost facts also concern the question "cabled wires *versus* open wires for exchange lines"; the solution of all the facts is favorable to cables if the number of exchange lines along a route is more than a dozen or two.

Feasibility, first cost, owning-and-using costs, self-interest, and public policy are the considerations which control the decision whether cable shall be overhead or underground. Cities steadily increase the areas in which local laws prohibit pole lines on the street. In cities having such laws at all, and having also adequate development of telephone service, the area in which it is *economical* to place wires underground usually is larger than the area in which it is legally *obligatory* to place them so. This is fortunate for all concerned.

In general terms, the solution of the facts of costs and policy usually shows that wires shall be placed underground when there are more than 500 lines in the route. Underground cables for electrical service generally may be placed directly in the earth as gas pipes are; but gas pipes are self-protecting against most attacks, such as by picks and shovels. Cables are less so. Access to cables for changes in them is necessary; they require to be changed in position and connection and to be replaced by others. Standard underground telephone-cable practice is to provide an underground system of ducts adapted to protect the cables against mechanical damage and to allow them to be placed and replaced without further opening of the earth than was first required to lay the system of ducts. Underground cables so placed cost less to maintain than do aërial cables. The value of a cable after withdrawal from a duct is greater than that of a similar aërial cable after being taken down.

The open aërial wires of exchange lines have to be larger and further apart for mechanical reasons than they do for electrical reasons. This is not true of the open aërial wires of long-distance lines. Electrical reasons, in the design of long-distance circuits, make low resistance and low mutual capacity important. Unless the inductance be increased by loading the line, cable circuits are limited in their speaking distance from one-tenth to one-fifth the speaking distance of the same wires on poles in open air.

In other words the smallest practical open wires for a given length of exchange line are larger than their *electrical* requirements demand; the smallest practical open wires for a given length of long-distance line are larger than their *mechanical* requirements demand. Also, exchange wires would fulfill electrical requirements sufficiently well if much closer together; while long-distance wires would fulfill electrical requirements much better if much further apart. Mechanical reasons only control the spacing of both kinds of wire.

When cables are laid under water, it usually is because there is no other practical way of placing them. The solution as to the best way generally has no alternatives. A given submarine cable may not be the best way of meeting the requirements; it may be the only way.

CHAPTER XLII

OPEN WIRES

Wire for open use on insulators is made of copper, bronze, steel, or iron, or of steel covered with copper. Copper for all physical reasons is best; iron and steel are cheaper; bronze is little used. Copper-clad steel, combining strength, conductivity, and freedom from corrosion with possible low cost, is likely to become more and more useful.

Iron. Iron and steel are poorer than copper in specific conductivity. Calling the specific conductivity of copper 100, that of iron is from 12 to 18 and of steel from 8 to 12, depending upon the state and purity of the metal. Iron and steel are stronger than copper. That they rust is a great fault. Galvanizing is a protection, but its value varies widely in different situations; in certain regions having dry air and no smoke, galvanized open iron wires last twenty-five years. In most cities of the temperate zone, such wires last six to eight years. In cities burning much soft coal and near smelters, such wires often last only three years. The larger the wire, the longer it will last, as there is more of it to rust away.

Galvanizing. Galvanizing is a name for the coating of iron or steel with zinc. The coating is applied, in the "hot" process, by dipping the iron or steel in molten zinc in the presence of a flux. This is a dipping process, not an electroplating process, though the name implies the latter. In the "cold" process, the iron or steel is zinc-plated by electrical means. The hot, or dipping, process is the present standard for wire.

The test for acceptable galvanizing is:

> Immerse the sample in a saturated solution of copper sulphate for one minute, then wipe it clean. Do this four times in all. If the sample appears black after the fourth wiping, the galvanizing is acceptable; if it has a copper color, wholly or in spots, the iron is exposed. Reject such galvanizing, for the coating is too thin.

Strength. The strength of iron wire is about 3.1 times its weight per mile; of steel wire about 3.7 times its weight per mile.

Mile-Ohm. The term "mile-ohm" sometimes is used to indicate the resistance of wire. It is the weight of a wire 1 mile long and having a resistance of 1 ohm. The lower the conductivity of a metal the higher is its weight per mile-ohm. For example, for soft copper the mile-ohm is about 860 pounds; for hard-drawn copper, 880 pounds; for the best iron, 4,500 pounds; for good iron, 5,400 pounds, and for steel as high as 7,000 pounds.

Copper. Copper is drawn into wire by pulling it successively through smaller and smaller holes. It hardens in being so drawn, so it is softened (annealed) by heating and cooling. If it is not annealed after the last drawings, it has much greater strength. This is hard-drawn copper. Its uses are in open wire lines, either bare or insulated. The uses of soft copper are in other circuits. Even though from the earliest times it was known of drawn copper wire that after one or two drawings the wire became so hard as not to be successfully drawn without softening, no wire was furnished to the market in such a hardened state. The earliest uses of copper wire for line purposes were failures and it was standard practice for many years to use copper only in electrical circuits where it did not have to bear its own weight. Credit for the development of the right method is due to Thomas B. Doolittle, who developed the present successful method of producing hard-drawn copper wire for use in open lines.

Copper vs. Iron. When high conductivity and long life are required, use copper. Hard-drawn copper is stronger than soft (annealed) copper. Where greater strength than that of hard-drawn copper is required and high conductivity is not of importance, use iron or steel. This case meets certain needs of long spans. Where low cost is important, corrosive causes are not great, and high conductivity is not essential, use iron or steel. This case describes the needs of many country lines (toll lines, rural lines) under 15 miles long.

Copper-Clad Steel. The advantages of copper wire, in its superior conductivity and its freedom from corrosion when exposed to the elements, and the advantage of steel wire in its superior strength long have added zest to the search for a wire combining the advantages of both. Many efforts have been made to provide a strong steel wire with a good copper coating, but until recently these efforts have been unsuccessful. In some of the earlier attempts, the copper was applied to the wire by electroplating. It was not found that the coating would cling to the steel tightly enough to preserve it perfectly, and in time rust crept between the metals and the copper would fall away. Other attempts have been in the direction of fitting a billet of steel tightly into a copper tube, then drawing the whole into wire. In this attempt also the lack of a perfect union between the two metals defeated the attempt.

Monnot Process. The Monnot process, named after the inventor, is that employed by the Duplex Metals Company of New York, and consists of uniting the steel core and copper shell while they are hot. Under proper conditions actual welding and alloying take place between the two metals. Such a billet may be drawn into wire without breaking the contact between the two metals. The steel remains centered through many drawings and the experience which is available at the time of this writing indicates that copper-clad steel wire may be considered a practical element of electrical construction.

Characteristics. Compared with hard-drawn copper wire, copper-clad steel wire has, in general terms, higher tensile strength and lower conductivity. It is obvious that in the manufacture of copper-clad wire, its resulting tensile strength will depend both upon the grade of steel chosen for the core and upon the relative amounts of copper in a wire of given diameter. The more steel in the core, the less copper there will be in the shell, and, therefore, the greater the strength, and the lower the conductivity.

The inductance of copper-clad steel wire is less than that of iron, and yet it is more than that of copper, for the same diameter of wire, for the same distance between the two sides of the circuit, and for the same permeability of iron and steel.

Uses. Copper-clad steel wire for electrical uses may be had of conductivities 30 and 40 per cent of that of solid copper wire, but with these reduced conductivities go an increase of strength. As we have shown, there are many uses of wire for lines exposed to the elements in which a reasonable conductivity only is required, coupled with a minimum tensile strength. For these purposes a copper-clad steel wire is eminently suitable, if it is made in such a way as to be as non-corrosive as copper and if it can be bought at a lower price. Copper-clad steel wire has been used with considerable success for line wire in train-dispatching work. These lines are as a rule not of extreme length, and the freedom from corrosion of copper-clad steel wire, increased conductivity over iron, and greater strength than copper have, together with its moderate cost, made it attractive for railroads.

Insulated wires twisted in pairs for connecting subscribers' premises to nearby cable terminals would be perfectly satisfactory, so far as conductivity is concerned, if they were as small as No. 22 B. & S. gauge, as the remainder of the line in the cable is of that size. But wires as small as No. 22 B. & S. gauge can not support their own weight successfully, so that the added weight of the rubber insulation and braid would break them down promptly. If these were of high-grade steel, they might support themselves successfully, if of No. 22 B. & S. gauge, but wherever exposed at terminals or elsewhere, the steel wire would rust. It is in such cases as these and in moderate length of bare-wire lines that copper-clad wire finds use if costs permit.

Insulated Open Wire. Even when carried on glass or porcelain insulators on poles, open telephone wires sometimes require to be insulated by an actual wire covering. The circumstances making this necessary usually are where foliage may touch the wires. The best practice is to insulate such conductors with rubber compound of high insulating quality and to cover this in turn with a heavy cotton braid saturated with some weatherproof compound.

Drops. In some plans of construction, wires which leave a pole line to reach a subscriber's premises are both open wires. These wires are called "drops" or "drop wires." Where two single wires make up such a drop and the span is long, it is good practice to have at least one of them insulated, so that if the two wires swing together, as is more likely than in a straight span of a pole line, they will not short-circuit the line and throw it out of service.

The better practice for drop wires, and that which is becoming customary with the wide use of cables and the limited use of open wires in city systems, is to use two insulated wires twisted into a pair for drop service. Such twin or paired wire is known as drop wire. The conductor usually is of No. 14 or No. 16 B. & S. gauge, if of hard-drawn copper, or of No. 17 gauge, if of copper-clad steel wire. No. 14 wire is used where the climate makes ice a possible burden. No. 16 is suitable in climates where ice does not form. If No. 18 copper-clad steel wire of suitable quality can be had with a tensile strength as great as that of No. 16 hard-drawn copper, it forms an acceptable substitute in regions where ice does not form.

Wall and Fence Wire. It is becoming a more general practice to terminate underground cables on the back walls of buildings and to carry twisted pairs of wires through rings along horizontal and vertical lines on those back walls. As compared with a distributing pole, the method is more sightly and as simple to maintain. The distance between the rings being short, no great tensile strength is required of the wire. It is, therefore, good practice to use No. 18 B. & S. copper wire, with a thinner insulation than is required of drop wires.

Braiding. All classes of insulated line wires for outdoor use require a braiding saturated with a weatherproof compound as a

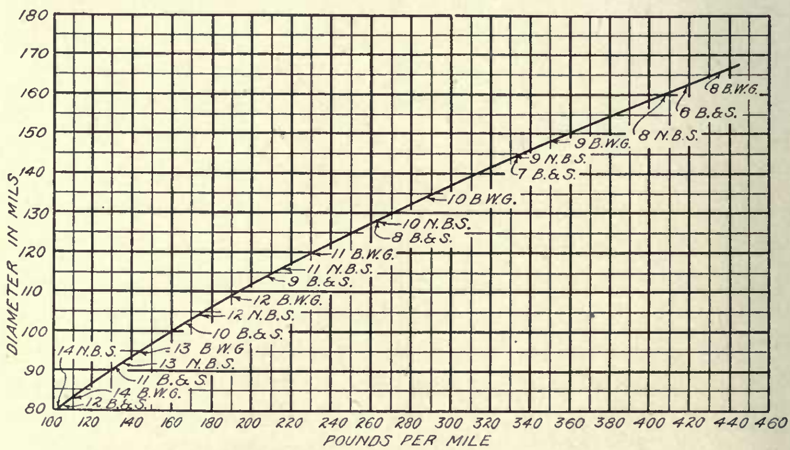


Fig. 500. Sizes and Weights of Line Wires

protection to the rubber covering, for rubber deteriorates by exposure to the air and to the sunlight, the action of sunlight being a particularly powerful deteriorating cause.

Designation of Sizes. There are three ways in which wires may be designated as to their size: by their diameter, by arbitrary gauge numbers indicating this diameter, and by their weight per unit length.

TABLE XVIII

Sizes of Copper Wire Suitable for Bare Line Construction, in Various Standard Gauges

(Arranged in Order of Size)

Number	Diameter in Mils	Weight per Mile in Pounds	Resistance per Mile of Wire in Ohms, 60° F.	Resistance per Mile of Circuit in Ohms, 60° F.
8 B. W. G.	165.	435	1.9742	3.9484
6 B. & S. G.	162.	419	2.0481	4.0962
8 N. B. S. G.	160.	409	2.0998	4.1996
9 B. W. G.	148.	350	2.4541	4.9082
7 B. & S. G.	144.3	331	2.5925	5.1850
9 N. B. S. G.	144.	331	2.5925	5.1850
10 B. W. G.	134.	287	2.9838	5.9676
8 B. & S. G.	128.5	262	3.2810	6.5620
10 N. B. S. G.	128.	262	3.2810	6.5620
11 B. W. G.	120.	230	3.7330	7.4660
11 N. B. S. G.	116.	215	3.9948	7.9896
9 B. & S. G.	114.4	208	4.1363	8.2726
12 B. W. G.	109.	190	4.5244	9.0488
12 N. B. S. G.	104.	173	4.9701	9.9402
10 B. & S. G.	101.9	166	5.1665	10.3330
13 B. W. G.	95.	144	5.9558	11.9116
13 N. B. S. G.	92.	135	6.3518	12.7036
11 B. & S G.	90.74	132	6.4891	12.9782
14 B. W. G.	83.	110	7.8038	15.6076
12 B. & S. G.	80.81	105	8.1946	16.3892
14 N. B. S. G.	80.	102	8.4005	16.8010

All three of these ways are in common practice. Wires for use in open lines are frequently designated merely by their weight in pounds per mile. As the weight and conductivity both vary as functions of the cross-section of the wire, speaking of the weight immediately suggests the conductivity. Stating the diameter of the wire in fractions of an inch or of a meter is good practice and avoids errors which are introduced by the use of the third method, that of arbitrary gauge numbers. If there were but one wire gauge in use throughout the world, these errors would not arise as often as they do. The requirements of practice having become more exact, it often is found that a wire having exactly the right cross-section to meet a given case falls between two sizes of a given wire gauge system.

Wire Gauges. For use in actual telephone lines, there are three principal wire gauges. These are the American wire gauge (also known as the Brown and Sharpe gauge, abbreviated B. & S.), the new British standard gauge (legal in Great Britain; also known as English Legal Standard and abbreviated N. B. S. and E. L. S.), and the Birmingham wire gauge (B. W. G., also known as Stubs gauge).

All of these gauges are in common use in the United States. The Brown and Sharpe gauge is only universal in this country for the smaller wires. Wires in windings of apparatus, for example, do not follow any other gauge. In line construction, the special needs of a case may make it necessary to choose sizes in other than the Brown and Sharpe gauge.

TABLE XIX

Size, Weight, Approximate Elastic Limit, Approximate Breaking Weight, and Average Resistance of Copper-Clad Wire

(40 Per Cent Conductivity)

B. & S. Gauge No.	Weight Per Mile	Approximate Elastic Limit	Approximate Breaking Weight	Av. Resistance in Ohms per Mile at 60° F.
0000	3140.	8523.	9470.	0.634
000	2490.	6660.	7400.	0.800
00	1975.	5922.	6580.	1.009
0	1570.	4707	5230.	1.272
1	1240.	4104	4560.	1.605
2	985.	3240.	3600.	2.024
3	780.	2970.	3300.	2.552
4	620.	2340.	2600	3.217
5	491.	1980.	2200.	4.060
6	390.	1530.	1700.	5.117
7	309.	1305.	1450.	6.450
8	245.	035.	1150.	8.132
9	194.	855.	950.	10.26
10	154.	684.	760.	12.93
11	122.	558.	620.	16.33
12	97.	441.	490.	20.57
13	77.	351.	390.	25.90
14	61.	288.	320.	32.70
15	49.0	225.	250.	41.20
16	38.3	180.	200.	52.05
17	30.5	149.	165.	65.45
18	24.1	117.	130.	82.68
19	19.1	90.	100.	104.2
20	15.2	72.	80.	131.1

Characteristics of Copper Wire. The diameters, weights, and resistances of copper wires of all the sizes in common use in bare-wire telephone lines appear in Table XVIII.

The curve of Fig. 500 gives the weight per mile of wire of the sizes given in Table XVIII. The curve gives at a glance an idea of the similarity between certain sizes of the different gauges.

Characteristics of Copper-Clad Wire. The mechanical and electrical characteristics of copper-clad wire, having a conductivity of about 40 per cent of that of copper wire of the same gauges, are given in Table XIX.

Characteristics of Iron Wire. The mechanical and electrical characteristics frequently specified for iron wire, of the sizes most commonly used for telephone lines, are given in Table XX.

TABLE XX

Size, Weight, Tensile Strength, and Approximate Resistance of Iron Wire Commonly Used in Telephone Lines

B. W. G. Gauge	Dia. in Mils	Length of Bundles Miles	Weight in Lb. per Mile	Min. Tensile Strength in Lbs.			Approx. Resis. in Ohms, per Mile		
				E.B.B.	B. B.	Steel	E.B.B.	B. B.	Steel
6	203.	$\frac{1}{3}$	590	1475	1652	1770	8.0	9.5	11.0
8	165.	$\frac{1}{2}$	390	975	1092	1170	12.1	14.4	16.7
9	148.	$\frac{1}{2}$	314	785	879	942	15.0	17.8	20.7
10	134.	$\frac{1}{2}$	258	645	722	774	18.2	21.7	25.2
11	120.	$\frac{1}{2}$	206	515	577	618	22.8	27.2	31.6
12	109.	$\frac{1}{2}$	170	425	476	510	27.7	32.9	38.2
14	83.	$\frac{1}{2}$	99	247	277	297	47.5	56.6	65.7

CHAPTER XLIII

CABLES

Early Types. Early telephone cables were copies of telegraph cables. For outdoor use, the wires were insulated with rubber; for indoor use they were insulated with cotton. Rubber soon was found unsatisfactory for telephone cables, principally on account of its high specific inductive capacity. Cotton insulation, as used on the wires of indoor cables, was found preferable in that respect, so such cables, covered by a lead sheath to keep the cotton dry, were used somewhat widely. The lead sheath was applied by threading the cable through successive lengths of lead pipe, and soldering together the adjacent ends of the sections of pipe. A next step in the development of the process was to pass the cabled wires through a machine to make the lead pipe directly upon them, in a continuous length. The cotton covered and cabled wires were saturated with paraffin or with some hydrocarbon compound.

Dry Paper. The search for an insulating material of still lower specific inductive capacity finally led to the adoption of the present standard, dry paper, a material much better than others because a cable insulated with it contains so much air, not only in the paper itself, but in the spaces between the wires, when the core of wires and paper is not compressed too tightly.

Manufacture. The process is roughly that of insulating the untinned copper wire by loosely wrapping paper ribbon around it, twisting two wires so insulated into a pair, laying up the requisite number of pairs into a rope, and forming a lead sheath over it.

Conductors:—Cables for exchange uses usually are formed of No. 19 or No. 22 B. & S. gauge wires. Paper ribbon $\frac{1}{2}$ to $\frac{5}{8}$ inch wide, and from .002 to .004 inch thick, is wrapped spirally on the wire. The edges of the spirals of paper overlap. Either one or two paper wrappings are applied, as required by the fancy of the engineer or the real requirements of the cable's intended use. A single wrap suffices for all needs in most cases, though repairs requiring boiling out of moisture by hot paraffin are more certainly done when two wrappings exist.

Pairs:—Two paper-wrapped wires are then twisted into a pair, the two wires having different colored papers, to enable them to be distinguished from each other in splicing and terminating. The

Fig. 501. Paper Cable

"lay" of the twist, *i. e.*, the length of one complete spiral, varies from 3 to 6 inches, depending on the size of wire used; the smaller the wire, the shorter the length of lay. The reason for twisting the wires of pairs in cables is the same as that for transposing the wires of an open air line, viz, in order to neutralize the effects of electromagnetic and electrostatic induction between adjacent lines. In telephone cables, if the wires were not twisted into pairs, it would be possible for conversations which are being carried on on one line to be overheard on another line.

Core:—A number of pairs are taken as a beginning, and others are wrapped around them in a spiral layer. Over this, other layers

Fig. 502. Paper Cable

are wrapped, the direction of the spiral reversing from layer to layer. When all the pairs are in place, one or more layers of paper tape are wrapped over the entire cable-core to hold it in form. Some makers use a binding of cotton yarn instead of the paper tape, or with it. The wick-like nature of cotton yarn is an objectionable quality, as cotton carries moisture further from a fault than does paper tape alone.

Drying:—The cable-core now is dried, to free the paper from moisture absorbed from the air before and during the manufacture of the core. Heat is applied by putting the reeled core into an oven, and often by exhausting air from the oven. The core is then drawn directly from its reel in the oven into and through a lead press to apply the sheath. Figs. 501 and 502 show finished cables.

Forming Lead Sheath:—It is an interesting way in which the lead press acts, to mould a lead or lead-alloy sheath directly upon the cable-core. Fig. 503 is not a slavishly exact picture of a lead press in action, but is meant to help show how a lead press works. The core of the cable *6* passes into the press at the right of the figure, and emerges at the left with its sheath *1* moulded over it. Let *4* represent, in general terms, a strong containing vessel, acting as the barrel of the press. Note that everything shaded as are the areas *2* in the figure, is a part of one mass of lead, hot but not quite fluid. The piston *5* presses downward on this mass of lead, and the lead is forced out through the opening in the part *7*, through which also the cable emerges. This opening and the part *3*, taken as a unit, form the *die* of the press, and it is the die which is the unique feature of the whole matter. Obviously the mere hole in the side of the press would squeeze out lead and the cable together, by the pressure of the piston, but this would compel the sheath to compress the core. The part *3* cares for this feature. The outer surface of the part *3* moulds the *inner* surface of the sheath, just as the walls of the hole in the part *7* mould the *outer*. If it be noted that the mass of lead is always *one* mass, a part always exuding from the press in the form of a pipe, carrying

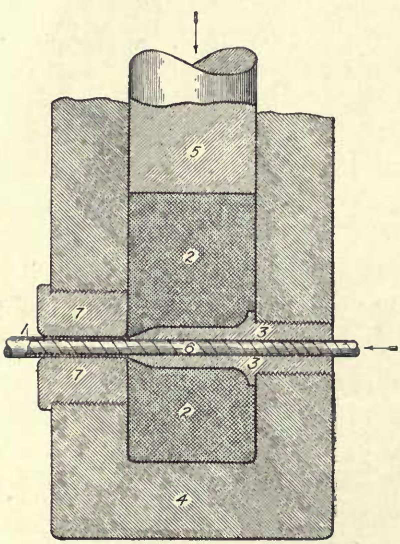


Fig. 503. Principle of Lead Press

the cable within it, the thought will be complete. If the core should be omitted, a mere lead pipe would exude. This re-suggests the fact that the lead is not molten but semi-molten only, and flows partly because softened by heat and partly because of the great pressure upon it.

Alloyed Sheath:—An alloy of 97 per cent lead with 3 per cent tin is used as sheath material in some cables. The tin originally was adopted to lessen the corrosive effect of acetic acid from wood ducts, but that hazard having disappeared through the change of methods in duct construction, the tin was retained in the belief that it gave a tougher sheath, less likely to be crushed by misuse or to be cracked from vibration and flexure. The tendency of present belief is favorable to the alloy with tin.

Capacity. In a cable formed of No. 19 B. & S. gauge wires it is possible to secure a mutual electrostatic capacity as low as .05 microfarad per mile of pair, the term *mutual capacity* meaning the ca-

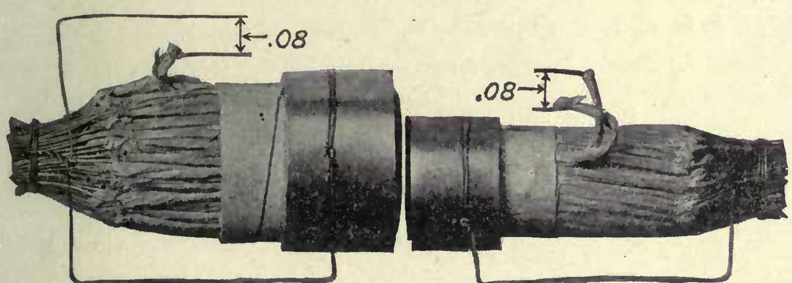


Fig. 504. Relative Sizes of Cables Having Same Numerical Capacity

pacity from one wire to another only. Capacities are also expressed in terms of the capacity of one wire with relation to its mate and all the other wires together. Measured in the latter way, the capacity is about 50 per cent greater than when measured in the former way. Capacity by the second method is sometimes known as *"regular"* capacity, although one is no more regular than the other.

Mutual and "Regular." The two methods of specifying should be contrasted. One says: *"The electrostatic capacity of the wire, measured against its mate, the remaining wires being grounded to the sheath, shall be not more than x microfarads per mile."* This is *mutual* capacity. The other says: *"The electrostatic capacity of* *the wire, measured against the remaining wires grounded to the sheath, shall be not more than x microfarads per mile.*" This is "*regular*" capacity.

Fig. 504, which is from a photograph loaned by the Standard Underground Cable Company, shows the relative sizes of cables specified to have *the same numerical capacity* in the two methods of expression. In actual terms, the capacity of the larger cable is only .054 microfarad per mile, expressed in the preferable form, as mutual capacity. The reason for calling the mutual expression the better is that it is the amount of mutual or shunt capacity which determines the influence of capacity on voice currents. For purposes of calculation the capacity enters in that form. Therefore, it is rational to speak of and think of it in those terms.

Effect of Temperature on Capacity. Cables should have their specified capacities when the core has a temperature of 60° or 80° F., or some other known temperature. If the test is not made with the core actually at that temperature, the corrective factors given in Table XXI should be used to learn the capacity at 60° F. To apply them, merely multiply the observed capacity by the factor in the table corresponding to the observed temperature. The product is the capacity at 60° F. This table is due to the tests of H. W. Fisher.

Insulation. The insulation resistance of dry-core telephone cables should be specified as not less than 500 megohms per mile at 60° F. Each wire is measured against all the others grounded to

TABLE XXI

Corrective Factors for Capacity

Observed Temperature, Fahrenheit	Factor
30°	1.065
40	1.043
50	1.021
60	1.000
70	0.970
80	0.945
90	0.918
100	0.894
110	0.864
120	0.836
130	0.805

the sheath. If not tested at that temperature, the corrective factors given in Table XXII should be used. That is, multiply the observed insulation resistance by the factor corresponding to the observed temperature. The data of this table is also due to tests of H. W. Fisher.

It will be seen, therefore, from a study of Tables XXI and XXII that the colder the cable, the better it is, the insulation being higher and the mutual capacity lower.

Diameters and Weights. The electrostatic capacity, thickness of sheath, external diameter, and approximate weight of paper insulated cable, of the sizes most frequently employed in telephone use, are given in Table XXIII. It must be understood, however, that these figures, particularly as to diameters and weights, are subject to considerable variation.

Submarine Cables. *Paper.* Submarine cables for telephone lines, in present practice, are of limited length. Unless they differ radically in construction, submarine cables have the same general characteristics as underground cables. Present apparatus enables good speech to be limited by about 35 miles of No. 19 B. & S. gauge dry-core cable, unless loading coils are inserted. Under that length, for distances where unloaded underground cables would be practical, submarine cables are used freely.

Armor:—The usual practice, for such reasonable lengths of submarine cables, is to add to the cable, over the sheath, a protecting armor of some kind. No ducts being available in submarine work,

TABLE XXII

Corrective Factors for Insulation

Observed Temperature, Fahrenheit	Factor
60	1.00
65	1.67
70	2.45
75	3.33
80	4.66
85	6.85
90	7.66
95	9.45
100	11.65
110	19.40
120	39.00

TABLE XXIII

Aërial and Underground Telephone Cable

No. Pairs	Gauge B. & S.	Electro-static Capacity	Thickness of Sheath	Approximate External Diameter	Approxim'e Weight Per Foot
5	22	High	$\frac{1}{12}$	0.48	0.55
10	22	High	$\frac{1}{12}$	0.59	0.71
15	22	High	$\frac{1}{12}$	0.66	0.83
20	22	High	$\frac{1}{12}$	0.72	0.93
25	22	High	$\frac{1}{12}$	0.77	1.02
50	22	High	$\frac{1}{12}$	0.97	1.45
50	20	High	$\frac{3}{32}$	1.10	1.88
100	22	High	$\frac{3}{32}$	1.32	2.36
100	22	Low	$\frac{3}{32}$	1.50	2.63
100	20	High	$\frac{1}{8}$	1.57	3.60
100	20	Low	$\frac{1}{8}$	1.81	4.11
200	22	High	$\frac{1}{8}$	1.84	4.43
200	22	Low	$\frac{1}{8}$	2.11	4.99
200	20	High	$\frac{1}{8}$	2.11	5.47
200	20	Low	$\frac{1}{8}$	2.46	6.19
200	19	High	$\frac{1}{8}$	2.24	6.08
200	19	Low	$\frac{1}{8}$	2.65	6.94
300	22	High	$\frac{1}{8}$	2.21	5.71
300	22	Low	$\frac{1}{8}$	2.51	6.32
300	20	High	$\frac{1}{8}$	2.53	7.09
300	20	Low	$\frac{1}{8}$	2.96	7.94
300	19	High	$\frac{1}{8}$	2.69	7.95
300	19	Low	$\frac{1}{8}$	3.20	9.04
400	22	High	$\frac{1}{8}$	2.51	6.84
400	22	Low	$\frac{1}{8}$	2.86	7.56
400	20	High	$\frac{1}{8}$	2.89	8.56
400	20	Low	$\frac{1}{8}$	3.43	9.37
600	22	High	$\frac{1}{8}$	3.20	9.21
90	16	Low	$\frac{1}{8}$	2.88	7.20
43	13	Low	$\frac{1}{8}$	2.88	7.17
50	10	High	$\frac{1}{8}$	2.88	8.95

NOTE. High capacity 0.067—0.090 mutual; 0.10—0.12 grounded. Low capacity 0.054—0.067 mutual; 0.080—0.10 grounded.

the armor is necessary for protection of the cable, lest its sheath be torn or punctured. In lakes and seas, anchors may foul the cable. The waters may chafe it against rocks. In streams, drifting things may encounter it.

Two kinds of armor are used, one of steel tape, shown in Fig. 505, and the other of steel wires, shown in Fig. 506, both of these being applied spirally. In both cases a cushion or bed of tarred jute is laid over the lead cable sheath, then the armor of wires or steel tape is applied, then another tarred jute covering, finished by applying lime and sand. The cable then may be reeled and unreeled without danger of the armor injuring the sheath or core by buckling.

The wire armor is the better and has been used since the first deep-sea telegraph cables were made; it protects many miles of lead-covered cable and very many more miles of gutta-percha cable without lead sheath.

Fig. 505. Submarine Cable Steel-Tape Armor

Double sheaths of lead sometimes are used in lieu of or in conjunction with armor. The failure of one sheath, in this construction, may still allow the other to protect the cable core from the water.

Loading. For longer lengths than those just considered, loading coils are essential, as the capacity can not be kept low enough in any cable to allow it to approach the speaking quality of an open wire line. There are only two known ways of loading cables: by inserting distributed inductance and by inserting "lumped" inductance — loading coils at intervals. Only the latter way has been generally employed; however, the former has been used in several instances with submarine cables. In underground cables, these coils are located in manholes. In submarine cables, they have to be incorporated in the cable itself, a matter of no great simplicity, as the cable needs to be paid out from a ship, and such lumps as loading coils add little to the ease of the task. Such a cable, however, has been laid in Lake Constance. It is a lead-sheathed, dry-core cable, the loading coils being within the sheath.

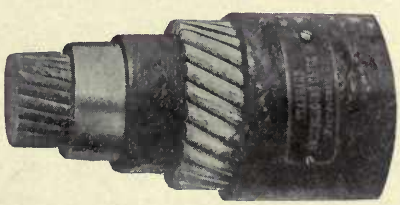


Fig. 506. Submarine Cable Steel-Wire Armor

Rubber and Gutta-Percha. For uses where capacity is negligible, such as for very short lengths, rubber-insulated wires may be formed into cables and armored with wires or tape as in Figs. 505 and

506, the lead sheath being omitted. The rubber compound on the wires serves as a sufficient protection against water.

Gutta-percha insulated submarine cables have the advantage that they also require only mechanical protection by armor, and no lead sheath. They have, however, the disadvantage that the specific inductive capacity of rubber is high. It has been asserted by competent cable engineers, however, that the contribution to human knowledge by O. Heaviside is not limited in its application, and that as inserting serial inductance in small degree offsets shunt capacity of small degree, the same general result would ensue if larger inductances were inserted to offset larger capacity.

This seems reasonable. Indeed, it would be strange if it were not so. The proof is at hand, in one of two telephone cables recently laid between England and France. An unloaded cable has been in service under those waters for years. Recently the governments of England and France agreed to lay two new cables, each govern-

Fig. 507. Arrangement of Loading Coils in Cables

ment to lay one of them. France laid a duplicate of the old one. England laid a loaded gutta-percha cable, of vastly superior working qualities, and having in it the loading inductances in lumps. This cable contains two pairs of soft copper wires, each weighing 160 pounds per mile of wire (about No. 10 B.& S. gauge). Each wire is insulated with 300 pounds of gutta-percha per mile. The length of the cable is 24.2 statute miles, and the total loop resistance of each pair, unloaded, is 302.5 ohms. Twenty loading coils are inserted in each wire; the two coils of a pair of wires, at each point of loading, are wound on one circular core. Therefore, two cores carrying two coils each are inserted at each point, the points being 1.153 statute miles (one nautical mile) apart. The coils have an inductance of .1 henry and a resistance of 6 ohms each. The mutual capacity these coils oppose is (for the unloaded cable) .12 microfarad per mile. Fig. 507 shows the arrangement of mounting the coils in cable. The increase in size of the cable at the loading point is marked, but it was possible to pay out the entire length of cable without unusual risk or difficulty.

CHAPTER XLIV

POLES AND POLE FITTINGS

Pole Equipment. *Poles.* The cheapest way to support line conductors and the way that is nearly always practiced, except in communities of dense congestion, is to place them on poles. The poles are usually of wood, although in special cases structural iron poles and reinforced concrete poles have been used. Owing to the increasing scarcity of timber in the United States, it is not unlikely that the reinforced concrete pole will find greater favor in the future, as the cost of wooden ones increases and as the methods of manufacturing those of concrete are bettered and cheapened.

Cedar:—All things considered, the Michigan, or white cedar, pole is the best adapted for telephone use. While cedar is not in itself a wood of very great strength, it has several important things in its favor. Principal among these is its long life. A good cedar pole, properly cut and seasoned, may under ordinary circumstances be depended upon for a life of from sixteen years up. Another thing in its favor is its shape. Nature caused it to grow in just about the form that an engineer would have designed it for strength, *i. e.*, large at the butt and gently tapering toward the top. Of less importance, it is a light wood and, therefore, easily transported and erected, and also presents a sightly appearance, if poles may ever be said to be sightly.

Chestnut:—Another good wood is chestnut. It has a life equal to or greater than that of white cedar and is of stronger fiber. It is not so well shaped as the white cedar pole, being relatively smaller at the butt for a given length and top diameter; its greater inherent strength, however, in large measure makes up for this deficiency, and while it is somewhat less sightly than cedar and also much heavier, there is very little to choose between them. Chestnut is very largely used in the eastern states and in the south, where the cost of transportation of cedar poles is almost prohibitive.

Other Timbers:—In sections of the country where neither white cedar nor chestnut are available, cypress, pine, tamarack, and Idaho cedar are employed with varying degrees of success. Cypress under certain conditions is said to have excellent lasting qualities, but the writers' experience with it and the experiences of others has seemed to indicate that cypress is, to say the least, a treacherous wood, and will often rot away to an astonishing extent in a very few years, leaving only a small core of sound wood at the center of the pole. There are, however, well-authenticated cases of cypress poles that have shown good life, and its very low cost in some localities frequently forces it into consideration, especially where the conditions for its endurance are known to be favorable.

Idaho cedar is widely employed throughout the country particularly where very high poles are required. The fiber of the wood is good, but these poles have a very grave defect in their extreme slenderness for a given top dimension. They are perfectly smooth and straight, and there is a common joke about them to the effect that either end of them may be put in the ground equally well.

In southern and western districts pine poles are widely used with varying success. Yellow pine, on account of the amount of pitch it contains, would lead one to believe that it would have good lasting qualities, but it frequently rots very rapidly.

Cutting:—Poles should be cut from live, growing timber, while the sap is down, and should be free from knots and shakes, and reasonably sound. With cedar poles a certain amount of butt rot, *i. e.*, rot exposed at the butt section of the pole, is to be permitted, since it is not commercially possible to obtain poles free from this. With cedar and chestnut poles it is not practicable always to secure perfectly straight poles and, therefore, a reasonable amount of crookedness is to be permitted.

Sizes:—Standard sizes of poles vary in length by five-foot steps. The usual way of indicating the size of a pole irrespective of its height is by the diameter in inches at its top. Thus, a pole referred to as a "7-inch 30" would be 7 inches in diameter at the top and 30 feet long. On account of the great variations that may occur in the butt sizes of poles of equal top diameter and length, it is well that the butt sizes be specified also, since this is a feature having most bearing on the strength of the pole.

Northwestern Cedarmen's Specifications:—The latest specification of the Northwestern Cedarmen's Association, which practically governs the purchase of white cedar poles in the United States, is as follows:

Standard Telegraph, Telephone, and Electric Poles.—Sizes, 5-inch 25 foot, and upwards. Above poles must be cut from live, growing timber, peeled, and reasonably well proportioned for their length. Tops must be reasonably sound, and when seasoned must measure as follows: 5-inch poles, 15 inches in circumference at top end; 6-inch poles, 18½ inches in circumference at top end; 7-inch poles, 22 inches in circumference at top end. If poles are green, fresh cut, or water soaked, then 5-inch poles must be 16 inches in circumference at top end, and 6-inch poles must be 19½ inches in circumference, and 7-inch poles must be 22¾ inches in circumference at top end. One way sweep allowable not exceeding 1 inch for every 5 feet; for example, in a 25-foot pole, sweep not to exceed 5 inches, and in a 40-foot pole not to exceed 8 inches. Measurement for sweep should be taken as follows: That part of the pole when in the ground (six feet) not being taken into account in arriving at sweep, tightly stretch a tape line on the side of the pole where the sweep is greatest, from a point 6 feet from butt to the upper surface at top, and having so done measure widest point from tape to surface of pole and if, for illustration, upon a 25-foot pole said widest point does not exceed 5 inches, said pole comes within the meaning of these specifications. Butt rot in the center including small ring rot outside of the center; total rot must not exceed 10 per cent of the area of the butt. Butt rot of a character which plainly seriously impairs the strength of the pole above the ground is a defect. Wind twist is not a defect unless very unsightly and exaggerated. Rough large knots if sound and trimmed smooth are not a defect.

Trimming:—The knots on all poles should be closely trimmed and the bark removed, as the presence of the bark induces rotting. It is preferable to remove the bark by stripping, but if this is not feasible it should be done by shaving, and the amount of shaving in all cases should be kept a minimum, since the strength and life of a pole is reduced by too deep shaving. The poles should be thoroughly seasoned before setting.

Treating:—The constantly increasing cost of wooden poles, due to the scarcity of timber, has led in some cases to the practice of treating the poles with a preservative. This is not generally done where cedar and chestnut are used, but in the south where the difficulty of securing a long-lived pole is very great, there is a growing tendency toward the use of these preservative processes. The most successful of these so far is the process of creosoting, which consists in the impregnation of the pole with creosote, which is a dead oil of coal-tar.

There are a number of methods by means of which this impregnation is accomplished, some of them securing a penetration of the creosote

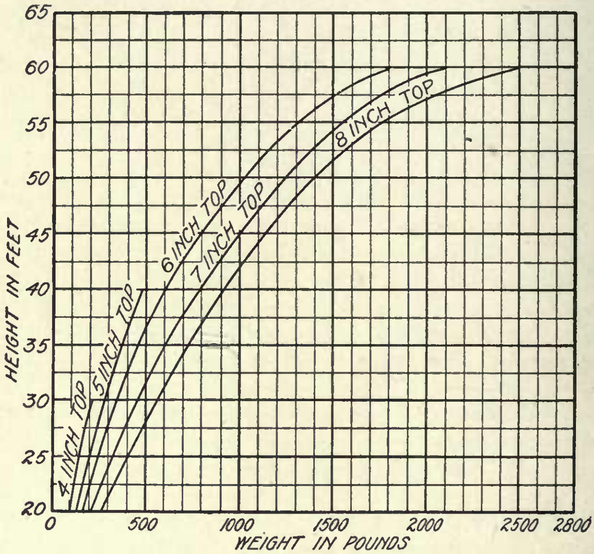


Fig. 508. Weights of Cedar Poles

for only a short distance below the surface, and others a penetration reaching almost or quite to the center of the pole. Another material used for impregnation is chloride of zinc. The reports of the United States Department of Agriculture give much valuable information and data on the subject of preservation of timber, particularly that used for telephone and telegraph poles, railway ties, etc.

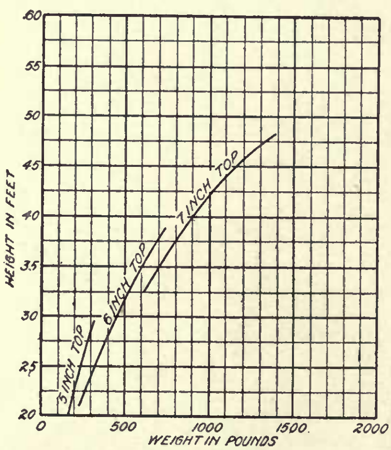


Fig. 509. Weights of Cypress Poles

In localities where timber is cheap and not of good lasting quality and where creosoting plants have been established, it is undoubtedly economical to use creosoted poles. In other localities it is found that creosoting an already expensive pole results in prohibitive cost.

It is the practice, however, of the large telephone and telegraph companies to treat the poles externally by painting them for a distance of about three feet, above and below the ground line, with two coats of *carbolineum avenarius.* The roofs and gains of the poles are also painted with the same material. In city work the poles are usually painted all over with a good oil paint.

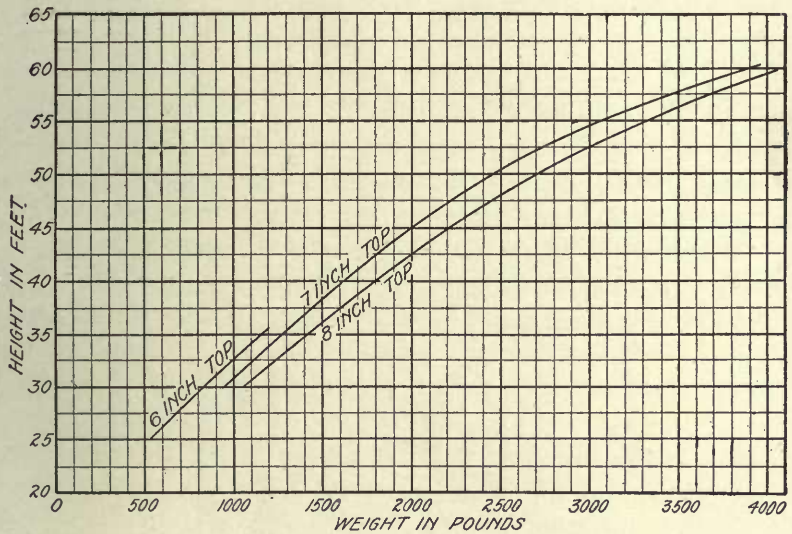


Fig. 510. Weights of Chestnut Poles

Weights:—The curves of Figs. 508, 509 and 510 give the approximate weights of different sizes and lengths of cedar, cypress, and chestnut poles.

Table XXIV gives useful information concerning the loading of cedar poles on cars. Forty-foot poles and longer are usually loaded on two cars, and the number of poles in each case as given in this table is that constituting a single or double load.

Gaining:—Where a pole is to carry more than one or two bare wires, cross-arms are provided for supporting the wires, and in order to afford a seat for these, gains or mortises are cut in the side of the pole. It is a mistake to make these gains too deep, as the pole is greatly weakened and its life is shortened thereby. It should merely be a

TABLE XXIV

Cedar Poles

On Single Cars		On Double Cars	
Size	Number in Load	Size	Number in Load
4″ 25′	175 to 225	7″ 40′	60 to 75
5″ 25′	150 to 200	7″ 45′	50 to 65
6″ 25′	100 to 125	7″ 50′	40 to 50
7″ 25′	75 to 100	7″ 55′	35 to 45
5″ 30′	100 to 125	7″ 60′	25 to 35
6″ 30′	75 to 100	7″ 65′	20 to 25
7″ 30′	60 to 80		
5″ 35′	75 to 100		
6″ 35′	60 to 80		
7″ 35′	55 to 75		

rectangular notch about ½ inch deep and of sufficent height to just accommodate the cross-arm.

Roofing:—In order that the tops of the poles may drain as rapidly as possible, and thus rid themselves of moisture which would otherwise tend to rot them, the top is usually beveled in two planes

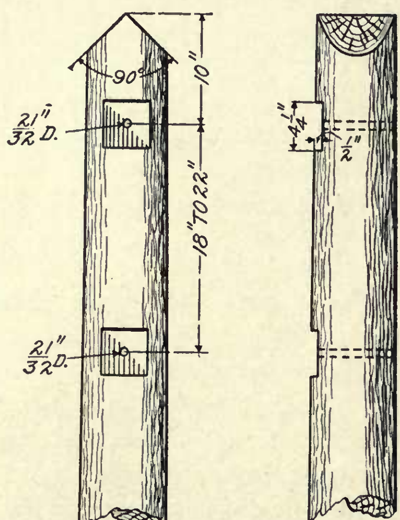


Fig. 511. Details of Roofing and Gaining

parallel to the direction of the pole line so as to form a roof. The details of the roofing and gaining of a pole are shown in Fig. 511.

The distance between the centers of the gains and, therefore, between the centers of the cross-arms, varies from 18 to 22 inches, according to the type of line.

Cross-Arms. Cross-arms for telephone work may be of two, four, six, eight, and ten pins each, and the best practice usually is to employ only ten-pin arms, even though a fewer number of wires than ten are to be strung. This provides for growth, which nearly always is greater than expected. Good cross-arms are becoming scarce. They are most commonly of white pine, yellow pine, or Washington fir. The latter is by far the most expensive in most parts of the United States on account of the transportation charge, but as a rule it is true economy to use them. The life of cross-arms varies from four to sixteen or more years, according to the kind of wood used and the climatic conditions. There are two sizes of cross-arms employed in telephone work, one known as the *telephone arm* and having a cross-section of $2\frac{3}{4}$ by $3\frac{3}{4}$ inches. The other, known as the *standard arm,* has a cross-section of $3\frac{1}{4}$ by $4\frac{1}{4}$ inches. The saving in cost of the smaller arm does not usually warrant its use.

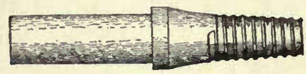


Fig. 512. Insulator Pin

Pins:—The arms are bored usually with $1\frac{1}{4}$-inch holes, into which the pins for supporting the insulators are placed. A standard pin

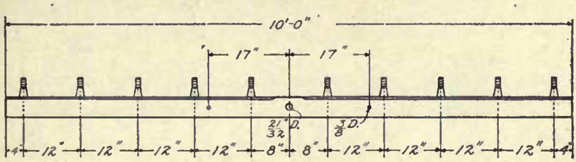


Fig. 513. Ten-Pin Cross-Arms

is shown in Fig. 512. They are made of various woods, locust, catalpa, maple, Bois d'Arc, kalkeen, or oak. A ten-pin arm equipped with pins is shown in Fig. 513, the spacing between pins being that of standard practice.

Hardware. Through Bolts.—The standard way of attaching a cross-arm to the pole is by means of a through bolt long enough to pass through the pole and the cross-arm and receive a nut on its screw-threaded end. A large, flat iron washer about $\frac{3}{16}$ inch thick and $2\frac{1}{4}$ inches square is placed under the head of the bolt and under the nut to afford a large bearing surface on the wood against

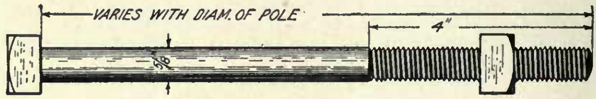


Fig. 514. Through Bolt

which the bolt may draw. The details of a standard through bolt are shown in Fig. 514.

Braces:—In order to more rigidly support the cross-arm on the pole, two braces are employed for each arm. These consist usually

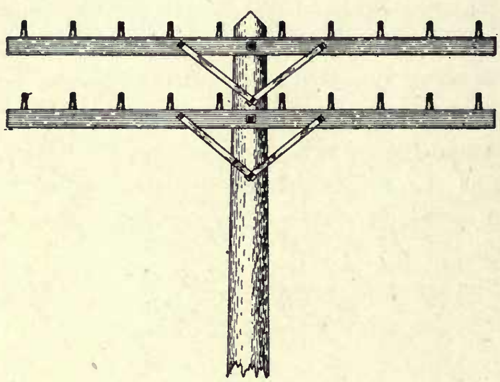


Fig. 515. Cross-Arms Attached

of rectangular strips of wrought iron about $\frac{1}{4}$ by $1\frac{1}{4}$ inches in cross-section and from 20 to 30 inches in length. The details of the method of securing a cross-arm to a pole, including the attachment

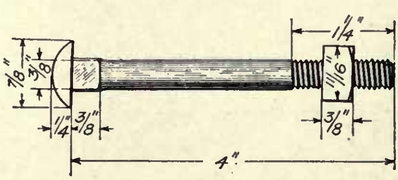


Fig. 516. Carriage Bolt

of the cross-arm braces, is shown in Fig. 515. Where the two lower ends of the braces meet at the pole they are secured by a single lag screw passing through both of them at the end of the pole, and the outer ends of the braces are secured to the cross-arm by means of carriage bolts passing through both the brace and the arm and held in place by a nut and washer.

Carriage Bolts and Lag Screws:—The form and dimensions of a

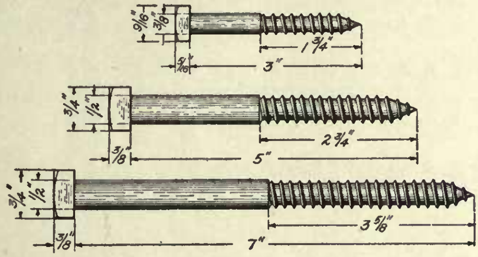


Fig. 517. Lag Screws

carriage bolt for attaching braces to cross-arms are shown in Fig. 516. Fig. 517 shows three sizes of lag screws, the 5-inch size usually being employed to secure two braces to the pole.

Pole Steps:—The standard iron pole step is shown in Fig. 518 and is made of $\frac{5}{8}$-inch stock. It is attached to the pole by drilling a $\frac{1}{2}$-inch hole in the pole to a depth of from 2 to 3 inches for cedar and about 4 inches for harder woods, and then the step is driven into the pole to such a depth that the distance from the pole to the outside edge of the step is approximately $5\frac{1}{2}$ inches. Ordinarily the


Fig. 518. Pole Step

lower five steps on a pole are made of triangular pieces of wood secured to the pole by one 60d and one 20d nail. The purpose of employing the wooden steps at the bottom is to avoid the injury which the projecting iron steps might cause to passing persons or teams.

Hardware Requirements:—The cross-arm braces, bolts, steps, and other pieces of hardware employed in pole line work are commonly referred to as pole hardware. In general the material should of course be free from flaws, cracks, and other imperfections.

In the case of bolts, rods, braces, steps, and like fittings, the wrought iron or mild steel, of which they are necessarily made, should have the properties which conform to the standard specifications adopted by the bridge builders, as set forth in the handbook on constructional iron, issued by the Carnegie Steel Company in 1893. Where malle-

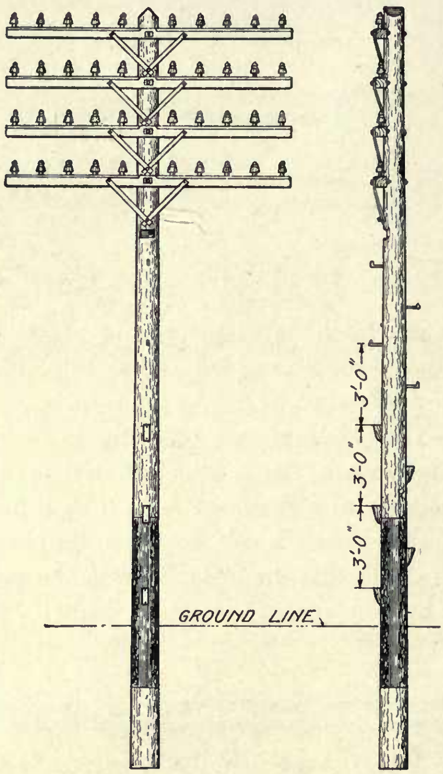


Fig. 519. Equipped Pole

able castings are used, as in clamps, they should be reasonably straight, smooth, and true to pattern and free from imperfections. They should also be capable of being bent to a reasonable degree without breaking. All bolts and rods should be capable of standing a 90-degree bend on a radius equal to the diameter of the bolt without fracture of the steel on the outside of the bend. The breaking strength of all bolts and drive screws should be at least equal to the following:

Size of Bolt	$\frac{3}{8}$ inches	Breaking Strength	3400 pounds
	$\frac{1}{2}$ inches		6300 pounds
	$\frac{5}{8}$ inches		10000 pounds

The holding power of the nuts on such bolts should not fall below the figures just given.

Galvanizing:—Hardware, including bolts—threads and nuts—should be thoroughly galvanized. A coating of zinc should be evenly and uniformly applied and should be capable of withstanding the standard four-immersion test in a saturated solution of sulphate of copper.

Equipped Pole. The number of cross-arms on a pole depends, of course, on the number of open wires to be carried, it being understood that in standard practice ten wires is the maximum that any arm may carry. The growing tendency to use cable is causing the gradual disappearance of very heavy bare wire pole leads, and poles of enormous height carrying ten, fifteen, and even twenty-five cross-arms are no longer seen. Few lines are now to be found with more than six cross-arms, and these only in heavy cross-country lines.

A pole completely equipped with four cross-arms is shown in Fig. 519. The steps shown on the sides of this pole would ordinarily be employed only in city work, and not on toll lines except at test poles.

Pole Setting. The distance to which poles should be set in the ground depends on the height of the pole, character of the soil, and

TABLE XXV

Pole Setting Data

Length of Pole	Depth in Soil	Depth in Rock
20 feet	4 feet	3 feet
25 feet	5 feet	3 feet
30 feet	5½ feet	3½ feet
35 feet	6 feet	4 feet
40 feet	6 feet	4½ feet
45 feet	6½ feet	4½ feet
50 feet	7 feet	4½ feet
55 feet	7 feet	4½ feet
60 feet	7½ feet	5 feet
65 feet	7½ feet	5 feet
70 feet	8 feet	5½ feet

the strain to which the pole is to be subjected. In general, Table XXV represents good practice.

Where a pole is set on a sloping bank, the depth as given in Table XXV should measure from the lowest side of the opening of the hole.

With this preliminary discussion of poles and pole fittings we may divide the discussion of pole lines into three principal headings: Toll Lines, Rural Lines, and City or Exchange Lines.

Toll Lines. The term toll lines is rather loosely applied to lines extending across country between cities or towns and carrying the wires which serve as interurban trunks. A governing factor in the construction of such a line is the number of wires that it will ultimately carry, since this determines the number of cross-arms and, in large measure, the height and the strength of the pole.

Sizes of Poles. The usual well-constructed toll line of the present day is built *close to the ground,* that is, it is built on poles as short as will allow the use of the required number of cross-arms and at the same time give the required clearness under the wires. A great many toll lines are built of 25-foot poles, with the use of longer poles as required by the contour of the country and the necessity at crossings. Such a line would be called a 25-foot line. Where more wires must be carried, 30- or 35-foot poles are employed, the line being graded with taller poles as required. The following discussion will apply equally well to a 25-, 30-, or 35- foot pole line.

The diameter of a pole enters as a factor not only in its strength but in its lasting quality. For the highest grade of construction nothing smaller than 7-inch tops should be used, but on less important toll lines 6-inch and even 5-inch tops are sometimes used.

Route. The general route of the toll line preferably follows the highways, but frequently the route may be made much shorter or difficult construction may be avoided by locating on private property. Wherever this is done permanent rights of way should be obtained from the property owners for all poles, guys, and braces, and other fittings, including the wires that are on the private property. All rights of way so obtained should be in writing and should include permanent tree-trimming privileges.

Locating Poles. In laying out the line, a stake should be driven firmly in the ground to locate each pole, guy stub, or anchor. It is a good plan to number these stakes in order that full data as to the kind of stub or anchor may be kept in the field book of the survey. It is not the usual practice to employ surveying instruments in laying out the line, the survey being made by sighting between stakes. On the other hand, in laying out long lines, a transit may sometimes be used to advantage, although there is danger of wasting time with it if the man using it attempts to do too fine work.

The line should be laid out as straight as possible and where long curves occur they should, as far as possible, be reduced to straight sections joining each other at corners. Except for the very heaviest type of construction, forty poles to the mile is a good average, and this means that the poles on straight sections will be about 132 feet apart. On curves and corners the distance between poles should be shortened. Wherever the angle between any two spans is 30 degrees or over, the distance between the poles of those spans should be reduced to about 75 feet. For smaller angles the distance between poles may be proportionately greater. Wherever possible right-angle turns should be made on two poles, that is, the line wires should make two 45-degree bends instead of one 90-degree bend. The span adjacent to such corner in each case should be reduced to about 75 feet. It is also well at the terminal of the line to reduce the last span to 75 feet.

Frequently, owing to the contour of the ground, longer spans must be employed. Sometimes as the line approaches a ravine the choice must be made between running the line down into the ravine or spanning it with a single span. If the depression may be cleared with a span of about 200 feet, this is to be preferred to the use of very high poles in the bottom of a depression or to very abrupt changes in the level of the line that would occur by setting poles of ordinary height in the bottom of the depression. Spans of very much greater length than 200 feet may be employed where absolutely necessary, but such spans should always be made the subject of special study. Wherever the pole line changes from one side of the road to the other, the crossing should be made at an angle of about 45 degrees.

On railroad rights-of-way no poles should be set less than a distance of 12 feet from the outer edge of the nearest rail, and in any event the minimum distance must always be subject to the terms of the agreement under which the right-of-way is secured. In passing through towns or cities the poles should be located as generally as possible at corners of intersecting streets or alleys, so as to facilitate the employment of side guys, if necessary, and also to facilitate the branching off of wires to other pole lines if the necessity for such exists.

Grading. The length of the poles is, as stated, determined by the character of the line being built, the shortest poles being determined by the number of cross-arms that are to be carried. Longer poles are used where, on account of the profile of the country, it is necessary to do so in order to avoid abrupt changes in the level of the wires.

The number of poles, longer than the standard of the line, will depend on the character of the country through which the line passes. In general it may be stated that an effort should be made to accomplish the required grading by the use of as few poles as possible that are over 5 feet longer than the standard pole of the line. The use of many long poles is not only expensive but such poles are not so strong or durable.

For sharp depressions that are too wide for a single span and that would ordinarily require the use of extra high poles, the poles should be placed close enough together to make the change in level on any pole as small as possible. In such cases, in order to facilitate the grading, poles as short as 20 feet in length in a 25-foot line, or 25 feet in length in a 30-foot line may be used on the highest ground adjoining depressions.

At highway crossings the poles should be of such length that no wire or attachment will be less than 18 feet above the crown of the highway. Of course, local ordinances or laws may require a greater height. At railway crossings the height of the wires or pole attachments above the rail should not be less than 28 feet.

To clear obstacles, poles of such length or such method of construction should be used as will give a clearance of at least 18 inches from the obstacles when all of the arms are full of wires. In avoiding trees or other obstacles, side arms may be used and their use is to be preferred to the use of very high poles. The side-arm construction will be illustrated later in connection with city pole line work.

Distributing Poles. In distributing poles from wagons or cars, the heaviest poles should be placed at corners or bends in the line and at the terminals of long spans. The straightest and best looking poles should be employed through the cities and towns, and particularly in front of good residences.

Equipping Poles. In general, it is better to attach the cross-arms and braces to the poles before the poles are set. The cross-arms are fitted with the standard pins and with the braces attached at one end before they are distributed. The pins are held in place on the arms by driving a wire nail through the arm and shank of the pin after the pin is driven home in the arm. After the cross-arm is attached in position on the pole by the through bolt, it is squared with the pole and then the free ends of the braces are overlapped on the pole and attached by a 5-inch lag screw, as already pointed out, thus maintaining the square position of the arm on the pole.

In countries where lightning storms are common, it is a good plan to equip about every tenth pole with a lightning rod, which may be made of No. 10 B. W. G. galvanized iron wire. This wire may be wrapped two or three times around the extreme butt end of the pole before the pole is set, and extended up the pole, being attached every two feet by a $1\frac{1}{2}$-inch galvanized-iron wire staple.

Setting Poles. In setting the poles it is important that all of the holes should be sufficiently large to allow the butt of the pole to enter without scraping in so much dirt from the side of the hole as to partially fill it up. Sufficient space should be left all around for adequate tamping. Also, in order to prevent the dirt from being filled in faster than it can be properly tamped, it is well to employ two tampers for each shoveler. The soil should be piled up above the surface and packed around the pole approximately 12 inches above the surface of the ground.

On straight lines the poles should always be set so that the cross-arms will be at right angles to the direction of the line, and the arms on adjacent poles should face in opposite directions. The reason for this is to prevent the strain on the cross-arm on all the poles being away from the pole rather than against it, in case such a condition should arise as to cause a heavy pull of all the wires in one direction. For the same reason the arms of the last few poles at the end of a straight lead should be placed on the side of the pole toward the end of the lead so as to make them all pull against their respective poles.

Guying and Bracing. It is not sufficient to rely only on the strength of the poles or on the firmness of their setting in the ground to maintain the rigidity of the line, particularly when the line is subjected to the stress of violent storms. In order to give the line greater stability, therefore, guys or braces are used. Guys may be defined as *tension members in the form of wires or ropes extending from a point near the upper end of the pole to some stationary object, such as an anchor, tree, or another pole.* Braces may be defined as *compression members, usually of wood, extending at an angle from a point high up on the pole to a solid foundation in the ground.* Guys act to resist the forces which tend to pull the pole out of its proper alignment by the tension of the guy wire or rope. Braces act to resist such forces by the compression in the brace member.

Guys may be classed as *side guys* when they are placed at right angles to the direction of the line to prevent the line from going over sidewise; as *head guys* when they are placed in the direction of the

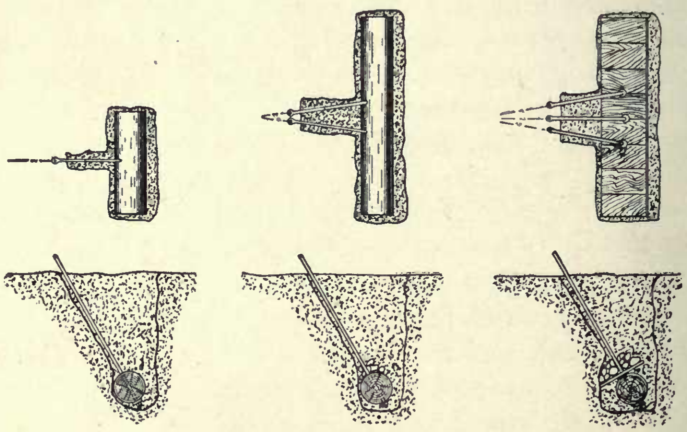


Fig. 520. Log Anchors

line to prevent the line from going down endwise; and as *corner guys* when they serve to resist the pull of the line wires on corner poles, due to the bend in the direction of the line.

For bare-wire line construction guys may be of No. 6 B. W. G. solid wire for lighter construction, and of stranded steel for heavier construction. For ordinary 25- and 30-foot pole lines, $\frac{5}{16}$-inch galvanized strand is an excellent material, since it possesses the adequate strength and is more easily handled than the larger sizes of solid wire. Where necessary, two or more strands of this may be used in order to resist excessive pulls.

The subject of anchors is an important one. For heavy work the practice is to bury anchor logs deep in the ground, wrought-iron anchor rods extending from these logs to a point above the surface of the ground in the direction in which the guy wire will run. In Fig.

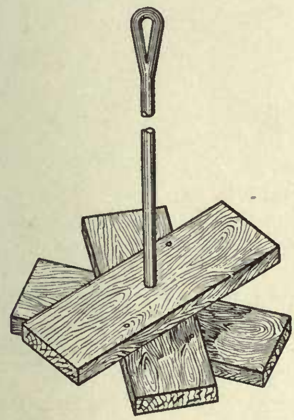


Fig. 521. Plank Anchor

Fig. 522. Matthews' Anchor

520 are shown the details of a number of anchors made in this way. The anchor log itself is usually made of a section cut from a pole.

Fig. 523. Setting Matthews' Anchor

Railway ties also make good anchor logs. For lighter construction an anchor may be made of 2-inch planks nailed together, as shown in Fig. 521.

Except for very heavy construction some of the many forms of patent anchors may be used with good results and economy. A

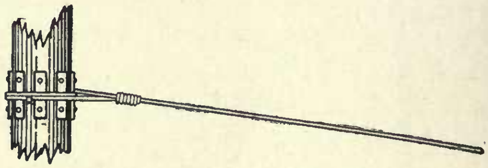


Fig. 524. Solid Iron Wire Guy

familiar type of these is the Matthews' anchor, which is of such form as to bore itself into the ground when turned. Such an anchor is shown in Fig. 522, and the method of setting it in Fig. 523. Other forms of patented anchors require a hole to be drilled by an earth auger, after which the anchor is put in place and the tension which is put upon it sets the body of the anchor crosswise of the hole in such a way as to resist its being pulled out. Still another type, known as the D. and T. anchor (drive and twist) is put into the ground by driving it with a sledge, and it is then set or expanded by twisting on the rod.

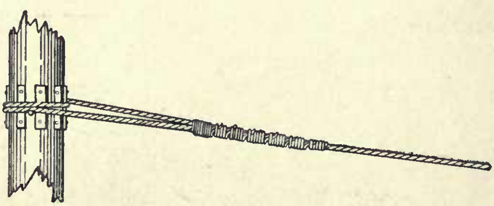
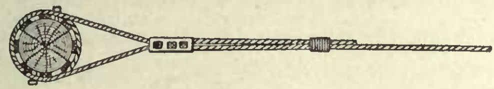


Fig. 525. Stranded Wire Guy

The efficacy of any of these patented forms of anchors depends largely on the character of the soil in which they are used. They are not effective in sand, and indeed it is hard to get an anchor that is.

The method of attaching solid iron guy wire to a pole is shown in Fig. 524. There are two distinct methods of attaching a stranded guy wire to the pole. One is to pass the guy strand twice around the pole and then fan out the separate strands and wrap each about the main body of the guy strand, as shown in Fig. 525. Another is to employ guy clamps, as shown in Fig. 526, and this is the plan in general to be preferred.



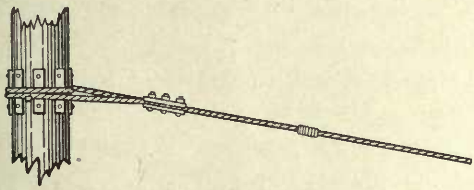
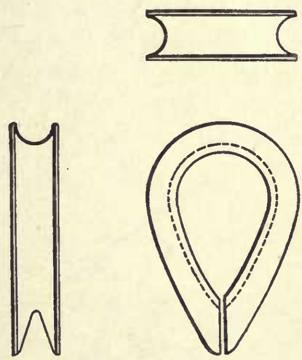


Fig. 526. Stranded Wire Guy

Attaching the guy wire or rope to the eye of the anchor rod is usually done with the aid of a thimble, the form of which is shown in Fig. 527. This may be done either with or without guy clamps, Fig. 528 showing such a connection made with the use of guy clamps.



527. Guy Thimble

One method of attaching a guy to a tree is shown in Fig. 529. In rocky country it is often convenient to anchor a guy in rock and the manner of doing this is made clear in Fig. 530.

Sometimes, as where a guy must necessarily cross a road or sidewalk, insufficient clearance would be afforded under the guy wire if the guy were run directly to an anchor. In such cases guy stubs are used. These are in effect poles set in the

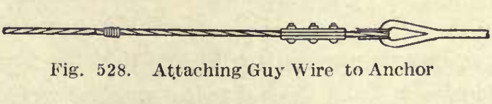


Fig. 528. Attaching Guy Wire to Anchor

ground, and to the top of these the guy wire is fastened. The guy stub may be made sufficiently rigid to need no guying itself but nevertheless it is preferable to guy it to an anchor exactly as if it were a pole. Such a construction is shown in Fig. 531. If it is not feasible to anchor the guy stub because of lack of space in which to place the anchor or guy thereto, the guy stub may be made extra heavy and set very deep in the ground, the setting being reinforced by concrete or by heavy planks placed sidewise across the hole. The reinforcement at the top of the hole should, of course, be toward the pole to which the guy runs and those at the bottom of the hole on the side of the stub opposite the pole.

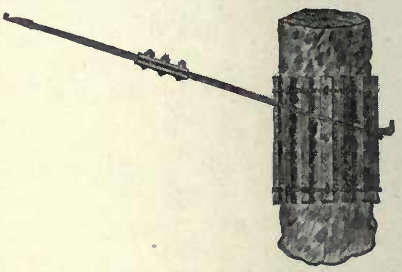


Fig. 529. Attaching Guy to Tree

In locating guy anchors the horizontal distance from the butt of the pole to the anchor should be as great as possible up to a distance equal to the length of the pole.

The length of the anchor rod is usually about 8 feet, and in any event, sufficient to allow the eye of the anchor rod to project 6 or 8 inches above the ground. Practice differs as to the galvanizing of anchor rods, some advocating that it be done and others claiming that it is useless.

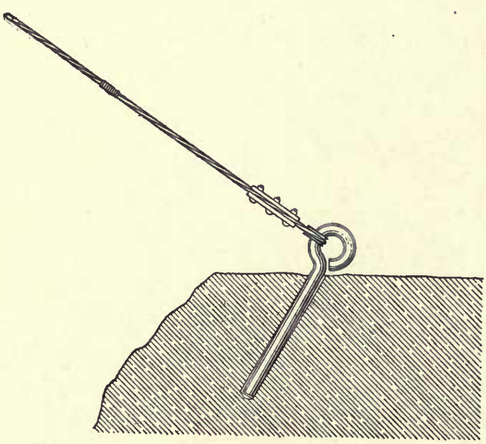


Fig. 530. Rock Anchor

On a line containing one cross-arm only, the guys should be attached to the pole at a point just below the arm, but with two or more cross-arms, the guy should be attached about midway between the bottom and the top arms.

At the end of pole leads the last pole should be guyed to an anchor beyond the last pole and in the direction of the last span, and head guys should be run from a point near the top of each of the last few poles to a point near the base of the next pole toward the end of the line.

Pole braces, or push braces, as they are called, may be used in cases where a guy is objectionable or impossible. Where used, the pole to be braced should be set deeper in the ground than usual. The butt of the brace should be set about $3\frac{1}{2}$ feet in the ground and should be supported on a heavy plank or flat rock laid in the bottom of the hole. The upper end of the brace is beveled at an angle to fit snugly against the pole; but in no case should the pole itself be cut away. The brace is attached to the pole by a standard through

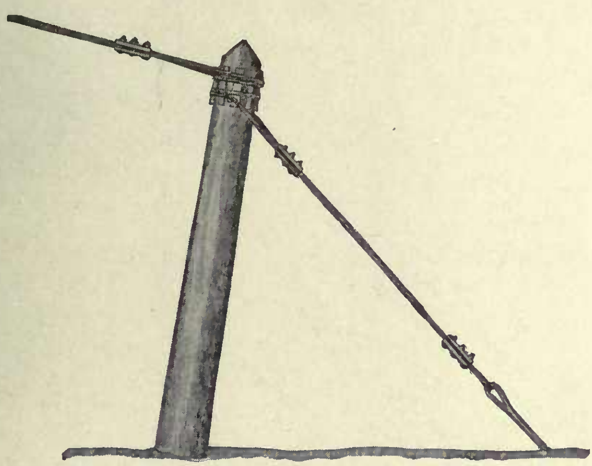


Fig. 531. Guy Stub

bolt of the type used in attaching cross-arms. Before drawing up the bolt the end of the brace and the part of the pole against which it is to rest should be given a coat of *carbolineum avenarius.* A standard method of pole bracing, as employed by some of the Bell companies, is shown in Fig. 532. In this the butt of the brace is bolted to an anchor log instead of resting directly against it, and the brace is thus enabled to resist pulling as well as pushing stresses. When so made they are called "pull-and-push" braces.

Tree Trimming. The question of tree trimming is a troublesome one. The rights of property owners have to be considered and too much cannot be said against the way in which these rights have been ignored and against the ruthless destruction of shade trees that often has been practiced by the employes of telephone companies. On the other hand, a certain amount of tree trimming is necessary and it should be done in the way least objectionable. All trees close to the line should be trimmed so as to clear the wires by a distance of about 2 feet in all directions. Dead trees, which would injure the line by falling, should be cut down.

Stringing Wire. The insulator used for bare wire lines is nearly always of glass. The standard line insulator, shown in Fig. 533,

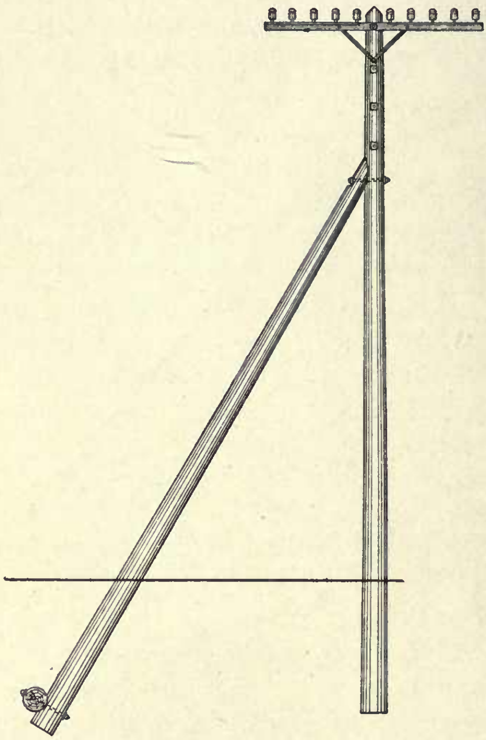


Fig. 532. Pole Brace

is provided with an internal screw thread to fit the thread on the wooden pins. The groove is for the tie wire by means of which the line wire is attached to the insulator. A factor in the design of insulators is the path for surface leakage from the wire to the pin and cross-arm. In dry weather the pins and cross-arms are themselves fairly good insulators, but in wet weather they become better conductors. The moisture which collects on the insulator also forms a path for leakage and the "petticoat" or downwardly hanging flange on the glass is to protect the pin and the inner surface of the glass from moisture as far as possible and to afford a long path over the surface of the glass from the wire to the pin.

Transpositions:—In making certain forms of transpositions in the line wires and also at test points, it is required to dead-end two wires on the same insulator. Insulators with two grooves are used for this purpose and are called *transposition insulators.* Fig. 534 shows one form of these, two grooves being formed in the same glass. A better form is that of Fig. 535 in which the two grooves are in sep-

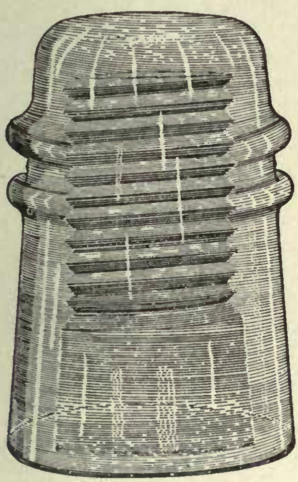


Fig. 533. Standard Insulator

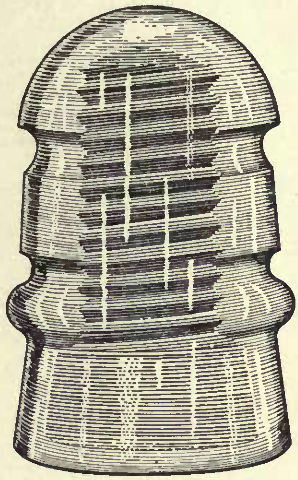


Fig. 534. Transposition Insulator

arate glasses. On account of the petticoat of the upper glass, better insulation is maintained between the two wires, and another advantage in this form is that the opposite stresses of the two wires are taken by the pin rather than by the structure of the glass, and as a result there is less breakage.

Tying:—The methods of tying the wire to the insulator differ for iron and copper wire. In neither case does the line wire pass around the insulator; rather it runs alongside of it and is held in the groove of the insulator by the tie wire which passes around the insulator. The form of tie largely employed for iron wire is shown in Fig. 536; that for copper wire in Fig. 537. It is to be noted that the copper-wire tie is now being largely employed for iron wire as well as for copper. In each case the tie wire is of the same gauge and metal as the line wire which it ties, but in each case it should be soft annealed instead of hard drawn. For standard insulators the copper tie wire should be about 19 inches long and the iron tie wire about 12 inches long.

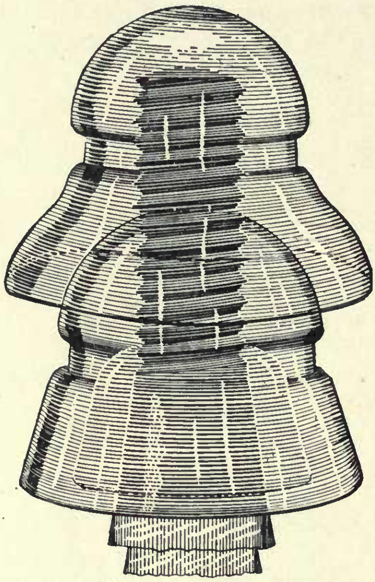


Fig. 535. Transposition Insulator

Joints:—The standard method of joining iron wire, known as the *Western Union joint*, is shown in Fig. 538. In this the ends of the two wires to be joined are laid side by side, in a pair of *special* pliers. The wires are then twisted by means of the pliers to make five complete turns, forming what is known as the neck of the splice. After this operation the splice is completed by wrapping each end tightly around the straight section of the other wire four or five turns. Tests of various splices show that the end turns have very little virtue in them, most of the holding power being due to the turns in the neck, and that a joint with five properly made turns in the neck will be as strong as the wire it is made of, and will yield but slightly at first or until it is set, after which there is practically no yield up to the breaking point.

Copper wire is usually joined by means of the McIntyre sleeve, which consists essentially in two parallel tubes of copper about 4 inches long secured together throughout their length, the internal diameter of the tubes being such as to just accommodate the size of wires to be spliced. To make the joint by means of this connector, the two wires are run through the parallel tubes in opposite directions and then each end of the sleeve is grasped in a special clamp and the sleeve twisted through three complete turns. The McIntyre sleeves before making a connection and a completed joint are shown in Fig. 539.

Sag:—In stringing line wires it is desirable that all wires in a span have a uniform sag. Obviously, the amount of sag will depend

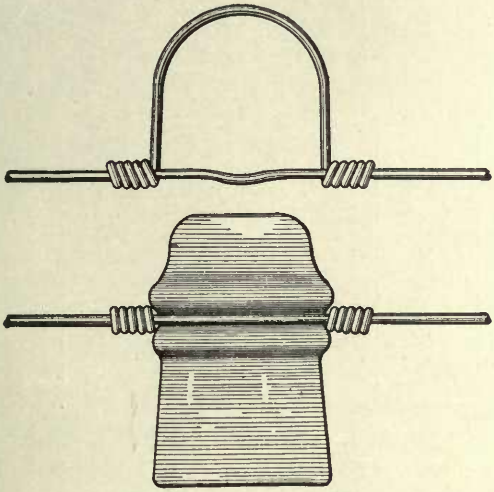


Fig. 536. Iron Wire Tie

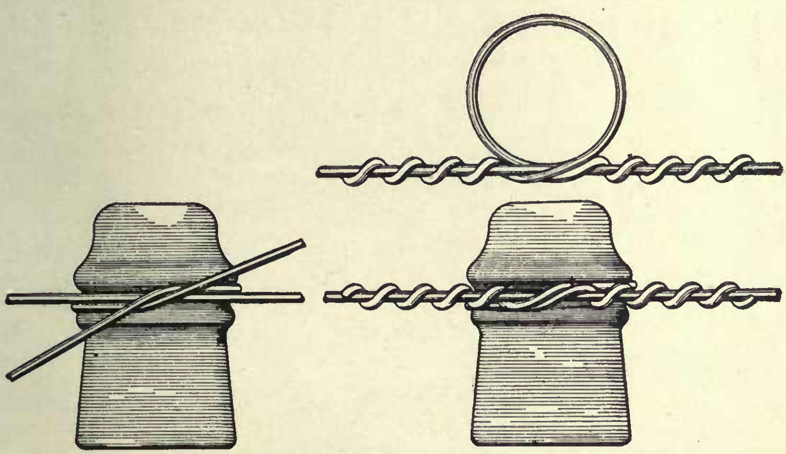


Fig. 537. Copper Wire Tie

Fig. 538. Western Union Joint

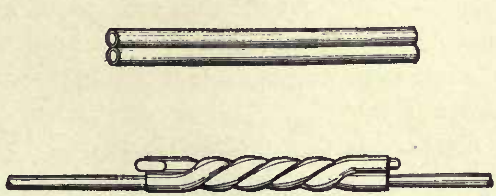


Fig. 539. McIntyre Joint

TABLE XXVI
Sag at Time of Erecting

Temp. Degrees F.	Length of Span					
	75′	100′	115′	130′	150′	200′
			Sag in	Inches		
10	$1\frac{1}{2}$	3	$3\frac{1}{2}$	$4\frac{1}{2}$	6	$10\frac{1}{2}$
30	2	3	4	$5\frac{1}{2}$	7	12
60	$2\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{2}$	7	9	$15\frac{1}{2}$
80	3	$5\frac{1}{2}$	7	$8\frac{1}{2}$	$11\frac{1}{2}$	19
100	$4\frac{1}{2}$	7	9	11	14	$22\frac{1}{2}$

on the length of span and, for a given degree of initial tightness, on the temperature. Since the wires are shorter in winter than in summer, wires that are pulled too tight in the summer time may become so tight as to break during the winter. Table XXVI shows good practice with respect to the sag to be allowed for different lengths of span erected at different temperatures.

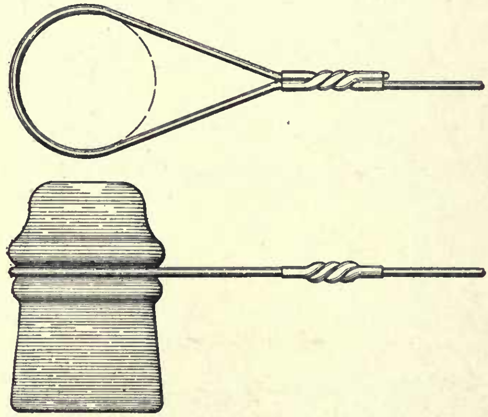


Fig. 540. Dead-Ending with Sleeve Joint

Dead-Ending:—At the ends of lines, at test points, and sometimes at transposition points it is necessary to dead-end the line wire. The method of dead-ending copper line wire is indicated in Fig. 540. In this a McIntyre sleeve of one-half the usual length is employed. The iron wire dead end is shown in Fig. 541, and is made without a sleeve, the wire being given two complete wraps around the insulator and then twisted around itself, as shown.

Test Points:—To facilitate testing on through lines, it is common to establish test points at which the line wire is cut and dead-ended and connected by some form of connecting clamp, which the

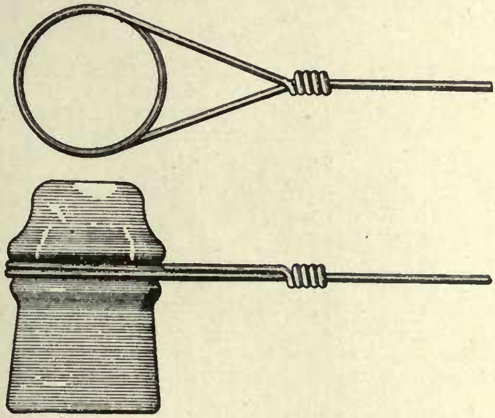


Fig. 541. Dead-Ending Without Sleeve Joint

tester may readily open in making his tests. A form of this construction is shown in Fig. 542.

Scheme of Transposition. The necessity for transposing upon circuit wires has already been dealt with. The scheme of transposition differs for the various cross-arms as well as for the different pairs on any one cross-arm. The reason for this is to provide for

Fig. 542. Test Connection

inductive neutrality between the wires above and below each other as well as those alongside of each other.

The poles on which transpositions occur are known as *transposition poles,* and they are located at about 1,300-foot intervals. The length of a transposition section for the present standard scheme employed by the Bell companies is 8 miles and includes 32 transposition poles. The scheme for one such section is shown in Fig. 543, this being repeated in each section.

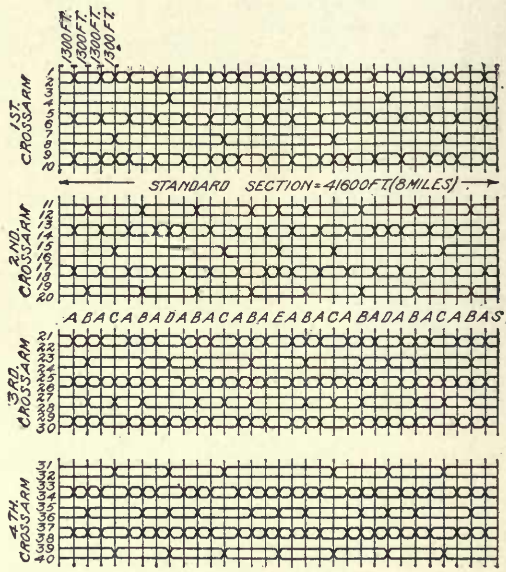


Fig. 543. Transposition Scheme

There are two general methods of making transpositions, one of which requires the dead-ending of both wires at the transposition pole and the crossing over of their free ends. With this method double-groove insulators are employed at the transposition point, each of the right-hand wires being dead-ended in a groove on each of the insulators and the two left-hand wires in the other grooves of the insulators. This method is shown in Fig. 544, the dead-ending and splicing of the free ends being done by means of McIntyre sleeves.

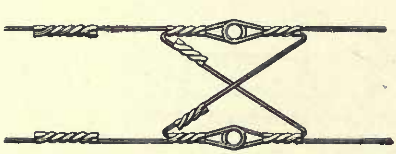


Fig. 544. Two-Pin Transposition

The other method of transposing, known as the *single-pin* or *running* transposition, may be done in two ways, as shown in Figs. 545 and 546. Of the two methods, the one shown in Fig. 545 is to be preferred, since it does not involve cutting the wires; however, it can only be made when the wires are being run out. When it is neces-

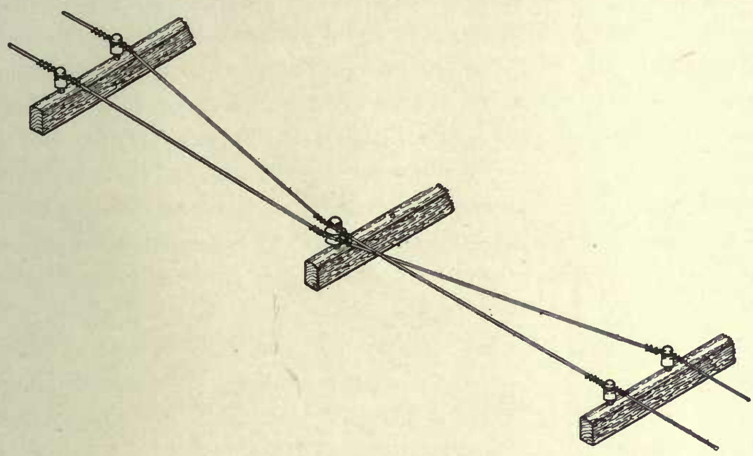


Fig. 545. Running Transposition

sary to make the transposition after the wire has been strung, the method shown in Fig. 546 is employed.

In the running transposition the wires on the transposition arm

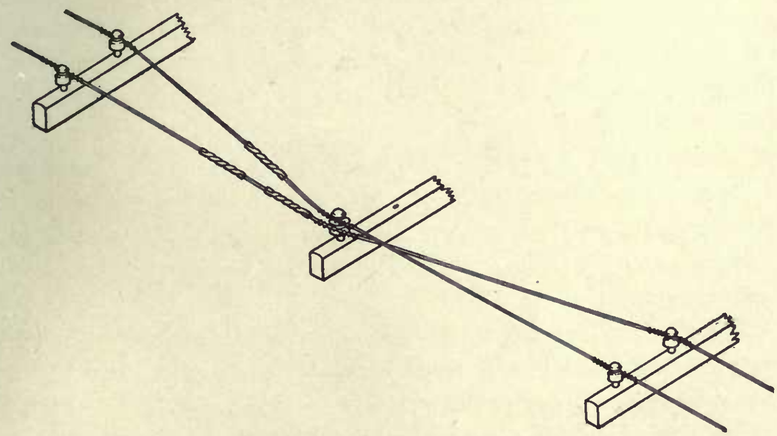


Fig. 546. Running Transposition

and the arms adjacent to it on each side should pull on the pins and not on the tie wires. On straight sections of the line, the outside pin is used for transpositions and the inside pin is left idle.

Rural Lines. For the connection of rural subscribers in the outlying districts of cities or towns such a high grade of construction as is employed on through toll lines is not warranted. The number of wires carried on such lines is small and the service is relatively unimportant. By this it is not meant that there is any justification for the miserably constructed lines often found along country roads and aptly termed "bean-pole lines." It is perfectly feasible to build lines for such rural service of shorter and smaller poles than those required for more important lines, and to space the poles farther apart, thus securing a cheaper yet adequate line.

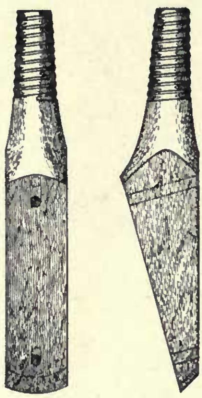


Fig. 547. Insulator Bracket

For such work the Bell operating companies in certain sections have adopted as a standard what they term a 22-foot line. Other companies employ 20-foot poles. A fair sized pole for this work is a 20- or 22-foot pole with a 5-inch top. A fair spacing is thirty to a mile.

Where the line is to carry but two or three wires, as is often the case, there is no need of cross-arms at all, the wires being supported from brackets nailed directly to the pole. The details of such a bracket are shown in Fig. 547. For a two-wire line, the location of brackets on the pole, on straight sections, and on curves is shown in Fig 548, the view at the left showing the arrangement on straight sections and that at the right, on curves. The reason for placing the brackets both on the same side of the pole on curves is so that both wires may pull towards the pole. If more wires are to be carried, a 6- or 8-pin cross-arm, or, if the poles are heavy enough, a 10-pin cross-arm may be employed.

The wire on such a line, if short, may well be of iron, although there are certain localities having much coal gas in the atmosphere where it has been proven that iron wire will last only a few years. In other places iron wire may easily have a life of from ten to fifteen years, and it is often to be expected that before this time shall have elapsed, the cheap pole line will have been replaced by one of more substantial construction, owing to the extended requirements of the growing community.

City Exchange Lines. The requirements for modern city aërial lines differ from those of cross-country toll lines, in that they are generally required to carry fewer or no bare wires and to carry cables. Frequently, and this practice is growing, city lines carry no bare wires at all and no cross-arms unless cross-arms are needed for supporting the cables.

Poles. All that has been said regarding the preparation of the pole in the first portion of this chapter will apply to poles for use in city lines. In addition to this it is considered good practice to paint all poles with one, or better two, coats of good oil paint, an excellent paint for this purpose being known as Acheson graphite. A few words may be said as to the color of city poles. It is

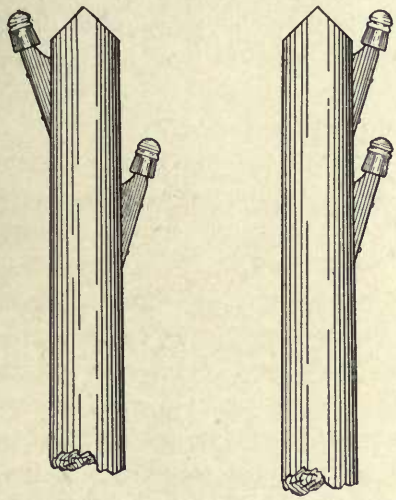


Fig. 548. Location of Brackets

usual to paint them white, or the upper portion of them white and the portion 6 feet above the ground, dark green or black. Such practice makes the poles as conspicuous as possible, and while this may be gratifying to the construction man or to the exchange owners, it is seldom so to the nearby property owners. It is believed that a better practice is to paint them a dull black or very dark green all over. This renders them inconspicuous and takes away the startling appearance of newness which often serves to fan the flame of dissatisfaction of the citizen.

TABLE XXVII

Pole-Step Data

25 foot poles	7 iron steps
30 foot poles	10 iron steps
35 foot poles	13 iron steps
40 foot poles	16 iron steps
45 foot poles	19 iron steps
50 foot poles	22 iron steps
55 foot poles	25 iron steps
60 foot poles	28 iron steps
65 foot poles	31 iron steps

Stepping:—As has been said, city poles should be stepped as they have to be climbed more frequently than those in cross-country runs and the marks of the climbing spurs of the linemen are detrimental, not only to the appearance of the pole, but to its life, and this is particularly true where the pole is painted. The method of spacing the steps is shown in Fig. 519.

For guidance in boring the holes for the iron steps, and for making the estimates as to the number of steps required Table XXVII is given. This table is frequently convenient in another way. In poles that have already been set it is often difficult to judge their height, and it may be necessary to ascertain this either in planning other construction that is to go over or under a given lead or in making appraisals. A knowledge of the number of iron steps for given heights of poles will, therefore, enable one to arrive quite accurately at the height of the pole by merely counting the steps.

Locating:—In setting poles along streets, the general location will be within the curb line. Where no curbing exists at the time of setting, or in case the present curb line is likely to be changed, its ultimate location should be obtained from the city engineer or proper city authority.

In setting poles within the curb, it is desirable to maintain a separation of at least 6 inches between the nearest point of the pole and the curb to avoid throwing the curb out of alignment by movement of the pole.

In setting poles on streets where their is an existing pole line of another company, it is, of course, preferable to take the opposite side of the street; but where the two must be placed on the same side of the street, the two sets of poles should be set in the same line so as to preserve as far as possible a sightly appearance for both leads. In alleys the poles should in general be set outside of and as close as possible to the abutting private property. When placed on private property the poles should be set to conform with the requirements stated in the permit from the owner.

Crossings:—When a pole line for cables must cross from one side of a street to the other, the crossing is preferably made at a street or alley intersection and parallel with the intersecting street or alley, as shown in Fig. 549. The reason for this is that the intersecting street or alley affords room for guys, and if an intersecting line is to be constructed on this cross-street the two poles on which the crossing is made will be available for that line.

The poles at steam railroad crossings should, if possible, be so located that the span over the crossing will not exceed 100 feet in

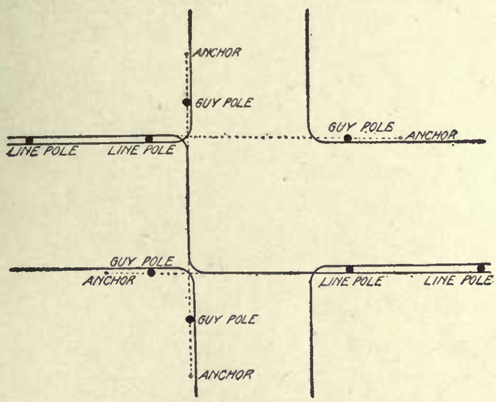


Fig. 549. Changing Sides of Street

length, and in all cases it must conform to the municipal regulations or agreements with the railroad company. The poles at such crossings should be no closer than 7 feet from the nearest rail, and, if possible, the crossing should be at right angles to the tracks.

Grading:—On comparatively level ground in cities, the poles should be graded so as to avoid changes of more than 5 feet in the level of the wires and cables on adjacent poles. In general, in city work it is good practice to make poles as low as possible. This is directly contrary to the plan that has been followed in many eastern cities where lines of 60- and 70-foot poles are an eye-sore and a menace to the public. It is, of course, necessary to make all poles of such height as to give the cables and wires which they support the clearance required by city ordinances. Cables and wires should clear all obstacles, and electric light and power wires, by at least 4 feet if possible, and enough separation should be always allowed to prevent swinging contacts.

Distributing:—The same considerations as to the distribution of poles should be given in city work as set forth for cross-country work, with the additional consideration that the most sightly poles should be placed on the streets and the worst looking ones in the alleys. A keen consideration for the personal feeling of property owners is not only morally right, but it has been amply proven to be the best of commercial policies.

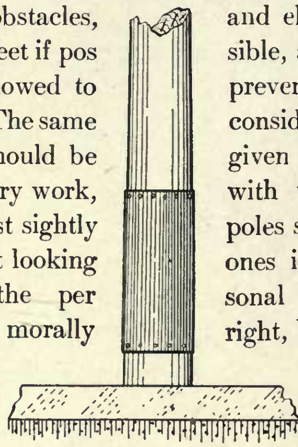


Fig. 550 Butt Protector or Hub Guard

Mechanical Protection:—Where there is danger of poles being injured by hubs of wagons, butt protectors, consisting of half cylinders of heavy sheet iron, should be attached to the pole at such a height as to receive the impact from the hubs of passing wagons. Such a butt protector on a pole is shown in Fig. 550. Where poles are so erected as to make them likely to be used as hitching posts for horses, particularly in village streets, cribbing guards should be installed to prevent the horses gnawing them. A pole so protected is shown in Fig. 551.

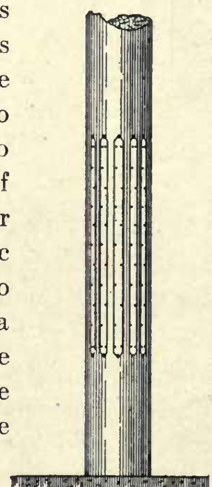


Fig. 551. Cribbing Guards

For the protection of persons and teams against injury which might occur from running into guy wires and for the protection of the guy wire itself, it is customary in cities to place a protecting guard over the guy wire for a distance of about 8 feet above the ground. Sometimes this is done by sliding an iron pipe over the guy wire before it is tied in place, but the more usual method is to put a cheap wooden box around the guy wire, this having the advantage of being readily applied after the guy is in place. A guy so protected is shown in Fig. 552.

Where guys pass close to electric light or trolley wires, they should be encased in a rubber hose for a distance of about 4 feet on each side of the point of crossing. The hose should be lashed in place by marline bound tightly to the wire at each end of the hose. Where it is possible to put the protecting hose on before erecting the wire, it is preferable to merely slide the hose over the wire, but where, as is usual, the protector is put up after the erection of the guy wire, the hose may be split and slipped over the guy wire, and then lashed in place with marline, the lashings extending throughout the entire length of the hose and occurring about every 4 inches.

Alley Arms:—Where bare wires are to be carried on the poles in city construction, the method of mounting and equipping the cross-arm and of stringing and tying the wires, as already described, is employed. Frequently, in city work, particularly in alleys, the pole line must necessarily be located so close to walls of buildings abutting the alley as to leave insufficient room to use the standard mounting of cross-arms. For this purpose the so-called alley arm or side arm is used consisting merely in an arm of standard length and pin spacing, attached to the pole at one end so as to project out over the alley, and secured by a suitable angle-iron brace. A pole so equipped is shown in Fig. 553.

Messengers. Usually in city work the bulk of the line wires on a pole is carried in cables. As cables have not sufficient mechanical strength to support themselves when hung between poles, it is necessary to provide supporting strands consisting of steel wire or steel wire rope supported by the poles. To this "messenger wire" the cable is fastened at short intervals, usually of about 18 inches, by some form of "cable hanger."

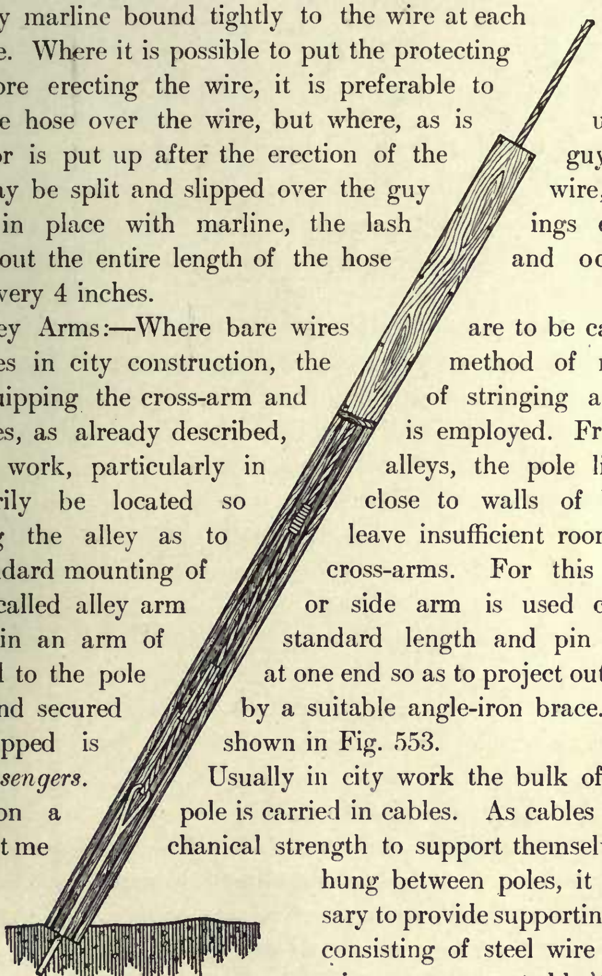


Fig. 552. Protected Guy

Sizes and Grades:—The sizes of stranded messenger wire range from ½ inch to ¼ inch in diameter and, for supporting smaller cables, a solid steel wire No. 4 or No. 6 B. W. G. is frequently used. Such

TABLE XXVIII

Size and Breaking Weight of Messengers

Size	Stranded					Solid	
	$\frac{1}{2}''$	$\frac{7}{16}''$	$\frac{3}{8}''$	$\frac{5}{16}''$	$\frac{1}{4}''$	.225″	.192″
Weight per 1000 feet	520	400	300	220	130	134	98
Bessemer Steel	9800	7600	5700	4200	2500		
Siemens-Martin Steel	11000	9000	6800	4860	3056	3500	2500
High Strength Steel	18000	15000	11500	8100	5100	5900	4300
Plow Steel	27000	22500	17250	12100	7600	8000	6000

messenger wire, whether stranded or solid, is made in different grades, which vary greatly as to breaking strength. The principal standard market grades are Bessemer, Siemens-Martin, "high strength" and "plow steel," these increasing in strength in the order mentioned. The weights per thousand feet and the breaking strengths of each of these grades in different sizes, both stranded and solid, are given in Table XXVIII.

Bessemer steel strand is the cheapest, and although frequently employed, it is finding less favor as a messenger strand on account of its liability to flaws. It has a tensile strength of about 60,000 pounds per square inch.

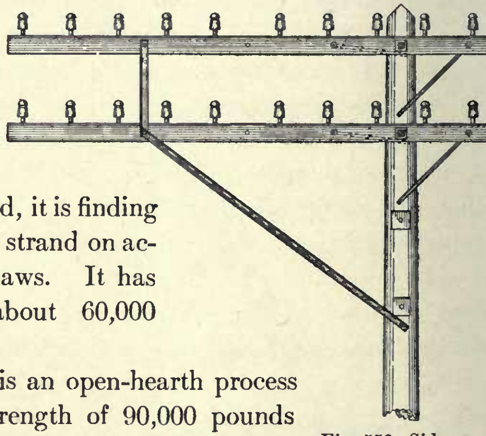


Fig. 553. Side or Alley Arms

Siemens-Martin steel is an open-hearth process steel, and has a tensile strength of 90,000 pounds per square inch, and sometimes considerably more. It is very uniform and the likelihood of flaws is remote. This is a thoroughly satisfactory steel for messenger wires in all cases, except where the very greatest strength is necessary.

The other grades, known as the high strength and plow steel, have tensile strengths of approximately 150,000 and 220,000 pounds per square inch, respectively.

Good practice in respect to the sizes and the grades of messenger wire for all ordinary spans may be outlined as follows, the grade of messenger in each case being Siemens-Martin.

For 10 to 30 pair, 22-gauge cables inclusive, or their equivalents in weight, No. 4 B. W. G. solid wire.

For 40 to 100 pair, 22-gauge cables inclusive, or their equivalents in weight, $\frac{3}{8}$-inch steel strand.

For larger cables up to 200 pair, 22-gauge, or their equivalents in weight, $\frac{7}{16}$-inch steel strand.

For all cables heavier than 200 pair, 22-gauge, $\frac{1}{2}$-inch steel strand.

This practice provides for a very large factor of safety, the strands being of ample strength to provide for changes in temperature, wind and sleet storms, and for other contingencies.

Methods of Attaching:—The messenger is attached to each pole, except the poles on which it is dead-ended, by means of messenger supports of various forms. Most pole lines in city work carry but a single cable and the messenger support in such cases is usually of malleable or wrought iron secured directly to the pole by lag or through bolts. Standard forms of messenger supports for this class of work are shown in Figs. 554 and 555.

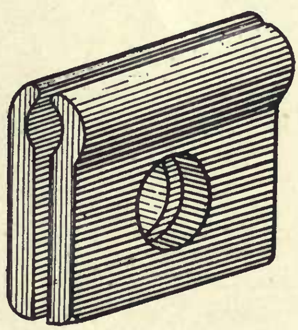


Fig. 554. Messenger Support

Under ordinary circumstances on new pole lines the messenger may be attached 12 inches from the top of the pole, except in cases where the poles are of extra height, so as to provide for the other fixtures, such as distributing terminals, in which case the messenger may be mounted as far below the top as is desired. The messenger wire should be graded as far as possible to avoid too abrupt changes in level. It should always be attached to the pole at such a height as to afford a clearance of not less than 20 feet over the crown of roadways when the cable is in place, and a greater distance may be required by city ordinances. Where messengers intersect each other, as in the case of pole lines crossing at right angles, care should be taken in placing the messengers on the four corner poles so that they will cross on the same level.

Where a messenger is erected on a pole line carrying open wires or cross-arms, it should not be less than 18 inches below the lowest arm unless the clearance over the roadway demands that it be placed higher up. This clearance below the arm is desirable so as to afford room for placing terminals and distributing brackets for service wires extending to subscriber's premises. Where it is impossible to attach the messenger this far below existing cross-arms, it must, of course, be placed where available space exists.

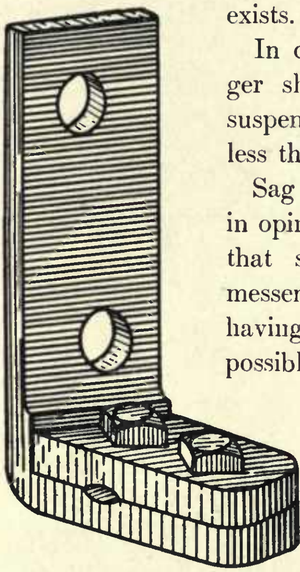


Fig. 555. Messenger Support

In crossing steam railroad tracks, the messenger should be so placed that the cable, when suspended, shall clear the top of the rail by not less than 28 feet.

Sag and Strains:—There is much difference in opinion and practice as to the amount of sag that should be allowed in cable supporting messengers. Some construction men believe in having the messenger wire initially as tight as possible. This has been referred to as "fiddle string" construction. There seems to be no good reason for it. It subjects the entire pole-line structure to an unnecessary initial strain, and is particularly severe on guys and anchors. About the only thing that can be said in its favor is that it presents, as long as it remains in place, a trim, ship-shape appearance. The extreme in the other direction is to hang the messenger loosely between poles with a very large sag, so that the cable is, as it were, festooned along the pole line. The resulting construction is not so pleasing in appearance and it is subject to the criticism that it permits a considerable swinging of the span by the wind, which may eventually injure the cable sheath. Whether there is any real cause for this criticism is to be doubted, as this loose construction method is extensively practiced in some large cities and no injury seems to result. Its advantage is greatest in short runs, consisting of but a few poles each, where conductors of an underground cable are led up to aërial cables for distribution. Where the aërial cables are light,

TABLE XXIX

Minimum Sag in Regular Spans

Span in Feet	Main Lines	Distributing Lines
50	4½″	3½″
60	6 ″	4½″
70	8 ″	6½″
80	11″	9 ″
90	1′1½″	11½″
100	1′5 ″	1′ 1½″
110	1′8½″	1′ 5 ″
120	2′0 ″	1′ 8 ″
130	2′3½″	2′ 0 ″
140	2′9 ″	2′ 3 ″
150	3′1½″	2′ 6½″
160	3′6 ″	3′ 0 ″

the very loose suspension makes it possible to do away largely with all guying, the poles being made, in all cases, sufficiently heavy and well set to be self-supporting.

Under ordinary circumstances where terminal guys are used, Table XXIX represents an intermediate practice in the matter of allowable sag, it being understood that the sag mentioned is that after the cable has been put up. These sags are worked out to give uniform tension in all spans.

For short pole leads carrying light cables, No. 4 or No. 6 B. W. G. wire may be used. Table XXX of sags has been worked out for various spans and for 10, 20, and 35 pair cables, with the idea of in no case subjecting the supporting strand to more than 700 pounds stress, which, under normal conditions, would not place a stress of more than 1,000 pounds on the terminal guys.

Where this practice is followed the No. 6 Siemens-Martin wire is of sufficient strength for both messenger and guying, since this wire has a breaking strength of about 2,500 pounds. It will be understood that unless the terminal guy on such a lead is in the same direction as the suspension strand, both vertically and horizontally, the stress on the terminal guy is always greater than that on the suspension strand or wire. This stress on the guy increases as the angle between the guy and the pole becomes smaller, and Table XXXI gives a factor by which the strain on suspension strands should be

TABLE XXX

Sags for Various Spans

Length of Span in Feet	Sag in Feet For		
	10 Pr. Cable	20 Pr. Cable	35 Pr. Cable
50	.35	.45	.6
60	.51	.65	.85
70	.7	.87	1.15
80	.91	1.15	1.5
90	1.1	1.41	1.9
100	1.43	1.8	2.3
110	1.75	2.15	2.8
120	2.06	2.6	3.3
130	2.5	3.	3.9
140	2.8	3.5	4.5
150	3.2	4.	5.2
160	3.66	4.6	6.
170	4.	5.15	6.75
180	4.6	5.8	7.5
190	5.15	6.4	8.4
200	5.7	7.15	9.3

multiplied in order to give the strain on the guy.

It goes without saying that where the poles are self-supporting the stresses on them should be reduced to a minimum and the cables

TABLE XXXI

Factor for Strain on Suspension Strand

When Distance From Anchor Guy at Ground Equals	Factor
The height of guy on pole above ground	1.4
Two-thirds the height of guy above ground..................	1.8
One-third the height of guy above ground	3.2

should be supported as low down on them as possible. The proper sag will depend upon the size of the poles, the height of the cable above the ground, and the character of the setting of the pole. Table XXXII will be found useful in determining the strain that may be expected, due to any given sag on a given size of cable.

To find the sag for any other span such as will give the same tension in the wire, divide the new span length by 100, square the result, and multiply by the sag given in Table XXXII.

TABLE XXXII

Strain at Center of 100 Foot Span

Using No. 6 B. W. G. Steel Wire

Sag	10 Pr. Cable .8 Lb. Per Ft.	20 Pr. Cable 1 Lb. Per Ft.	35 Pr. Cable 1.3 Lb. Per Ft.	60 Pr. Cable 1.7 Lb. Per Ft.
2.0 feet	500 pounds	630 pounds	800 pounds	1070 pounds
2.5 feet	400 pounds	525 pounds	650 pounds	845 pounds
3.0 feet	340 pounds	420 pounds	560 pounds	720 pounds
3.5 feet	280 pounds	360 pounds	470 pounds	600 pounds
4.0 feet	250 pounds	320 pounds	400 pounds	550 pounds
4.5 feet	220 pounds	280 pounds	360 pounds	470 pounds
5.0 feet	200 pounds	250 pounds	325 pounds	425 pounds
5.5 feet	180 pounds	225 pounds	300 pounds	390 pounds
6.0 feet	165 pounds	210 pounds	270 pounds	350 pounds

Example. What sag should be given a 150-foot span to give the same tension that a 2-foot sag gives to a 100-foot span in Table XXXII?

$$\frac{150}{100} = 1.5$$

$$(1.5)^2 = 2.25$$

The desired sag $2 \times 2.25 = 4.5$ feet. Answer.

The weight of cable given above includes that of the supporting wire and the marline hangers.

Pole Shims:—In pole lines carrying cables, good practice demands that, in dead-ending messenger wires on poles and in attaching all guy wires to poles, guy shims be used. These shims consist merely of short rectangular strips of iron about $\frac{1}{4}$ inch thick, 1 inch wide, and 6 inches long, with a nail hole at each end for attaching them to the pole. The guy shims are placed around the pole at such a point that the attaching messenger or guy wire will engage them at their middle. In the case of guy wires where there is an abrupt angular pull downward from the pole, 5-inch lag screws may be placed on both sides of the pole to prevent the guy from slipping down.

In some cases it is desirable to insulate the guy strand from the messenger strand for safety and for the prevention of electrolysis of the guy wire and anchor, in which case the guy strand should be attached to a different set of shims from that used in dead-ending the messenger. Where no such necessity exists, the guy wire may be attached to the same shims as the messenger. The two views in Fig. 556 will make this clear.

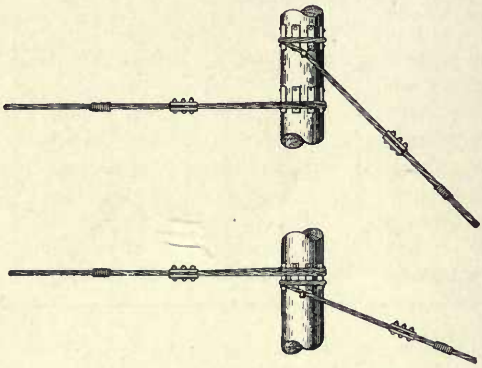


Fig 556. Guy Attachment at Terminal Poles

Splices:—In new work, where it is necessary to join ends of messenger wire, it is better to do so by dead-ending the two lengths on a pole rather than by making a joint at an intermediate point be-

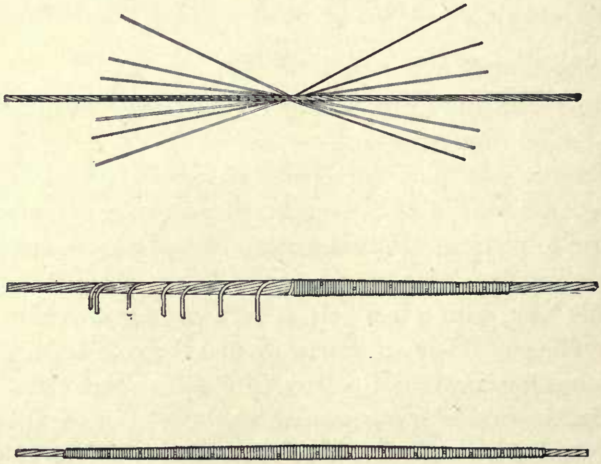


Fig. 557. Wrapped Splice

tween two poles. Where stranded messenger wire must be spliced in the span, it may be done by making a wrapped splice, as indicated in Fig. 557. This method has the advantage of presenting a comparatively smooth surface on the messenger wire in the erection of the cable, but it should not be practiced unless the proper skill is available for making a good job of it. The usual way of making splices is by means of regular guy clamps, the two wires being merely laid side by side and clamped together.

Cable. Erection:—In erecting aërial cable, the reel containing the cable is placed about 50 feet beyond one of the poles of the lead upon which the messenger strand has already been erected. A running-up wire, usually of the same material as the messenger strand, is fastened to the pole and to a stake in the ground near the reel. This running-up wire serves to support and guide the cable while it is being pulled up to and along the strand. The general scheme of erecting is shown in Fig. 558. In setting up, the reel should be so placed that the cable will always unroll from its top and be as nearly

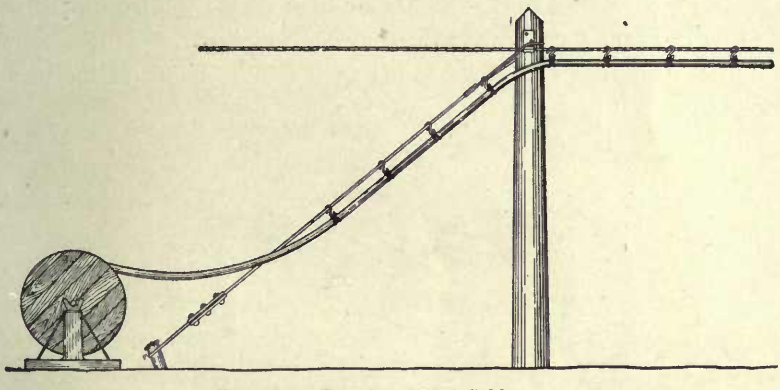


Fig. 558. Erecting Aërial Cables

in line with the running-up wire as possible. It is not generally desirable to pull up more than 1,000 feet of cable in single lengths, and that only in small sizes.

After the reel is set up on suitable jacks so as to allow it to turn freely, the pulling rope is fastened to the end of the cable. In fastening this rope a wrapping of wire or marline may be used, particular care being taken not to subject the end of the cable to such treatment as will break through the lead sheath. The cable rope should be provided with a swivel hook or ring so as to avoid twisting the cable. The cable may be pulled up by hand-power, horse-power, or by an engine-driven winch. The winch, or capstan, or whatever device is used, is placed at the distant end of the run and securely braced. The end of the cable pulling rope is then carried to the capstan drum and wrapped about it and the cable is slowly and evenly pulled into place.

Various methods are in vogue for supporting the cable while it is being pulled up. Some of these involve the placing of temporary trolley wheels on the messenger from which the cable is supported, these wheels running along the messenger wire as the cable progresses. In other cases the supporting trolley wheels are mounted on each pole adjacent to the messenger and the cable rolled over these as it progresses. Still another way is to employ no trolleys or temporary supports at all, but to apply the cable hangers to the cables and to the running-up wire as the cable runs off the reel, the hangers running along the messenger strand as the cable is moved. Unless provision is made, by means of special attachments at each pole, by which the cable hangers may ride past the messenger supports, it is necessary to station a man at each pole to lift each hanger hook off the messenger wire as it passes each pole.

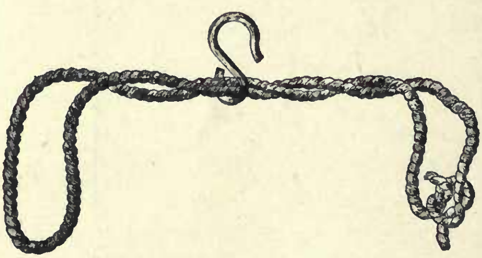


Fig. 559. Marline Cable Hanger

Hangers:—No matter what method is used the cable should be slowly and evenly pulled into place, and after it is all up care should be taken that all hangers are in place. The distance between hangers on a cable should be uniform. For 200 pair, 22-gauge cable or its equivalent in weight, the hangers should be about 15 inches apart. For smaller cables this distance may be increased, but in no case should it be over 24 inches.

Numerous forms of cable hangers exist, but the one that today seems best to meet the requirements of practice in practically all sections of the country is the marline hanger. This consists merely of an S-shaped hook of galvanized steel wire to which is attached a loop of marline. Its construction is shown in Fig. 559, and the method of supporting a cable by it, in Fig. 560. In placing the hangers on the messenger, the points of the hooks should be faced toward the pole.

The length of the loop in marline hangers varies for different sizes of cables. Table XXXIII illustrates good practice.

Splices:—A subsequent chapter will be devoted to the subject of splicing cables. It may be said at this point, however, that where it is necessary to join two cables so that one will form a continuation of the other, the wires in them are individually spliced together, taking extreme pains to maintain the insulation and particularly to keep the core dry. After this a lead sleeve is placed over the joined wires and secured to each end of the cable by a plumber's wiped joint, so as to maintain the continuity of the enclosing sheath and keep out all moisture. This is called a *straight splice.* It is also frequently necessary to tap a cable, that is, to lead out from it certain conductors which are to be made available for connection at an intermediate point on its length. This requires a *tap splice.* Again it may be necessary to join the conductors of one large cable to those of two or more smaller cables, this practice being followed where the larger group of wires is to be divided so as to enable them to follow different routes. When a cable thus branches out into smaller ones,

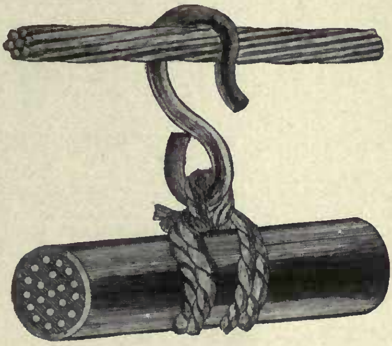


Fig. 560. Marline Hanger Supporting Cable

TABLE XXXIII

Loop in Marline Hangers

Less than 25 pair	22 gauge cable	9 inch loop
25 pair	22 gauge cable	11 inch loop
50 pair	22 gauge cable	14 inch loop
100 pair	22 gauge cable	16 inch loop
200 pair	22 gauge cable	19 inch loop

the resulting splice is a **Y**-*splice.* If the large cable connects with two smaller ones, it is a *two-way splice;* and so on

Supporting Splices:—In aërial work the supporting of the splices should be given particular attention. While the covering of

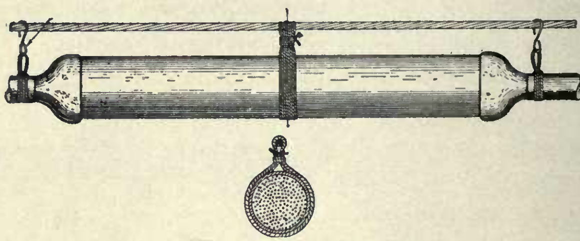


Fig. 561. Cable Splice Support

a *well-made* splice is just as capable of keeping out moisture as is the ordinary sheath of the cable, it should always be looked upon with suspicion, due to possible defects in workmanship. Therefore, great care should be taken to subject the cable to no unusual stresses at splices, particularly such stresses as would result in a bending of the

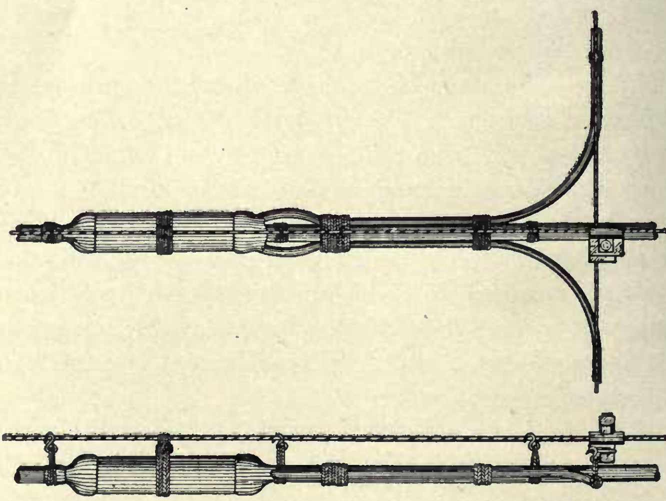


Fig. 562. Y-Splice Support

cable at the splice. An excellent way of supporting a splice is to provide a wrapping of marline around it, as shown in Fig. 561. If the cable is a heavy one, such a marline wrapping may be provided at each end of the splice, omitting the one in the middle.

The same practice may be followed in the supporting of tap and **Y**-splices. Sometimes it becomes necessary to make a **Y**-splice at a point where two messenger wires cross and where no pole is at the intersection. In such cases the messenger wires, which cross at the same level, should be rigidly secured to each other by a messenger clamp, and the splice and the cables leading from it supported by marline in addition to the usual hangers, as shown in Fig. 562. It will be noticed that the splice is made some distance back from the intersection on the main lead and that the two smaller cables leading from it are lashed to the main cable by marline, so as to make it impossible for any side stress on the cables which follow the intersecting messenger wire, to come on the covering of the splice itself.

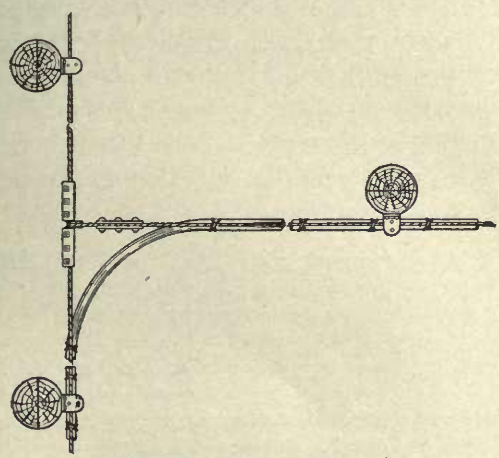


Fig. 563. Aërial Cable Turn

In turning corners with aërial cable, even where no splice occurs, particular care should be taken to avoid kinking the cable and also to avoid its chafing against the pole. If the turn occurs on a corner pole, the cable should pass on the inside rather than on the outside of the pole, and should be lashed to the messenger wire by a wrapping of marline in the same manner as used in supporting the cable splice, illustrated in Fig. 561. If the turn is made on an intermediate point between poles, it may be done as shown in Fig. 563. In this case plenty of slack should be left in the cable at the point of turning to allow for any drawing up that may occur, due to changes in temperature or to any influence that might cause the cable to creep.

In cases where the cable is subject to possible chafing from trees, poles, buildings, or other objects, it may be protected by wooden cleats lashed to it by marline or wire as shown in Fig. 564.

Terminals. The subject of terminals for aërial construction is one about which much has been written and said, and until recently no standard practice has resulted. This subject particularly is one which has required time to afford the necessary experience for determining what was desirable and what was not, and the art is so young that it is only recently that engineers have approached anything like agreement.

There are two purposes of the cable terminal for aërial construction: First, to provide access to the wires in the cable for connecting uncabled wires, such as those leading to the subscriber's premises or to bare wire leads. Second, to afford means for inserting protective devices in the line conductors at points between a section that is exposed to electrical hazards and one that is not.

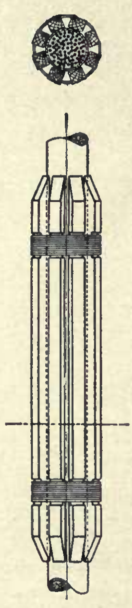


Fig. 564. Cable Protector

In any event the cable terminal must possess the following requisites:

It must afford ready means, such as binding posts or terminal clips, for attaching the wires that are to form the continuations of the cable conductors.

It must afford desired protection against the entrance of moisture to the core of the cable or cables which terminate in it.

It must afford high insulation between all of the terminal posts or clips and the wires leading to them, so that the insulation of the cable conductors as a whole may be maintained.

It must afford ready access to the terminal posts and connecting wires and to the protectors, if such exist.

It should be as compact as is consistent with the requirements for insulation and good mechanical construction.

It must be capable of protecting, in a reasonable degree, against the entrance of dust, moisture, and insects.

It should be as sightly as it is possible for such things to be.

For tap terminals at intermediate points on aërial cables, the usual requirement is for a relatively small number of conductors to be made available. This number ranges from ten to fifty pairs. At such points it is usual to continue the line wires by means of rubber-insulated twisted pairs which extend from the terminal pole to the premises of the subscriber. Such terminals are protected or unprotected according to the hazard of the continuing wires.

Unprotected:—An excellent form of unprotected terminal for such work, manufactured by the Western Electric Company and largely employed by the Bell operating companies, is shown in Fig. 565. This consists of a cast-iron box forming a chamber, from the

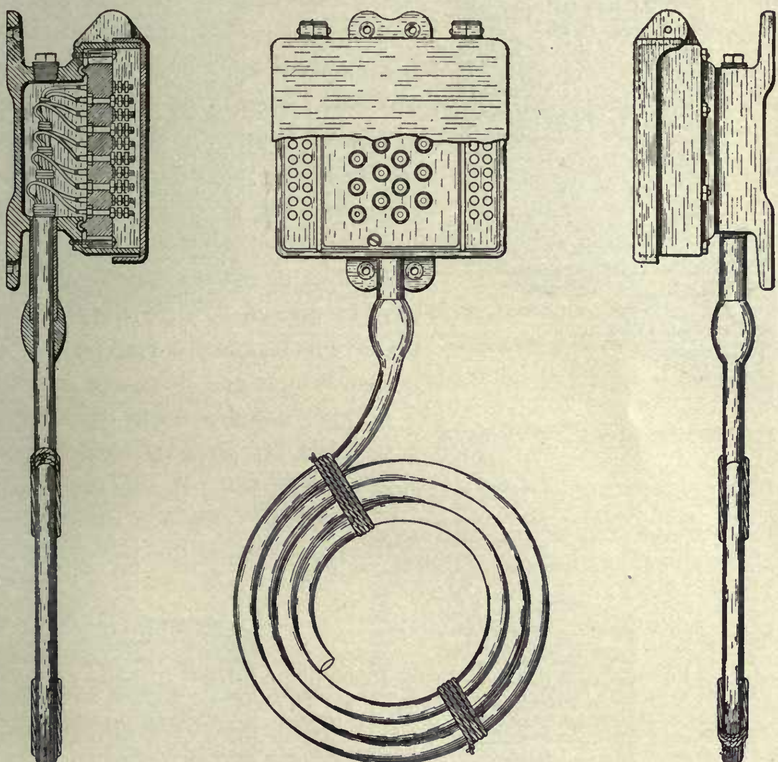


Fig. 565. Western Electric Terminal

lower portion of which there extends a brass tube of sufficient diameter to just admit the lead sheath of the tap cable. The front of this chamber is closed by a porcelain slab into which the lock-nut terminal binding posts are secured. To the rear end of the binding post studs, the individual cable wires are soldered, and the whole chamber is then filled with a hot insulating compound so as to hermetically seal the end of the cable and prevent the entrance of moisture to the insulated wires leading to the binding posts. By this means the terminals of the tap cable are continued to the lock-nut binding posts on the front of the porcelain slab, with no liability of the entrance of moisture to the cable. The whole device is compact, and owing to the high insulation resistance of porcelain and of the insulating compound used in filling the chamber, the very high degree of insulation required is maintained. As furnished by the Western Electric Company, this terminal has a length of lead-covered cable attached and its conductors properly connected, the joint between the brass sleeve and the sheath of the cable being made by a plumber's wiped joint. The box is provided with a hinged iron cover which guards against the entrance of moisture, dust, and insects.

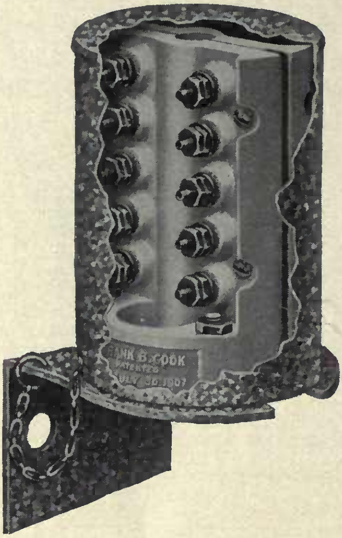


Fig. 566. Cook Unprotected Terminal

Another excellent form of cable terminal for this class of work, manufactured by Frank B. Cook, is shown in Fig. 566. In this the binding posts are mounted on two porcelain blocks. Two of these blocks are adapted to form a chamber between them for the insulating

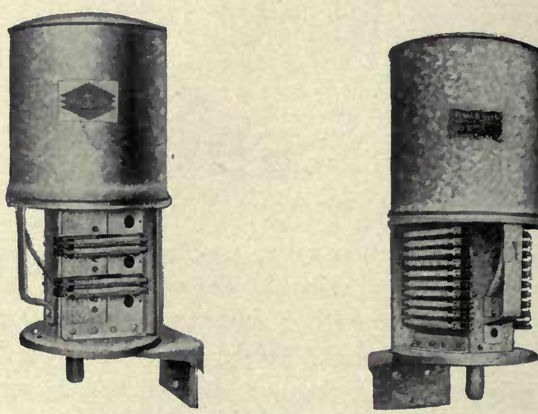


Fig. 567. Cook Protected Terminal

compound. This terminal may be procured either with or without a length of tap cable attached, according to whether the user desires to do this work for himself or not. In this form of terminal a cover, consisting of a cylindrical galvanized iron can, is provided, which, when raised, exposes all of the binding posts, and when lowered, affords them adequate protection.


Fig. 568. Wooden Terminal Box

Protected:—Where the wires leading from a cable terminal are bare and of considerable length, or where they pass through territory exposed to electrical hazards, the cable terminal should be provided with protectors. This point has already been dealt with in Chapter XIX. Cook protected terminals, providing fuse and carbon arresters for each wire, are shown in Fig. 567.

The type of terminal shown at the left in Fig. 567 is only partially equipped with protectors in order to show more clearly the method of mounting them in units. The one at the right is completely equipped. This general type of terminal is easily adaptable for use at the junction point between aërial and underground cable.

Another form of protected terminal—commonly used where aërial cable leads and bare wire leads of considerable sizes join—consists in fuse and air-gap protectors mounted in wooden boxes. A view of such a wooden terminal box is shown in Fig. 568. For use in such boxes, strips of combined air-gap and fuse protectors are procurable, the

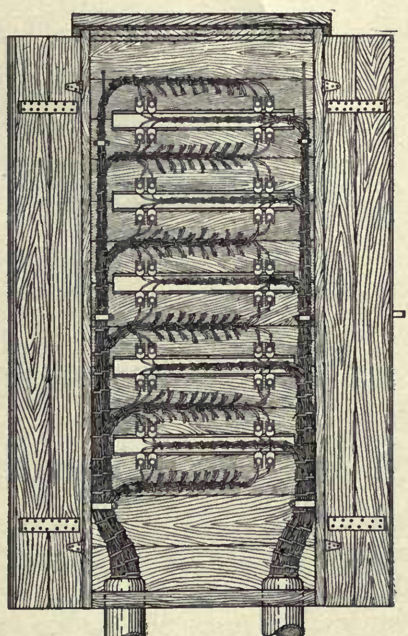


Fig 569 Wooden Terminal Box

strips being added in units of ten, twenty, or more, as required.

This wooden terminal box has the advantage of being able to accommodate a large number of line conductors, and for that reason is the most common form of protected terminal box for use between the junction of aërial and underground cables. The details of wiring within such a box when used for joining aërial to underground cable wires through protectors, is shown in Fig. 569.

These wooden terminals, whether used at the outer terminal of an

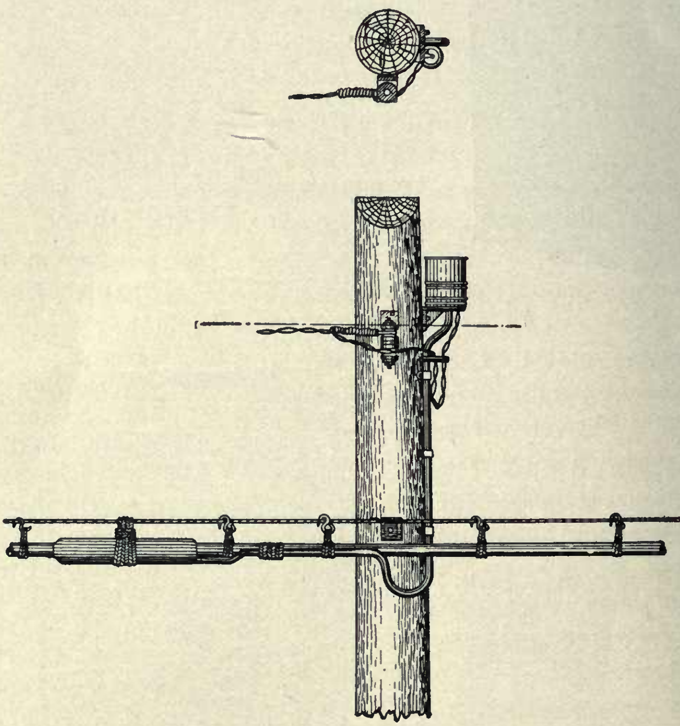


Fig. 570. Tap Cable Terminal

aërial lead or for joining underground and aërial cables, provide no means for sealing the cables which terminate in them. For this reason, it is necessary to "pot-head" the cables; that is, they are terminated in a special form of splice which serves to connect all of the cable conductors with uncabled rubber-insulated conductors, and at the same time completely to seal the end of the cable against the entrance of moisture. The matter of pot-heads will be considered in the chapter dealing with cable splicing.

Position:—The relation as to position between the cable terminal and the other features of aërial construction merits attention.

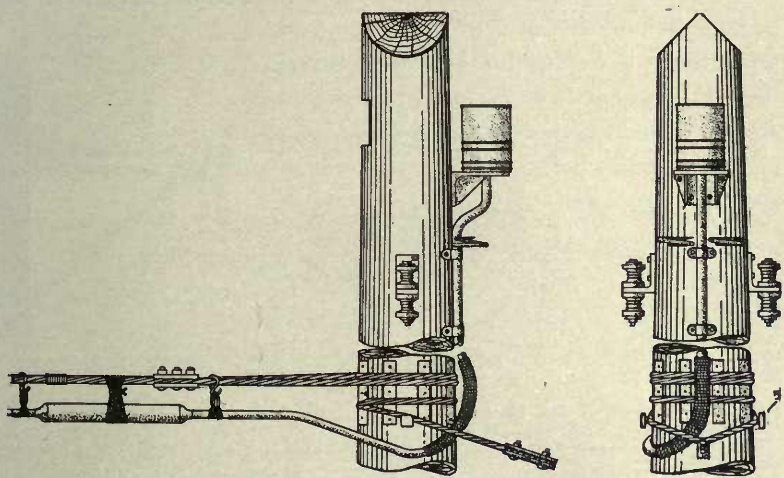


Fig. 571. Aërial Cable Terminal

Where terminals are used for the purpose of distributing the cable conductors to the drop wires which extend to the adjacent subscrib-

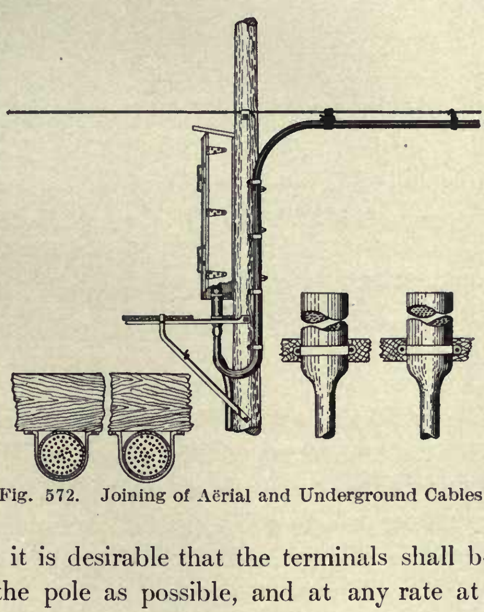


Fig. 572. Joining of Aërial and Underground Cables

er's premises, it is desirable that the terminals shall be mounted as high up on the pole as possible, and at any rate at a point from which there will be the most direct and clearest run to the neighboring houses or adjacent poles.

Fig. 570 shows a terminal of a tap cable and the method of supporting the splice and the tap cable. The tap cable is lashed to the main cable beyond the point where it emerges from the splice and is then looped down and up vertically along the pole, being held to the pole by straps of sheet iron.

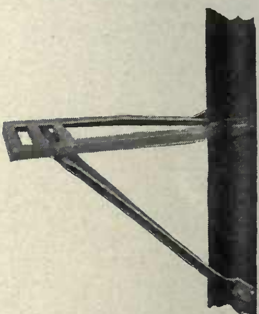


Fig. 573. Pole Seat

In Fig. 571 is shown the terminal at the outer end of an aërial cable, this showing also the dead-ending of the messenger wire and guying of the terminal pole. It also shows how the cable where it bends around the pole adjacent to the guy shims and guy and messenger strands may be served with a wrapping of marline to guard against abrasion.

The details of the most common method of inserting protection between aërial and underground cables is shown in Fig. 572. The cable leading up from the underground conduits is shown at the bottom of this figure, and the aërial cable is shown extending from a messenger wire down the pole and then up to the terminal box. This figure also shows details of the mounting for the pot-heads, in which both the aërial and the underground cables terminate. The rubber-covered wires leading out of the potheads pass upwardly within the box alongside of the terminal strips of the protectors and are there soldered into place so as to form permanent connections.


Fig. 574. Pole Balcony

Pole Seats:—Where 50 or more pairs of wires terminate in an aërial terminal, it is convenient to equip the pole with some form of seat or balcony for convenience of the cablemen. This is particularly true where protected terminals are used. This may be a simple seat for the workmen, as shown in Fig. 573, or for larger and more important terminals it may assume the form of a "balcony," as shown in Fig. 574.

CHAPTER XLV

UNDERGROUND CONSTRUCTION

Reasons for Placing Wires Underground. The demands of the public and the welfare of telephone companies alike require the placing of wires underground in the most densely built-up portions of cities. The view given in Fig. 575 is in itself a sufficient argument for the placing of wires underground in such places. Usually

Fig. 575. An Argument for Underground Wires

the "enlightened self-interest" of the operating company dictates a greater area of underground construction than that required by the public through city ordinances.

Interests of the Public. From the standpoint of the public, overhead wires are objectionable for several reasons: They are unsightly; they are dangerous to workmen and passersby; they interfere with the work of firemen; and when down in the streets they obstruct traffic.

Interests of the Operating Company. The wisely managed telephone company will choose to place its wires underground in congested districts for still other reasons, of which the principal one is that of economy. Where a large number of wires are involved it is cheaper under average city conditions to place them underground than overhead; but the main feature of economy is from the standpoint of maintenance. Well-constructed telephone conduits are almost as durable as the foundations of buildings and require comparatively small expense for up-keep. Wires contained in such conduits are subject to a minimum amount of electrical hazard, and are less exposed to the elements and to the acts of careless or malicious persons. The depreciation of underground conduits is almost *nil*, and that of underground cables very much less than of those overhead.

Buried Cable. The very early practice in underground cable work involved the placing of the cable in a trench and filling in the earth on top of it. The main objection to this was that the cable was not accessible for repairs or changes. A cable once buried in this way was often virtually lost if it became faulty, since the cost of digging it up was more than its salvage value. This method provided no facilities for growth and necessitated the frequent digging up of the streets. Another objection was that the cable was unprotected from the tools of workmen engaged in making subsequent excavations.

Underground Conduit. The method that is now universally practiced involves the building of an underground conduit into which cables may be drawn and from which they may be withdrawn as occasion requires. Such conduit, once wisely planned and properly constructed, affords the required mechanical protection and provides not only for the present demands but for those reaching far into the future.

The conduit, irrespective of cables, consists of one or more permanently installed ducts or openings extended between manholes through which access is afforded to the ducts. These ducts or openings are made of sufficient internal diameter to accommodate the largest cable that it seems probable ever will be used. The number of ducts installed at the time of building the conduit is made equal to the largest number of cables that it seems probable will be required along that route within a given period of years. Such a degree of flexibility is provided by this plan that only those cables which are required by the present needs of the system are installed at the outset, others being added from time to time to meet the growth or changed requirements.

Duct Material. The materials available for conduit ducts are vitrified tile, creosoted wood pipe, iron pipe, paper or wood pulp pipe impregnated, cement lined pipe, concrete pipe, and sometimes the ducts are formed in the concrete structure itself as it is being laid. Of these materials the most used are vitrified tile, impregnated fiber pipe, iron pipe, and creosoted wood pipe. Clay tile and paper or fiber pipe are perhaps the most used in main conduit runs in city streets or alleys, where many ducts are required. Clay tile has the advantage of being known to be practically everlasting under the action of the elements. It has the disadvantage of being heavy and, therefore, somewhat expensive on account of transportation charges in those localities that are far removed from the source of supply. It is fragile and, therefore, subject to a considerable breakage loss in handling.

Fiber pipe has the advantage of being light and easily handled and transported, and, therefore, in some localities cheaper than tile. Its breakage loss is less than that of tile. No one knows how long it will last, but when properly made and laid it has proven its ability to stand, without appreciable deterioration, throughout long periods of time. Both clay tile and fiber pipe have so little ability to withstand shock—as from the pick axes of workmen—as to make it usually necessary to provide for them an envelope of concrete which wholly or partially encloses them.

Iron pipe has the advantage of needing no protecting envelope, as a rule, but has the disadvantage of being very expensive and of gradually deteriorating under the action of certain soils. It is, however, largely used in main conduit work for cases requiring special treatment, and for the subsidiary or branch runs from main conduits where but one or two ducts are required.

Creosoted wood or "pump log" conduit is more expensive in first cost than clay or fiber, but less expensive than iron and it has such resisting power against ordinary shocks and strains as to make it feasible to lay it directly in the ground without an enclosing envelope.

Well-impregnated wood is known to have a life of many years in all ordinary soils, and the consensus of opinion is that creosoted wooden pipe has a long enough life to make it satisfactory in that respect as a duct material.

Vitrified-Clay Conduit. Taking under consideration, first, the construction of conduits employing vitrified clay, it may be said that

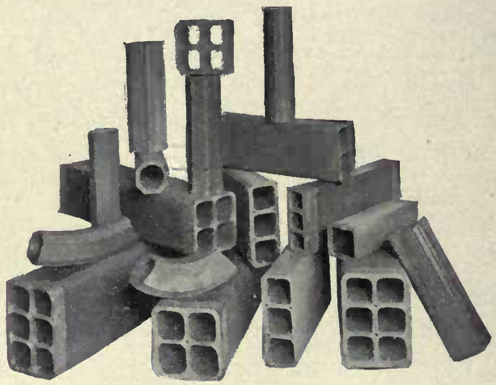


Fig. 576. Single- and Multiple-Duct Clay Tile

tile of this material is obtainable in a variety of forms, which may be classified as single-duct and multiple-duct. Illustrations of these forms, furnished by McRoy Clay Works, are given in Fig. 576.

Single-Duct Tile:—In laying, these are piled together side by side and tier on tier in the trench in order to make up the desired number of ducts and the proper cross-section. The ends are butted together, the joints being staggered and the whole mass set in concrete so as to form a practically continuous structure.

In order to maintain the proper alignment between the abutting ends of these single-duct tiles, it is customary during the process of

Fig. 577. Dowel Pin

laying them to employ a mandrel, about 3 inches in diameter and 30 inches long. This is laid in the duct and pulled along through it by workmen as each additional section is laid. Otherwise the laying of this single-duct tile is about the same as that of ordinary brick.

Multiple-Duct Tile:—Another form of tile that is largely used is the so-called multiple-duct, several forms of which are shown in Fig. 576. In laying this, after providing a proper foundation usually of concrete, the tiles are placed together so as to form the proper cross-sectional arrangement of ducts. The butt joints are held in

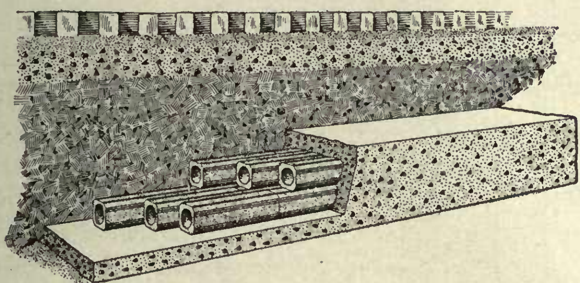


Fig. 578. Conduit of Single-Duct Tile

alignment by dowel pins of the form shown in Fig. 577. This pin is of iron 3 inches long, of such diameter as to loosely fit the dowel pin holes in the duct ends, and having a washer formed at its center so as to divide it equally between the abutting sections of conduit. In order to prevent dirt or concrete from entering at the joints in the

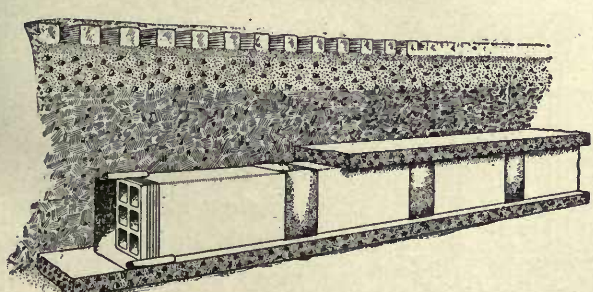


Fig. 579. Conduit of Multiple-Duct Tile

ducts, each abutting joint is wrapped with a layer of muslin or burlap cut into strips about 8 inches wide and long enough to surround the conduit and lap over several inches. This strip is saturated with water to make it cling to the conduit, after which it is plastered with cement mortar. In Fig. 578 a good idea is given of the formation of a conduit composed of single-duct vitrified clay, and in Fig. 579 of one built of multiple-duct.

Use of Concrete with Clay Tile:—Until comparatively recently it has been customary to completely surround the line of conduit—top, bottom, and sides—with a concrete envelope about 3 inches thick, as shown in cross-section in Fig. 580. During recent years there has been a growing tendency to curtail the expense in concrete work and several arrangements have been tried and each has its advocates. One of these, shown in Fig. 581, is to lay about a 4-inch foundation of concrete in the bottom of the trench and then build up the tile on this. This is covered with a layer of heavy creosoted plank and the earth is then tamped in on sides and top.

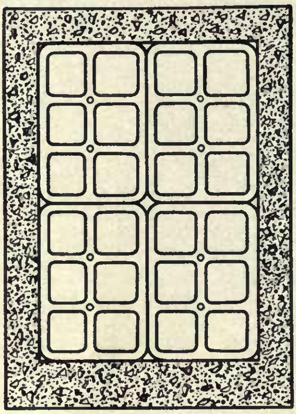


Fig. 580. Conduit Cross-Section—Complete Concrete Envelope

Another method consists in laying the foundation as just described, then building up the line of ducts and tamping in the earth on the sides only, and finally covering this with another layer of concrete about 3 or 4 inches thick so as to give protection at the top against the pick axes of workmen. Both the top and bottom layers of concrete serve also to provide the necessary mechanical rigidity. This construction is shown in Fig. 579 and indicated in cross-section in Fig. 582.

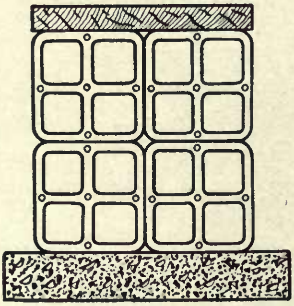


Fig. 581. Conduit Cross-Section—Concrete Bottom and Plank Top

Still another method is to place no concrete on the bottom of the trench, this being made to grade and tamped to a proper degree of hardness and smoothness. On this the tiles are laid without other foundation and earth filled in at the sides to a point a few inches below the level of the upper tiles. Concrete is then thrown into the remaining space on the sides and top to a depth of about 3 inches above the upper tile, as shown in Fig. 583. This forms an inverted channel of concrete which gives a considerable sidewise rigidity as well as the necessary protection on top.

Undoubtedly the best way, where one wishes to be perfectly safe, is to make the concrete envelope entirely surround the vitrified tile—top, bottom, and sides. This makes a more rigid structure and one less liable to injury in the event of settling of the earth from any cause.

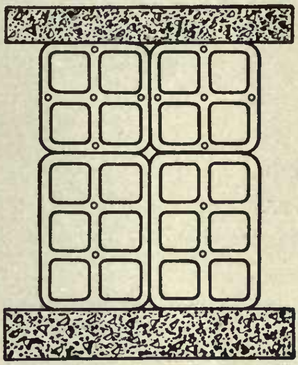


Fig. 582. Conduit Section—Concrete Top and Bottom

Fiber-Pipe Conduit. The bituminized fiber pipe employed for duct material is sometimes made of paper, being wound on a mandrel of proper size to give the requisite internal diameter and thoroughly impregnated with asphaltum or bituminous compound. It is necessary to exercise care in laying this so-called paper pipe in hot weather that it is not squeezed out of its cylindrical form under the pressure imposed by tamping the concrete into place.

Another form of fibrous conduit is made by wrapping very thin layers of wet wood pulp or fiber on a forming mandrel, under great pressure, until the desired thickness of wall is obtained. This conduit, unlike the paper pipe, has its individual fibers felted and formed into a solid homogeneous wall, which is then taken off the mandrel, thoroughly dried, and placed in a vat of impregnating compound.

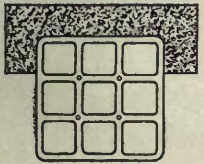


Fig. 583. Conduit Section—Concrete Top

This compound permeates the entire structure and acts as a preservative, and also renders the wall impervious to moisture. The black hard material which results, somewhat resembles hard rubber and is of such texture as to permit its ends being dressed in a lathe to form the desired mortise or tendon joints, by means of which the alignment is secured when the ducts are laid in the trench. This material has been used in large quantities by the writers and has not been found subjeet to the fault of distortion under pressure, mentioned above. Two lengths of this fiber conduit are shown in Fig. 584.

The length of the standard duct is 5 feet, its internal diameter, in the sizes most used for telephone work, 3 or $3\frac{1}{2}$ inches, and the thickness of wall $\frac{1}{4}$ inch.

Recently a type of duct formed of the same material, with the length and internal diameter the same, but the thickness of wall

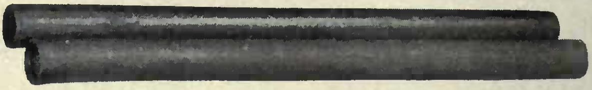


Fig. 584. Fiber Pipe

being $\frac{1}{8}$ inch, has been produced. This is too thin to permit of the socket joint formation, so the joints are made by merely butt-ending the two lengths and slipping over the joint a sleeve of the same material about 4 inches long. A good idea of this duct and of the joining sleeve may be had from Fig. 585.

Laying Fiber Ducts:—Fiber-pipe conduit when used in main conduit runs must be set in concrete, as the strength of the wall is not sufficient to make it safe to do otherwise. In laying it, after the trench has been properly opened and graded, a foundation layer of concrete about 3 inches deep is laid and tamped, the upper surface being well graded. Upon this foundation the first layer of duct is laid, the horizontal separation between the outer walls of the ducts being about 1 inch. This separation is readily provided by driving stakes in the ground or by employing so-called combs. These combs consist merely of wooden strips slightly less in length than

Fig. 585. Fiber Pipe and Joining Sleeve

the width of the trench and having short strips secured at right angles to them; the distance between these strips being just sufficient to include the external diameter of the duct, and the width of the strips being equal to the required horizontal separation between the ducts when laid. After the first layer of ducts is in place and temporarily held by the stakes or combs, concrete is slushed in and tamped lightly. If there is to be more than one layer of ducts, the depth of the concrete thus applied is made sufficient to cover the first layer about 1 inch deep. The surface of this concrete layer is then leveled and tamped so as to form the foundation of the second layer, after which the same operation is repeated until the required number of ducts are

Fig. 586. Laying Fiber Duct

laid. After the top layer of ducts has been laid, a layer of concrete is thrown in and tamped to a depth of about 3 inches above the top of the ducts. In tamping the concrete in place, care must be taken to prevent ramming stones through the walls of the ducts, particularly where the $\frac{1}{8}$-inch pipe is used.

The process of laying runs of fiber conduit is shown in Figs. 586 and 587. It is not usually necessary to line the sides of the trench with planks, as shown in Fig. 586; but this is sometimes done where

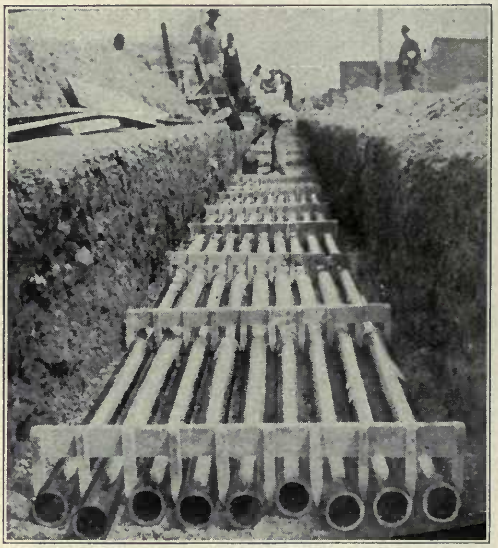


Fig. 587. Laying Fiber Duct

ıe character of the soil is such as to make it difficult to excavate so as to leave proper vertical side walls.

Wooden Conduit. Creosoted-wood or pump-log conduit is usually laid without any concrete whatever, the bottom of the trench

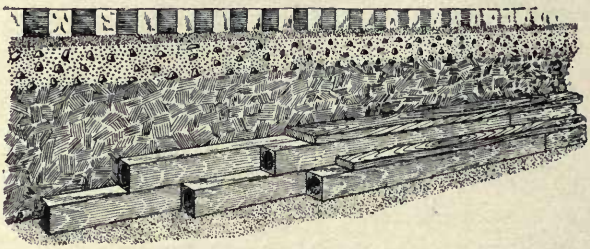


Fig. 588. Creosoted Wood Conduit

being properly graded and tamped and the ducts laid directly on the bottom of the trench without other foundation. Sometimes a foundation of 2-inch creosoted planks is used and the ducts laid on this;

and on top of the ducts a single layer of 2-inch creosoted plank is placed to afford protection in case of subsequent excavation. In treacherous soils it is always well to provide the foundation layer of 2-inch creosoted plank at the bottom of the trench. The usual construction, without the bottom layer, is shown in Fig. 588.

Iron Conduit. Iron pipe is not usually employed for main-line conduit work except in places of especially difficult construction Where it is used in main conduits, it is completely encased in concrete. A large amount of the general conduit system, employed by the telephone and signaling companies in New York City, is of 3½-inch iron pipe laid in concrete. This is used in the downtown districts where almost unparalleled congestion occurs, and where economy of space and great rigidity of construction are essential features. Where used as subsidiary or lateral ducts branching off from main conduit runs, it is customary to lay the iron pipe directly in the ground without any protecting covering whatever. This is the main use of iron pipe in underground conduit work.

Conduit Cross-Sections. The cross-sectional arrangement of the ducts in the main lines of conduits deserves some attention. It is common practice to pay little regard to this, but it is our belief that, except in conduits having a very large number of ducts, and except where it is difficult to make the trench sufficiently deep, it is far more convenient to so arrange the cross-section that the conduit will be no more than four ducts wide and as many high as the total number requires. The reason for this is that this arrangement permits a more systematic disposal of the cables in manholes or vaults than would be the case if the width of the conduit was greater than four ducts.

Fig. 589 shows conduit cross-sections made from standard multiple-duct tile varying in number of ducts from two to twenty-four. In no case within this range need the conduit be more than four ducts wide, except where unusual conditions as to digging or obstructions are met. Fig. 590 shows economical arrangements as to cross-section of fiber pipe conduits of various sizes.

General Features of Conduit Work. Having outlined the various kinds of duct material and the methods ordinarily employed in laying them, we will discuss briefly the more general features of conduit construction, including that of manholes and laterals.

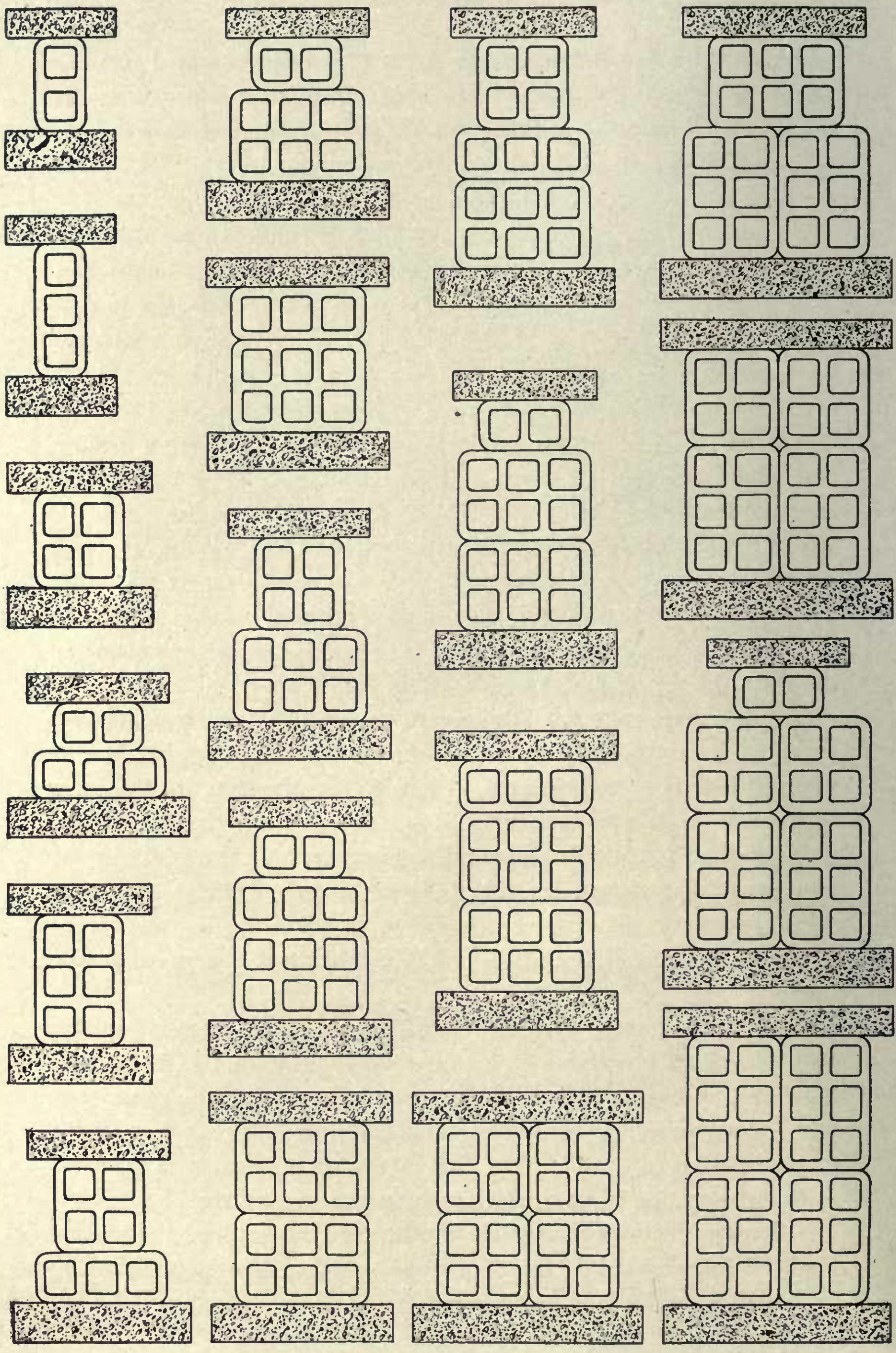


Fig. 589. Cross-Sections of Tile Duct

Main Line and Lateral Conduit. As has been stated, manholes are necessary at frequent intervals along a line of conduit to provide means of access to the cables. This access is necessary, first, for

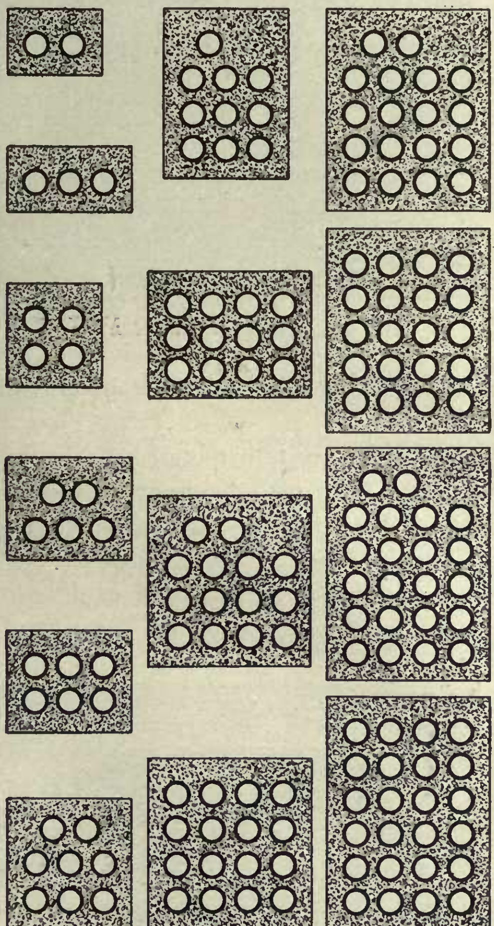


Fig. 590. Cross-Section of Fiber Conduit

drawing the cables in or out as required; and second, for leading off branch cables through lateral pipes to poles or other aërial structures or to the basements of buildings. The main conduit line, therefore, consists of one or more ducts leading between adjacent manholes, and the subsidiary conduit consists in lateral ducts or pipes leading from the manholes or sometimes from intermediate portions of the conduit either to poles or buildings for affording con-

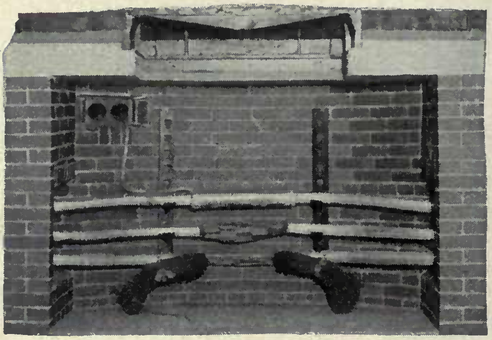


Fig. 591. Section of Brick Manhole

nection either with aërial or interior wires leading to the subscriber's premises.

Manholes. These consist merely of holes in the ground, lined on top, bottom, and sides with brick or concrete. They have a suitable opening at the top for the access of workmen and have in their side walls openings into the various ducts.

The choice between concrete and brick as the material of which to construct manholes depends upon the following considerations.

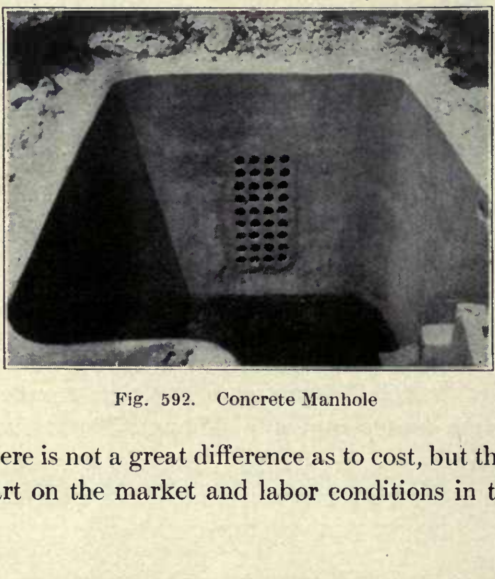


Fig. 592. Concrete Manhole

Ordinarily there is not a great difference as to cost, but this will always depend in part on the market and labor conditions in the locality in question. A factor of considerable importance that favors the employment of concrete is, that skilled bricklayers are not required, and this makes it possible to employ the same class of labor for constructing manholes as is used on the conduit itself. For this reason, if for no other, the concrete manhole is usually to be preferred in places where the underground conditions are such as to permit the construction of the manholes in standard sizes and shapes. In the down-town districts of large cities, however, this is usually not possible, since the presence of pipes and other underground properties often demands the building of manholes of irregular shapes and sizes. Brickwork lends itself much more readily to the requirements of such conditions than does concrete. A good idea of the interior of a brick manhole is given in Fig. 591, which shows a cross-section taken through a completed manhole. Fig. 592 shows a concrete manhole before the top has been placed.

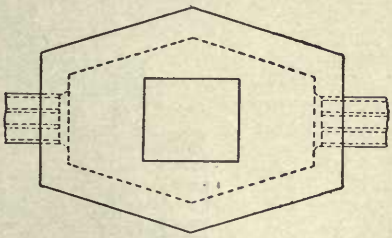


Fig. 593. Plan of Manhole

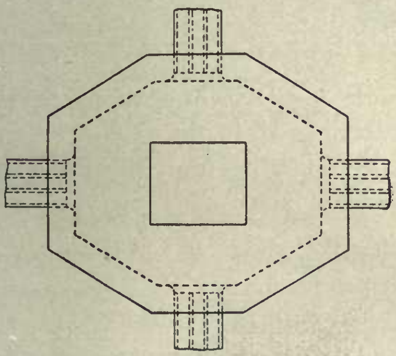


Fig. 594. Plan of Manhole

Shape of Manholes:—The shape of a manhole will always depend to some extent on the number and the directions of approach of the various conduit runs leading to it. It will depend also upon the character of the obstructions found in excavating for it. Where the manhole occurs between two adjacent runs of conduit in the same line, and where there is no intersecting run, the general shape shown in plan in Fig. 593 is a good one. Where the manhole occurs at the

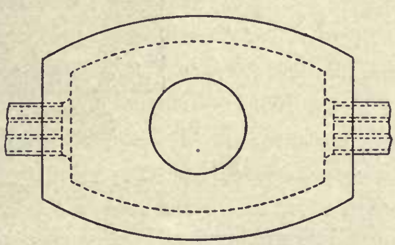


Fig. 595. Plan of Manhole

junction between a main line and an intersecting line this shape is necessarily slightly altered, as shown in plan in Fig. 594. These

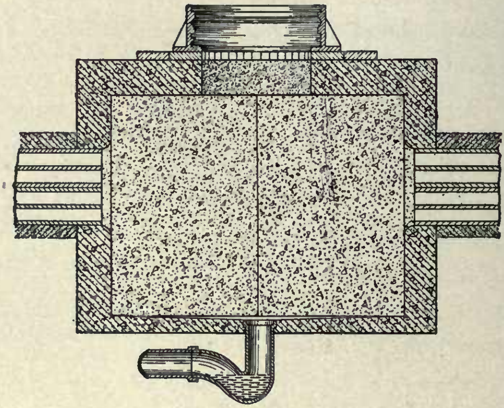


Fig. 596. Section of Concrete Manhole

shapes lend themselves readily to the employment of simple wooden forms around which the concrete is poured, in the case of concrete construction, and are also equally desirable from the standpoint of simplicity where brick is the material employed.

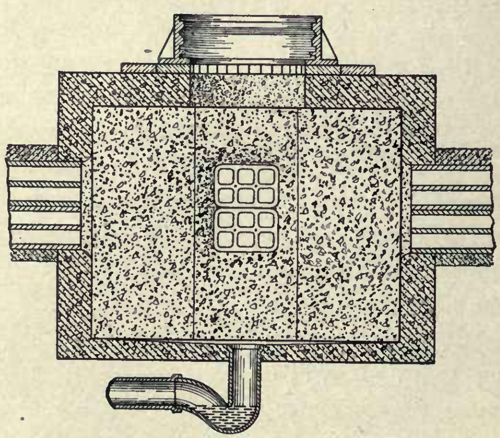


Fig. 597. Section of Concrete Manhole

Some prefer, in the case of a manhole occurring in a straight run, to curve the sides, giving a resulting plan as shown in Fig. 595. The details of construction of the non-intersected and the intersected types of manholes are shown in Figs. 596 and 597.

TABLE XXXIV

Inside Dimensions of Manholes

Straight Runs Not Intersected			
No. of Ducts	Length	Width	Height
1 to 6	4′6″	3′6″	4′6″
7 to 15	6′	4′	5′
16 to 24	8′	5′	5′6″
Intersected Runs			
No. of Ducts	Length	Width	Height
1 to 6	4′6″	4′6″	4′6″
7 to 15	6′	5′	5′
16 to 24	8′	5′	5′6″

Sizes of Manholes:—The size of manhole will, of course, vary with the number of ducts entering it. No definite rules may be laid down, but the sizes as given in Table XXXIV are suggested for different sizes of intersected and non-intersected runs.

Location of Manholes:—In laying out a conduit system the location of the manholes is an important factor. It is not always possible to locate a manhole exactly where originally planned, because upon excavation it may be found that pipes or other obstructions that cannot be moved will necessitate a change. In general, however, manholes should be located at street or alley intersections, since this allows a single manhole to serve for intersecting runs, and also places them at the most convenient points from which to distribute lateral pipes. This rule is by no means universal, however, and frequently manholes other than at street intersections are necessary or desirable.

The distance between manholes should, of course, not be so great as to make it impossible to draw single lengths of cable into the intervening ducts. However, the req rements for distribution in cities laid out in the ordinary way usually demand the spacing of manholes at distances considerably shorter than the limiting lengths set by the possibilities of cable drawing. In general, it may be stated that manholes are placed at distances apart of about 400 or 500 feet or less. It has been found possible, however, to draw with success and safety lengths of cable considerably in excess of this distance, and we have without difficulty or danger, in special cases, drawn in pieces of 400-pair cable, 800 feet in length.

Construction of Conduit. *Test Holes.* In laying out the main conduit, after its general method of construction and the streets and alleys on which it is to be located have been determined, it is frequently necessary to dig test holes at street intersections to disclose the nature of the existing underground obstacles. These test holes are usually in the form of narrow trenches across the streets. If the engineer is fortunate enough to find city records of underground structures that are to be relied upon, or, if the city is so small or new that chances for such obstacles existing are small, the digging of test holes may be dispensed with. As a rule, conduits should not be located in the center of the street on account of the possibility of interference with subsequent sewer or electric railway work, and not too close to the curb line on account of the greater exposure to surface drainage.

Trenching. In opening the trench the paving or surface material of the roadway is to be placed on one side so as to be available for re-surfacing when the work is completed. Sometimes the trench is excavated in parkways, between the sidewalk and the curb, or across lawns on private right-of-way, in which cases care must be taken to cut and preserve the sod and to replace it upon the completion of the work. Occasionally it is required to spread a cloth on the grass to receive the excavated dirt, so that as little of the grass may be injured as possible.

In general, the trench for the main conduit is to be excavated to such a distance as will leave not less than 24 inches from the top of the protecting envelope to the ultimate grade of the street. The width of the trench will, of course, vary according to the width of the conduit run. When the character of the soil will permit, the sides of the trench should be cut clean and vertical from the bottom of the trench to a level that will correspond with the top of the conduit when laid. From this point up to the surface of the ground it is frequently convenient, in some kinds of soil, to allow a considerable slope. In some soils it is necessary to provide shoring to prevent the sides of the trench from caving in.

Where blasting is required, as in rock soils, it should always be done by a person competent in the use of explosives. In such work the blast is covered with heavy logs and chains to prevent injury to life and property, and only moderate charges of explosives should be used. It is a wise precaution to study the requirements of local authorities before doing any blasting. Where gas, water, or other pipes or underground property of any nature is met, the work, if possible, is to be conducted without interfering with them, care being taken to properly protect and support by temporary braces or chains any such properties which it may be necessary to undermine.

Grading. It is desirable to open an entire section of trench between adjacent manholes before laying the ducts so as to show the nature and location of all obstructions. The final grade is then determined and the bottom of the trench graded and tamped, if necessary. The grading is to be so done as to avoid sumps or traps in which water may accumulate. This means that the grade should be a descending one from one manhole to the other, or from a high intermediate point to both manholes. A grade of at least 6 inches for each 100 feet will do, but more is desirable.

Where possible, the various runs of ducts should enter a given manhole at about the same level, those entering one side of a manhole being preferably located directly opposite those in the other side. This is a convenience in rodding ducts, as will be subsequently described, permitting the rods to be pushed from one section to the other without uncoupling them.

Curves in Conduit Line. The trench should, if possible, follow a straight line between manholes. Often, however, this is impossible. Wherever curves are unavoidable, they should be of as great radius and as small deflection as possible. If the section of the conduit is not more than 100 feet in length, a 60-degree curve may be permitted, but it should have a radius of at least 25 feet. In sections between 100 and 200 feet in length a 60-degree bend is allowable, but its radius should be at least 50 feet. For sections longer than 200 feet the curvature should be less than 60 degrees, and the radius should be proportionately longer. If a double curvature is necessary it is desirable that neither of them should be more than 15 degrees nor have a radius less than 50 feet. It goes without saying that the longer the run the more undesirable is any curvature.

Lateral Runs. The lateral pipes by which a cable is led from the main conduit line to a pole or building for distribution purposes are usually of iron, unprotected by concrete, although sometimes fiber pipe or creosoted wood may be used to advantage.

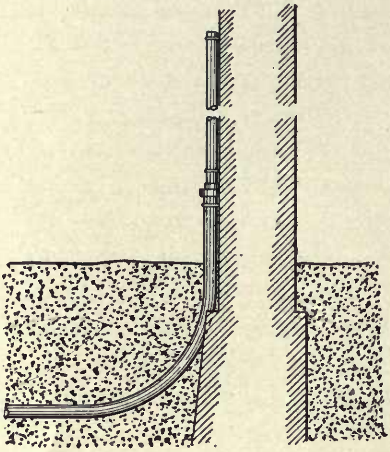


Fig. 598. Lateral Riser up Building Wall

Frequently, when the lateral pipe is to reach a point on the street intermediate between manholes, it is convenient to lay it for a certain distance in the same trench with the main conduit. Where this is done it is preferably enclosed in the concrete envelope with the main conduit, and may be of the same conduit material as the main conduit, or of the material of which the lateral pipe branching off from the main conduit is made. As the cables in lateral pipes are usualy smaller than those in the main conduits, it is frequently permissible to use smaller diameters of ducts for lateral pipes than for main conduit ducts. 2-inch iron pipe suffices in most cases, but where the cable to be accommodated is large, it is well to make the lateral duct of the same size of pipe as the main-line duct. Except where large cables are to be installed in lateral pipes, it is permissible to make right-angle bends in such pipes on a 30-inch radius.

Connections between the laterals laid in the main trench and the continuation of the lateral laid in a separate trench are made by means of bends in the duct material. Iron pipe may readily be bent, and fiber conduit and some other types of duct material provide specially bent lengths of duct for this and similar purposes.

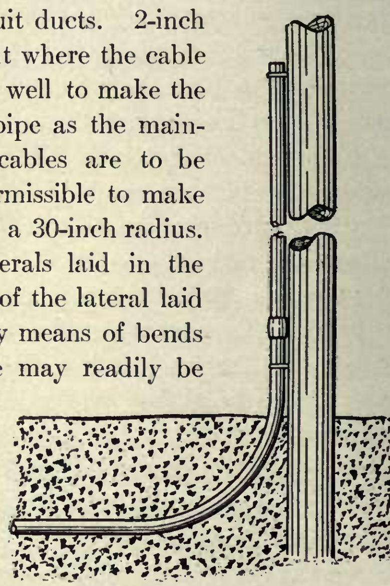


Fig. 599. Lateral Riser up Pole

Ordinarily it is not necessary to dig the trench for lateral pipe as deep as that required for a main trench—a trench 18 inches deep and as narrow as a man can dig with a spade being sufficient. If iron pipe is laid, all protection to it may ordinarily be omitted; but if fiber or wood pipe is used, it is a good plan, outside of the property lines, to fill in the space between the duct and the side of the trench and over the duct to a depth of about 3 inches with concrete lightly tamped in place. Inside of the property lines on private property this protection may be omitted.

Where possible the lateral should slope toward the manhole. This is particularly important in northern localities, where much trouble has been experienced due to the freezing of water in lateral iron pipes, resulting in a consequent compression of the cable, which causes the short-circuiting of its conductors.

Lateral Risers. Where the lateral cable is to extend up a pole or up the outside wall of a building, it should make connection with a wrought-iron pipe bend not having less than 30 inches radius, and a straight length of wrought-iron pipe should continue up the pole, preferably to a distance of 8 feet above the ground. This lateral riser, as it is called, should be strapped to the pole or to the wall of the building by standard pipe hooks or straps. The method of ending a lateral at a building is shown in Fig. 598, and of extending it up a pole in Fig. 599.

Cable Supports. Some form of support is necessary for the cables leading around the walls of the manhole. A cable support manufactured by the Standard Underground Cable Company is shown in Fig. 600. This is of sectional construction and may be extended as desired. It is frequently found convenient to provide cable supports by inserting into the wall of the vault during construction short lengths of $\frac{3}{4}$-inch pipe at the proper heights. The ends of these are set flush with the inner surface of the wall. When cables are installed a $\frac{5}{8}$-inch wrought-iron rod 12 or 14 inches long is inserted into this

Fig. 600. Cable Support

pipe, on which is placed a wooden shoe for supporting the cable. The details of this support are shown in Fig. 601. This has the advantage of not requiring the installation of the support until the cable is installed, and of permitting its installation without any drilling of the walls of the manhole.

Concrete. The matter of the proper kind of concrete for use in conduit construction is one concerning which there is much difference in opinion and practice. Some engineers employ the same strong mixture of sand, stone, or gravel and cement that would be employed where the greatest strength is required. The later tendency, however, has been to employ a much cheaper mixture, realizing that under no ordinary circumstances will the concrete be subjected to very great strains of any nature. Any good building cement will do. The ordinary concrete is made of a mixture of sand, broken stone or gravel, and cement in various proportions. Frequently "run-of-crusher" stone is procurable, which contains about the right quantity of small pieces to pack well, and if this is found upon experiment to make a good concrete when mixed with the proper portion of cement, the use of sand may be dispensed with. Frequently, also, gravel as it comes from the bank or bar has about the right proportion of sand, in which case, after experimenting, this may be used with cement to form the concrete.

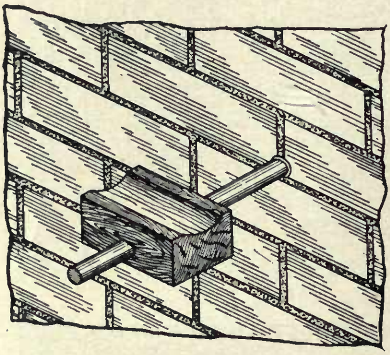


Fig. 601. Cable Support

The general subject of concrete construction is too large a one to treat of here, and much good literature is available on it. It may be repeated, however, that the demands of underground conduit structures are not such as to require an exceedingly strong or expensive mixture. For the concrete envelope surrounding the ducts, a mixture as weak as 1 part of cement and 4 parts of sand and 8 parts of stone or gravel, known as a 1-4-8 mixture, is considered by some sufficient. 1-3-5 or 1-3-6 mixtures may be considered standard practice. For manhole construction a 1-3-5 mixture is good. Frequently much money may be saved by a careful study on the part of the engineer of the cost of the materials available at the point where the construction is to be done and by a few simple experiments to determine the mixture that will give the best results with these materials. Concrete should be used within one hour of the time it is gauged in mixing.

Mortar. Cement mortar consists of a mixture of cement and sand or screenings. A mixture of 1 part of cement to 3 parts of sand or screenings makes a good strong mortar. Mortar should be used within thirty minutes of the time it is gauged in mixing.

Safeguards. It is necessary always to guard the excavations wherever made, for the protection of the public. This is done by means of fences or barriers carried as a part of the construction equipment. The location of all excavations, fences, barriers, or of material piled in the street, should at all times between sunset and sunrise be indicated by a sufficient number of red lanterns.

All construction work should be done with due regard to the rights of the public, temporary bridges being provided where necessary to facilitate traffic across trenches. No excavations should be made or material piled where they will interfere with the access of the public to fire-alarm boxes or of firemen to water hydrants.

Installing Underground Cables. The drawing of cables into underground ducts is a very simple matter, but owing to the fragile nature of sheaths and to the necessity for keeping their cores always absolutely dry, it must be done with great care.

Rodding. It is first necessary to have some sort of a pulling connection through the duct into which the cable is to be drawn. Sometimes a "fish wire," consisting of No. 9 galvanized steel wire, is drawn into the duct as it is being laid. Where this is done, the pulling rope or cable that is to be used in actually drawing the cable into the duct may be attached to one end of the fish wire and drawn by it into the duct. Where there is no fish wire, the process of rodding is necessary. This consists ordinarily in pushing short wooden rods into the duct from one manhole to another, these rods being provided with connecting sockets by means of which they may be joined together end to end. As each rod is pushed into the duct another is joined to it and pushed in, until the first rod emerges from the duct at the distant manhole, the chain of rods is then used in place of a fish wire to pull the pulling rope or cable into the duct.

The process of rodding in this way has the disadvantage of being slow. Where the interior of the ducts is smooth and where the length is not prohibitive, it is feasible to use a heavy, stiff steel wire instead of the rods, this being pushed through from one manhole to the other. A No. 6 steel wire is desirable for this purpose. Before actually pulling in the cable a mandrel should be pulled through the ducts to make sure that the passage is clear.

Drawing In. The power used for drawing in the cable may be that of man, horse, or engine. For small installations and light

Fig. 602. Cable Pulling Apparatus

cables a man- or horse-driven capstan is frequently employed. Sometimes the direct pull of a horse or team or of an automobile is employed. Where much and heavy work is to be done an engine-driven capstan is much to be preferred. It is more powerful, more easily controlled, and is capable of exerting a steadier pull and of drawing with greater rapidity than any of the other devices. For such work the capstan may be driven by an electric motor, connected by flexible insulated leads to the nearest trolley wire or other source of power current where the distribution of such is sufficiently universal to make it always available within a reasonable distance.

A better way is to employ a gasoline engine, since then no connections have to be provided for electric wires. Such a cable pulling outfit is shown in Fig. 602. This particular equipment has a 6-horse-power engine connected by belt and gear to the cable pulling drum. The reel from which the cable is being pulled may be seen in the distance.

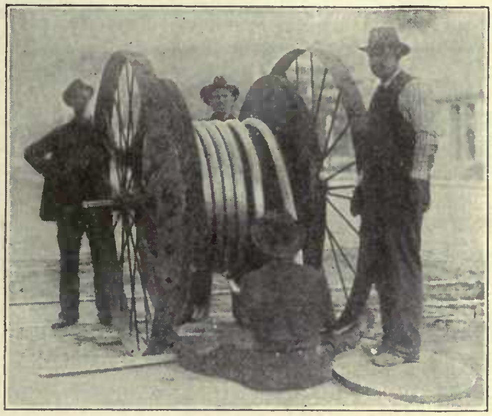


Fig. 603. Reel Supported on Wheels

For handling the reel from which the cable is to be pulled, the simplest and most convenient device consists of a pair of large wagon wheels, greater in diameter than that of the largest reel head. A heavy steel shaft passes through these as an axle, also passing through the hole in the center of the reel. This device may be used as a cart in transporting the reel through the streets and as a stand to support the reel while the cable is being drawn off into the duct. Such an arrangement, set up for drawing in, is shown in Fig. 603.

In setting up for pulling, the reel should be in line with the duct and ahead of the vault openings rather than back of it, the reel turning in such direction that the cable will feed from its top. Usually a steel rope is employed for pulling. The end of the pulling rope

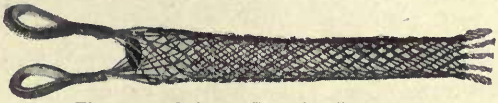


Fig. 604. Grip for Drawing In Cables

is attached to the cable either by a lashing of wire or by cable grips designed to clamp the end of the cable securely without subjecting the sheath to injury. One form of such a cable grip is shown in Fig. 604, this being a device which increases its grip on the cable as the lengthwise pull of the rope increases.

Skids and sheaves should be set up in the manhole so as to guide the cable into the mouth of the duct from a direction as nearly in a line with the duct as possible. Likewise, sheaves and skids should be provided in the manhole toward which the pulling is being done, so that the rope will not chafe against the side of the duct.

The general arrangement of the cable reel and of the apparatus employed in pulling in cables is shown in Fig. 605.

Lubrication. In pulling in heavy runs of cable, the work is greatly facilitated and the strain on the cable is greatly reduced by lubricating the cable as it passes into the duct. Grease, soap, graphite, and other forms of lubricant have been used, but in our experience powdered soapstone is the best, and it has the advantage of being cheap and cleanly. It may be fed into the duct opening as the cable enters by a funnel and scoop, or sprinkled on the top of the cable at the point where it is entering the duct.

The greatest care should be taken to inspect the cable as it is being pulled in, the man at the reel watching for any imperfections

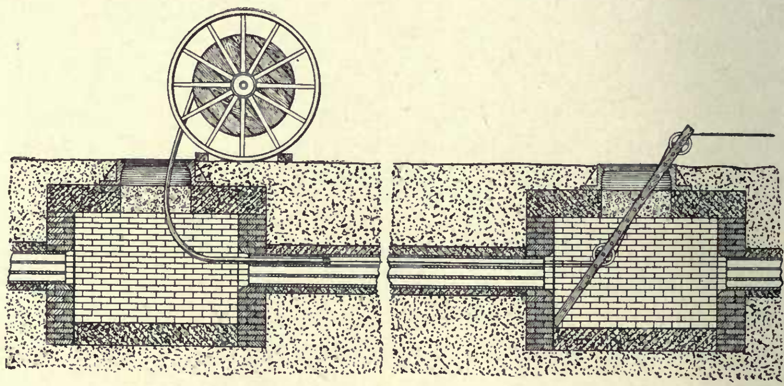


Fig. 605. Pulling In Cable

in its sheath. Care also should be taken that the reel turns at uniform speed, since if it runs ahead it is likely to cause sharp kinks in the cable.

After the cables are drawn in, their ends should be left projecting in the manholes a proper distance for making the splices. The forward end of the cable, where the hitch was made to the pulling rope, if at all damaged, should be cut off and resealed with molten solder to prevent the entrance of moisture.

Speed of Drawing In. John M. Humiston has recorded some tests made on the power required to pull a cable into a duct at varying speeds with and without lubricant. A 300 pair, No. 19 gauge,

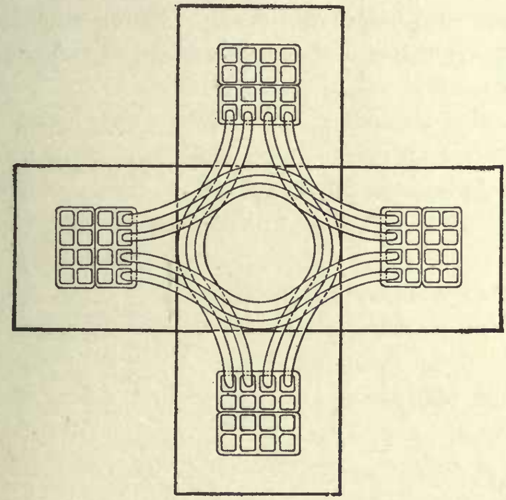


Fig. 606. Arrangement of Cables in Manholes

lead-covered paper-insulated cable, weighing 7 pounds and 7 ounces per foot, and having an outside diameter of 2⅝-inches, was used. The duct was of vitrified clay rectangular in cross-section, 682 feet in length. The cable was first pulled in by a capstan turned by a horse. The maximum stress on the rope noted was 3,500 pounds, this occurring about 50 feet before the finish was reached, and being due to the drawing having stopped and started again. The maximum stress during continuous drawing occurred at the end of the pull and was 3,200 pounds. The rate of pulling in this experiment was 25 feet per minute. The same cable was then drawn in at a higher

TABLE XXXV

Drawing In Stress on Cable

Weight of Cable Pounds	Length of Section Feet	Speed Feet per Minute	Lubricant	Stress Pounds
5060	628	25	None	3200
5060	679	120	None	2800
5060	682	120	Soapstone	1200

rate of speed by means of a heavy automobile truck. The maximum stress in the cable when being drawn at the rate of 120 feet per minute, was 2,800 pounds. Thus practice indicates that a higher rate of travel resulted in a lower friction, as theory would indicate. The same cable was then pulled into the duct, using powdered soapstone as a lubricant. In this case the stress was only 1,200 pounds, showing

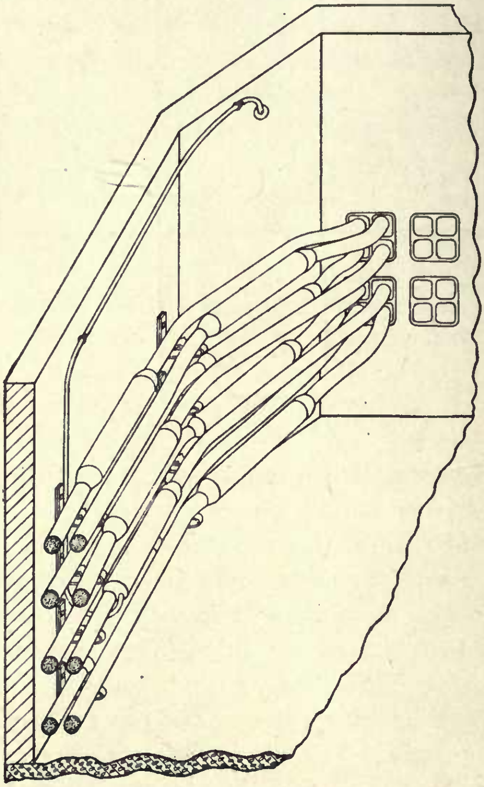


Fig. 607. Arrangement of Cables in Manholes

marked saving in power by this very simple scheme of lubrication. Table XXXV summarizes these experiments.

Long Conduit Sections. Humiston also gives some information as to successful drawing in of heavy cables into very long runs of conduit. He concludes from these that where no street obstructions intervene, it is entirely feasible to locate the vaults as far apart as 800 feet. He cites one example where heavy cables have been pulled into a section of conduit 882 feet in length with two reversed curves or offsets in it. These instances are interesting as illustrating possible extremes in this phase of underground cable practice.

Arrangement of Cables in Vaults. Practically all of the splices in underground cables occur in manholes. A well-made splice may be spoiled by subsequent misuse. Much depends, therefore, on the way the cables are stowed away in the manholes. It has already been stated that where possible it is preferable to have the conduit runs not more than four ducts wide. This makes possible a very systematic arrangement of cables in the manholes as suggested in Fig. 606, which shows the sides of a square manhole laid out flat for purposes of illustration.

When the conduit is not more than four ducts wide it is possible to arrange the cables on each side of the vault in not over two tiers, thus making the cables next to the wall more easily reached. This way of arranging the cable is indicated in Fig. 607, which shows the cables leading from the two left-hand vertical rows of ducts around that side of the manhole. The splices are staggered. This arrangement is somewhat idealized, since it is not always practicable to accomplish it, especially where old work has to be dealt with. It is good, however, at least to have an ideal at which to aim.

Another feature to be borne in mind in the arrangement of splices and cables in manholes is the disposal of small tap cables leading to laterals. If the proper thought is given before making the tap splice, it is easy to lead the small cables from the splices to the lateral duct around the wall of the manhole, and behind the large cables, as shown in Fig. 607, and in this manner the smaller cables, which are least able to stand rough usage, are protected by the larger ones.

CHAPTER XLVI

CABLE SPLICING

Necessity for Dryness. On no feature of telephone work is the proper condition of a telephone plant more dependent than on the use of proper methods and care in splicing of its lead-covered paper-insulated cables. Dry paper, by virtue of its low electrostatic capacity, its high insulation resistance, and its low cost, is the only material that has been found suitable for the insulation of cable conductors where such conductors form considerable portions of the length of telephone lines. It is subject, however, to the grave objection that even a very small amount of moisture will destroy the insulation between the conductors. The avidity with which this paper will absorb any moisture makes it necessary to keep it completely isolated from atmospheric conditions, and, in fact, in a state of *extreme dryness.* The difficulties in the way of doing this would seem to the uninitiated to be unsurmountable. Aërial cables are exposed to rain, snow, sleet, and ice, and underground cables are sometimes completely immersed in water for considerable periods of time, as when the manholes and the conduit system are flooded. A pin-hole anywhere in the lead sheath of a cable will permit enough moisture to enter to make it unfit for use.

The cables employed for both aërial and underground work differ in no respect except, perhaps, in size; cables with 400, 600, and, in rare cases, 900 pairs of conductors being employed in underground work, while those having more than 300 pairs are seldom, and more than 400 pairs are never, so far as we know, suspended aërially.

The rule that must govern the cable splicer, first, last, and always, is—*Keep the core of the cable dry.* This does not merely mean that no noticeable moisture shall be present, but that it shall be dry in the sense that a thing is dry after it has been baked in an oven for a long time.

Whenever possible, splicing should be done in a dry place in dry weather. If conditions demand that it be done in a damp place, as is frequently necessary, extreme care should be taken to guard against the entrance of moisture and to expel whatever moisture does enter, as will be explained.

General Method of Splicing. In general, the method of making a splice consists in stripping back the lead sheath from the two ends to be spliced for a sufficient space to afford the proper working length of the exposed conductors, then the individual wires are joined together and covered with paper sleeves. Before beginning the splicing of the conductors, and during its progress if necessary, and always after its completion, the exposed conductors are subjected to a boiling-out process to expel all moisture. After the conductors are spliced and boiled out, they are bunched together and enclosed in a lead sleeve of sufficient diameter not to crowd the wires too much together, and of sufficient length to lap over the lead sheaths of the joined cables. Then the edges of the sleeve are beaten down to the cable sheath at each end and secured thereto by a plumber's wiped joint.

Straight Splice. A lead sleeve of proper size is first slipped over the end of one of the cables to be joined and pushed back out of the way. A mark is then made on the sheath of each cable to designate the point at which the sheath is to be cut and removed. The distance from the end of the cable at which this mark is made should

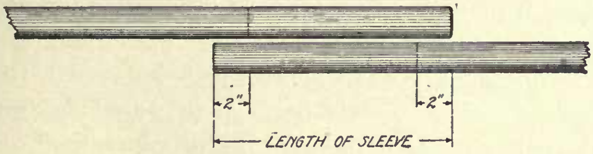


Fig. 608. Preparing Cable for Splice

be for all sizes of cable about 2 inches less than the length of the lead sleeve employed, as indicated in Fig. 608. A portion of the cable sheath about 4 inches back from this mark is then scraped bright so as to afford a proper surface for making the wiped joint at the end of the splicing operation, and this brightened surface is then rubbed with tallow to keep it bright during the subsequent operations. The reason for doing this scraping and brightening operation at this point in the work is to prevent the small particles of lead, scraped off, from getting in the splice, and endangering the insulation.

Preparing the Conductors. The lead sheath is then removed from the end of each cable back to the mark previously made. This is readily done by indenting the cable around its circumference with the edge of a cable knife, after which a slight bending back and forth will break the lead sheath on this mark and permit the end to be drawn off. The core of the cables is now exposed, and from this time on the greatest care should be taken not only to keep it dry, but to guard against mechanically injuring the insulation. The core of each end should now be bound tightly with narrow strips of dry muslin, just at the end of the cable sheath, packing this muslin back under the sheath for a slight distance to prevent the sharp edges of the sheath from injuring the insulation of the outer layer of wires. As soon as possible after this is done the cable ends should be boiled out. In the case of a small cable this may be done by immersing the exposed ends of the core in a kettle of hot paraffin, but for larger cables this is not feasible, the process then consisting in pouring hot paraffin over the exposed portions of the core, the drippings being caught in a pan placed directly beneath. This boiling-out process should include the entire length of the exposed core and the muslin wrapping under the end of the sheath. Great care should be exercised as to the temperature of the paraffin. It should be very hot, and yet not hot enough to scorch the paper. Overheated paraffin not only injures the insulation of the cable conductors, but is dangerous to life, since it may take fire. Underheated paraffin will not expel the moisture. If the paraffin is so hot that white fumes rise from it, it should be allowed to cool slightly before being used.

In boiling out, one should begin at the cable sheath and work toward the core end, or if the wires have been spliced, one should begin at the ends of the cable sheath and work toward the middle of the splice. This prevents a tendency for the heat to drive what moisture there is in the exposed ends back into the core within the lead sheath. The hot paraffin itself should soak back into the core covered by the sheath for some distance to keep moisture out during the splicing. After the ends are boiled out, the two cables should be placed in proper alignment, the distance between the ends of the sheaths being about 4 inches less than the length of the lead sleeve, as indicated in Fig. 608. The conductors are then bent back close to the sheath out of the way and spliced in the following manner:

Joining the Wires. Starting with the center wires of the cores, or with the lower back sides of the cores, two pairs, one from each cable, are loosely brought together with a partial twist, as shown in *a* of Fig. 609. The bend thus made in each pair marks the point at which the joint is to be made. A paper sleeve is then slipped over each wire of the pair and pushed back out of the way so as to make room for the joint, as shown in *b* of Fig. 609.

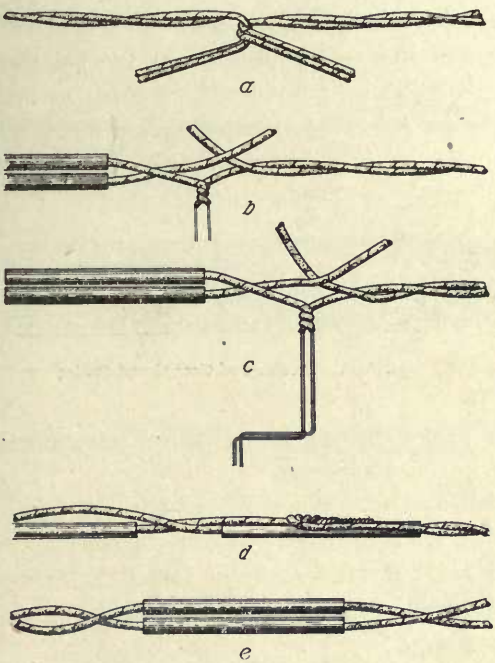


Fig. 609. Splicing Cable Conductors

The two colored wires of the pairs chosen are then twisted together for about three twists, as indicated in *b*, and the insulation stripped off beyond this twist. This twist is made at the points indicated by the bends previously made, as in *a*. In removing the insulation, care should be taken not to nick the conductors. The reason for including the insulation in the twist of the joint is to prevent its stripping back and exposing the wires. The exposed ends of the wires are then twisted together, and the method of doing it is indicated in *c*. The wires are bent so as to form a crank, the handle of the crank being held between the thumb and finger of the right hand, while the portion of the wires just beyond the insulation is similarly held with the left hand. The twisting is accomplished by merely turning this crank. There is a knack about it which requires practice to acquire. After the wires themselves are twisted together, they are cut off so as to let the twisted wire project about 1 inch from the end of the insulation. The twist is then bent down along the insulated wire, as shown in *d*, and the paper sleeve slipped over it. The completed joint is shown in *e*.

This process is repeated until all of the pairs are spliced. In order that all of the wire joints shall not occur at the same point in the splice, they are staggered, thus preventing the splice attaining too great a diameter at any one point. By reasonable care in dis-

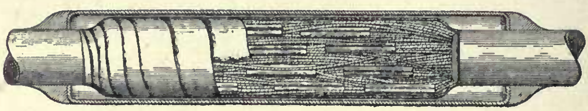


Fig. 610. Sections of Completed Splice

tributing the wire joints along the length of the splice, it may be kept uniform in size and shape.

Final Boiling-Out. When all of the wire joints have been made, the splice is again boiled out in hot paraffin until all moisture has been expelled. It will usually be found that some moisture has been gathered by the paper insulation from the hands of the workman or from the air.

Immediately after this final boiling-out and while the splice is still "piping hot," it should be wrapped with strips of dry muslin 2 or 3 inches wide, so as to compress the wires only to a sufficient extent to permit the lead sleeve easily to be slipped over them. Unless there is a suspicion that some moisture may have entered during this binding process, no further boiling-out need be done.

Enclosing the Splice. The lead sleeve is then slipped into place while the splice is hot and its ends, which will overlap, are dressed down so as to engage the cable sheath. After this a plumber's wiped joint is carefully made at each end of the sleeve and the splice is complete, as shown in section in Fig. 610.

In making the wiped joints, strips of gummed paper are used to limit the flow of the wiping solder on the sheath. Inspection of the completed wiped joints is an important feature, and sometimes a mirror will aid in examining the underside of the joint. As an inducement to proper workmanship, each splicer working on a job should be given a number and a steel stamp bearing this number,

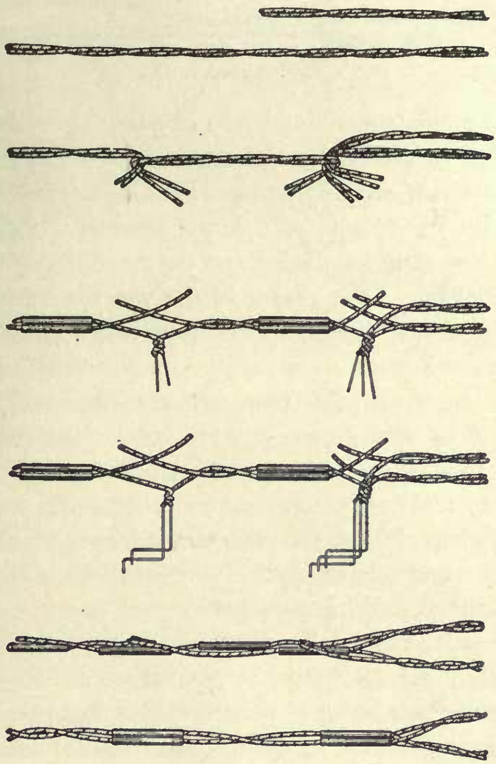


Fig. 611. Tap Splice

which number must be stamped on each splice when completed. By this method careless work may often be traced back to its proper source.

Tap Splice. The method of making a tap splice where the wires of a branch cable join those of a continuous cable, differs somewhat from that just described, since three wire ends have to be handled rather than two. The method to be followed in this will be clear from an inspection of Fig. 611. It will be seen in the second operation that a short piece of wire must be inserted in order to give sufficient length of wire to make the splice with the branch conductor.

The external appearance of a finished tap splice is shown in Fig. 612. The tap cable should always lead out from one end of the splice and should be lashed to the main cable with marline about 6 inches

Fig. 612. Finished Tap Splice

beyond the end of the splice to prevent any side strain being exerted by the tension of the tap cable on the splice itself.

Y-Splices. For Y-splices that are not in the nature of tap splices, but in which the conductors of a large cable are spliced into two smaller cables, the same method of procedure is followed as in the straight splice, so far as the joining of the wires is concerned. Frequently a larger cable will be spliced into two smaller ones where the sum of the conductors in the smaller ones more than equals the number in the larger. In this case certain of the conductors in the larger cable will be spliced straight through to the respective conductors in the smaller cables, and certain others in the larger cable will be joined to two conductors, one in each of the smaller cables. This results in some of the conductors in the large cables being made available at the terminals of both of the smaller cables, this being one of the phases of multiple-tap distribution.

Sizes of Lead Sleeves. Table XXXVI gives the sizes of lead sleeves for straight and Y-splices in various sizes of 22-gauge cable, the sleeves in each case being of pure lead, $\frac{1}{8}$ inch in thickness.

Where a branch cable is spliced into a continuous cable, and under certain other conditions of practice, it is necessary to employ split sleeves, *i. e.*, sleeves that are cut through one side of their length so as to enable them to be opened and slipped over the cable. Of course, when such a sleeve is used, the joint along its side should be carefully closed by solder so as to make it a continuously closed pipe. The paper sleeves for the individual wires are usually about 3 inches long and approximately $\frac{1}{8}$ inch in diameter. They should always be boiled in paraffin before using.

Pot-Heads. The pot-head, as already stated, is a special form

TABLE XXXVI

Lead Sleeves

Straight Splices 22 Gauge			Y-Splices 22 Gauge		
No. Prs.	Inside Diam. in Inches	Length Inches	No. Prs.	Inside Diam. in Inches	Length Inches
10	1	16	10	1	16
15	1	16	15	1	16
20	1	16	20	1½	16
30	1½	16	30	1½	16
40	2	18	40	2	18
50	2	18	50	2½	18
60	2	18	60	2½	18
80	2½	18	80	3	20
100	2½	18	100	3½	22
200	3	20	200	4	22
400	3½	22	400	4½	22
600	4	26	600	4½	26

of splice. Instead of joining two lead-covered paper-insulated cables, it joins the wires in one such cable with an equal number of individual rubber-covered wires, its purpose being to terminate the paper cable in wires that will not be injured by exposure to the atmosphere. Briefly, a pot-head is made by opening the end of the paper-insulated cable and splicing to its conductors rubber-insulated wires, and then enclosing the splice in a chamber filled with insulating compound, so that no moisture can enter the core of the cable.

The method of making a pot-head is as follows: A lead pot-head sleeve of proper size is slipped over the end of the paper cable and run back out of the way. The end of the paper cable is then prepared in the same manner as described for making a straight splice, the same care being exercised in boiling it out. The core is then wrapped with muslin at the point where it emerges from the lead sheath, this wrapping being tucked in under the edges of the sheath to prevent injury to the conductors, as in the ordinary splice. Rubber-covered twisted-pair pot-head wires, usually of the same gauge as the wires of the cable, are then spliced to the cable wires in exactly the same manner as described in making a straight splice, paper sleeves being used in the same way. To do this, the pot-head wire is skinned for a distance of about 1½ inches, the colored or otherwise distinguished wire of the rubber-covered pair being spliced to the colored wire of the cable. The same care as to staggering of the joints is also necessary to prevent the splice assuming unequal diameters along its lengths.

After the wires are spliced, they are neatly bunched and wrapped with twine or wicking, this being drawn only tight enough to compress the bunch so that the lead sleeve will readily slip over it. In no case, however, should the twine or wicking extend higher up on the splice than a point about 3½ inches below the top of the pot-head sleeve, after the latter has been put into place. This same instruction as to twine or wicking will apply to paper sleeves and to any other material of a fibrous nature, none of which should be allowed to extend further up than about 3½ inches below the top of the sleeve after it is in place.

Fig. 613. Section of Pot-head

After the wires are joined and bunched in this manner, the pot-head sleeve is drawn up over the splice and its lower end beaten or dressed into form against the cable sheath, after which it is secured in this position by a regular wiped joint in exactly the same manner as a straight splice.

Filling. The method so far described results in a splice that is open at one end and from this end projects the bunch of rubber-insulated conductors. The splice is now secured in a vertical position, open end up, and is ready for filling. Before pouring, the wires in the top of the sleeve should be loosened as much as possible so as to allow the insulating compound to flow freely between them. The entire sleeve is then warmed thoroughly with a blow torch, and the insulating compound, which has been heated so as to flow freely, is poured in it within ½ inch of the top of the lead sleeve. As the compound settles, more should be added to keep it to the height mentioned, the sleeve being kept hot to facilitate the process of settling. Sometimes after the pot-head has cooled it will be found that the compound has settled slightly, and in this case more should be added to bring the insulating surface to the required height. After the pot-head, Fig. 613, has been filled and allowed to cool, the remaining space in the top of the sleeve may be filled with Cimmerian asphalt, which has been heated so as to flow freely. Cimmerian asphalt is a compound which does not become hard and brittle with age and is, therefore, used as an added precaution to insure a perpetual seal.

Central-Office Pot-Heads. In making central-office pot-heads or splices for joining the conductors of the incoming paper cables to those of the silk and cotton cables or the wool cables, which lead to the distributing frame, the same general practice as to making the joints in the conductors is followed. Where a large line cable is joined to many silk- and cotton-insulated lead-covered cables, the resulting splice or pot-head, illustrated in Fig. 614, is formed as follows: The pot-head sleeve is first slipped over the main cable and back out of the way; likewise, the terminal cables are passed through the holes in the wooden disk shown in the drawing, and this is slipped back out of the way. The lead sleeve is then removed from each of the terminal cables and from the main cable, and splicing is done in the same manner as in a straight cable splice. After the splicing is completed the lead sheath is put in place, the joint is wiped, and the wooden disk is slipped down on the terminal cable so that its lower surface will be flush with the ends of their lead sheaths. If the cables do not completely fill the holes in the wooden disk, muslin should be crowded in around the cables. The top of the wooden disk is now about 1 inch below the top of the pot-head sleeve, and upon it is placed a layer of fine dry sand about ½ inch deep to form the foundation of the wiping solder to be used in sealing the top of the lead sleeve. This wiping solder is filled flush with the top of the sleeve and its surface wiped so as to join perfectly and continuously with the lead sheath of each terminal cable and with the walls of the pot-head sleeve.

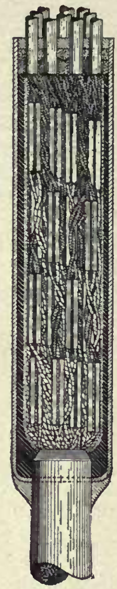


Fig. 614. Section of Pot-Head

Splices should always, if possible, be finished the same day they are begun. If the surroundings be dry and are of such a nature as to continue so, then a splice may be left unfinished over night, but it should always be protected from the atmosphere by a rubber blanket completely enclosing it and bound tightly against the cable ends. Wherever paper cable is cut, its ends should be sealed with solder before leaving it.

CHAPTER XLVII

OFFICE TERMINAL CABLES

In a modern plant the line side of the main distributing frame may be considered as the dividing point between the outside cable plant and the inside apparatus plant, since it is at this point that the conductors of the outside plant may be said properly to terminate. The matters now to be considered are: the method of leading the outside cables into the central-office building, and the method of so terminating the conductors of these cables that their insulation will not be impaired, either by the entrance of moisture or by mechanical injury to the insulation of the wires where they emerge from the lead sheath.

The entrance of the outside cables to the office building may be either aërial, underground, or both. Only in small plants, if they are modern, will the entrance be aërial, since if there is any underground work at all in the exchange, it will probably occur in the immediate vicinity of the central office where the cable runs are always heaviest.

Aërial Cable Entrance. Where aërial cables enter the central office, a heavy pole is set near the wall of the building, and all of the aërial cables are run to this pole. From this pole the cables are led, usually on an iron rack, to the wall and into the building, where they are connected to suitable terminal apparatus.

In very small towns, where only bare-wire lines exist, the line wires are brought to the office pole and there joined to the various conductors in an office cable which leads into the building. For this purpose rubber-insulated cable is usually employed, since by its use special treatment of the cable ends is avoided. Owing to the very short lengths of cables so used, the relatively high electrostatic capacity of the rubber-insutated wires is not a serious factor.

Underground Cable Entrance for Small Plants. Sometimes when the wire plant is almost wholly aërial, a short length of under-

Fig. 615. Underground Cable Entrance for Small Exchange

ground conduit will be used, and underground cables led through this to the central office. A somewhat idealized arrangement for a very small exchange, embodying an underground entrance for a wire plant that is otherwise all aërial, is shown in Fig. 615.

Underground Entrances for Larger Plants. Either of two general plans may be followed for effecting the entrance of the cables of an underground conduit system into the office building. An office manhole may be employed to which all lines of conduit lead, and from which all cables pass through a tunnel or regular conduit ducts to the basement of the building, Fig. 616. Or, the office manhole

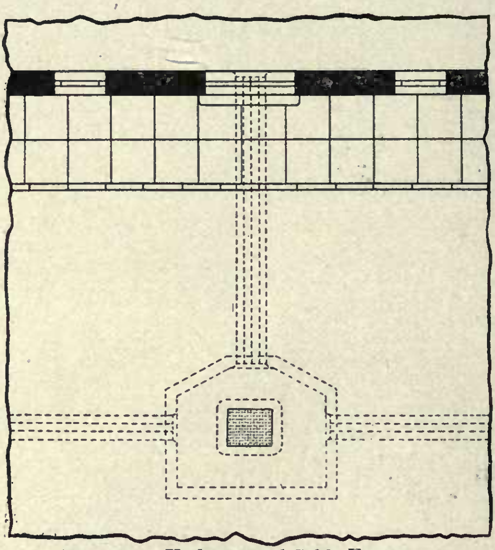


Fig. 616. Underground Cable Entrance through Office Manhole.

may be dispensed with and the conduits extended directly to the basement of the building, which, in this case, forms in itself the office manhole, Fig. 617.

Where the building is located directly on the street and where the conditions in the street are such as to permit the approaching ducts to extend directly to the basement, as required by the scheme shown in Fig. 617, this practice is simpler, cheaper, and better. Often the basement or cellar may be extended out under the sidewalk and street so as to intersect the conduit lines, without the necessity of curving the conduit approaches or running them diagonally, as was done in the installation shown.

By using the cellar of the central-office building as the office manhole, a large amount of splicing that would otherwise be done in a street manhole is done within the walls of the building, and generally the amount of splicing is reduced—both advantageous features.

Treatment of Cable Ends. There are three principal reasons why it is not good practice to run the paper-insulated cables to the distributing frame: First, the cable end, if thus exposed, would be likely, during wet weather, to absorb sufficient moisture to lower the

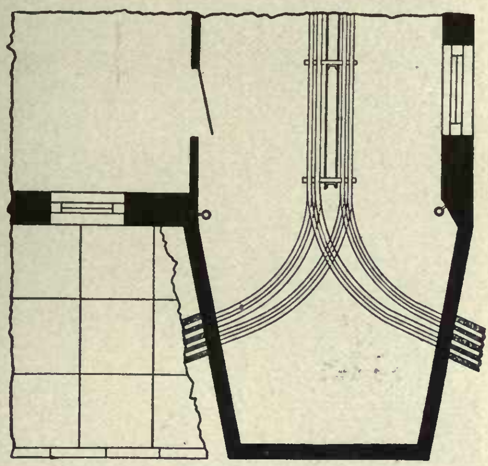


Fig. 617. Basement Cable Entrance.

insulation of the conductors; second, paper-insulated wires are not well adapted to stand the handling necessary in the work of fanning out the conductors and leading them to their respective terminals; and, third, the line cables entering the central office are usually of large size, having 400 or 600 pairs, and it is not convenient, as a rule, to subdivide such large units at the distributing frame. This latter fact makes it desirable to subdivide the large cables entering the central office before leading them to the distributing frame, entirely aside from any considerations as to the maintaining of the insulation.

Two general methods of overcoming these difficulties are practiced. One is to splice on to the paper-insulated cables, at a point some distance from the main distributing frame, cables of such character that moisture will not be likely to work back through them. Such cables are made of wool-insulated wires, lead encased. They are well adapted to stand the necessary exposure and handling at the distributing frame and they serve as a seal for the paper cables. The other method is to terminate the paper cables entering the office in pot-heads, which form the seal for the paper cables. From these pot-heads, cables, either of wool or of silk and cotton insulation—either of which are not so susceptible to moisture and are better able to withstand rough treatment than paper cables—are led to the distributing frame. The making of pot-heads for such use is con-

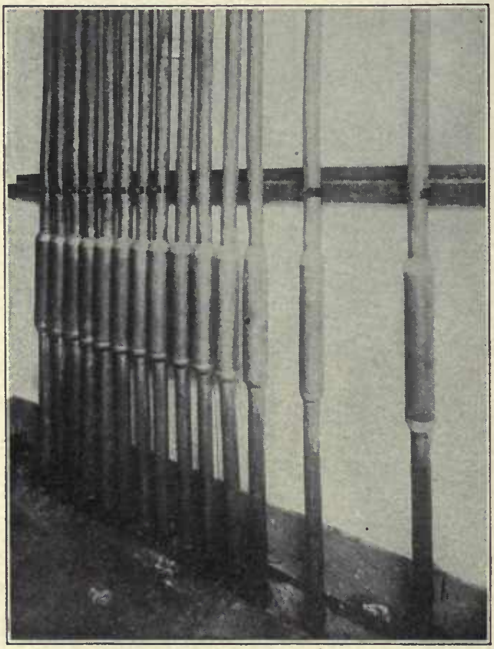


Fig. 618. Cable Splices.

sidered in another chapter; the general arrangement employed for disposing of these splices and pot-heads and of the cables leading from them to the distributing frame will, however, be considered here.

Wool Cable Ends. In using wool-insulated terminal cables, the splices may be made of ordinary form in the office manhole, or at the point where the cables enter the central-office building, or in fact at any point that is not so close to the main distributing frame as to leave a distance of less than about 25 feet in the length of each wool cable. It is not considered necessary to fill the splices with insulating compound, the length of wool cable being relied on to keep moisture out of the paper cable. The wool insulation on the wires, after they are exposed by the removal of the lead sheath at the distributing frame, is well adapted to withstand the necessary handling, being much tougher and less easily damaged than paper insulation.

In Fig. 618 are shown the splices between the 400-pair paper cables entering the Howard Street office of the San Francisco Home Telephone Company. These splices are made within the building

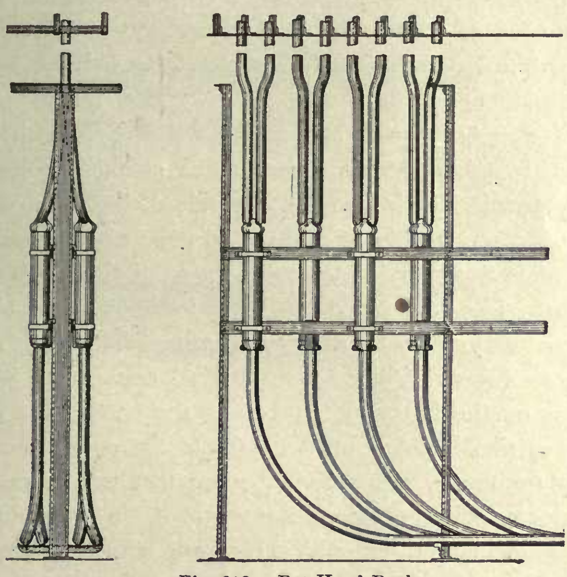


Fig. 619. Pot-Head Rack

in the vertical part of the cable run between the basement and the distributing frame room. The arrangement of the cables in a single row gives ready access to all of the splices.

Pot-head Method of Terminating. Where pot-heads are employed at the central office, the terminal cables that are spliced on to the paper cables are lead covered, and usually insulated with silk or cotton and less frequently with wool. It is customary to make these carry a relatively small number of conductors, as small cables are much more convenient to handle and may be led with greater neatness and with a smaller amount of exposed wire to their relative distributing frame terminals.

It is convenient to support the pot-heads vertically on an iron rack in the basement of the building, from which rack the smaller cables are led to the distributing frame room above. The details of such an office pot-head rack are shown in Fig. 619. In this installation each 400 pair of paper cable was spliced to two 200 pair of wool cables. The vertical terminal strips on the line side of the main distributing frame were equipped for 200 pairs, and consequently each of the wool cables occupied all the terminals on one of the vertical distributing frame strips.

The pot-heads in this case are each supported on a cast-iron shoe or bracket, as shown, the shell of the pot-head being held in vertical alignment on this shoe by means of iron straps bolted to the horizontal members of the frame.

Subdivision into Small Terminal Cables. Frequently the main line cables are subdivided into very much smaller cables than 200 pair. The terminal strips on the line side of the main distributing frame commonly carry blocks of 20 or 40 pairs of terminals. A neat arrangement is to subdivide the main cable at the pot-head into as many 40-pair silk- and cotton-insulated lead-covered cables as are necessary to carry the total number of wires, and then to lead each one of these 40-pair cables to a different one of the 40-pair terminal strips on the frame. In this way the conductors of the line cables are carried in lead sheaths right to the connecting strips on which they terminate, rather than having the lead stripped off at a point a greater distance from the ends of the conductors, as is necessary where larger terminal cables are employed.

Cable Runs. The method of conducting the terminal cables to the distributing frame is a matter which must always be carefully worked out in view of the particular requirements of each case, and should be provided for in detail in the design of the building. This is one of the important points of conference between the architect and the engineer. The method chosen will depend on the relative locations of the cable entrance, the pot-head rack, and the distributing frame. These all enter into the design of the building. It is also dependent on the vertical height of the main distributing frame, since the number of terminals in a strip or in a column is a matter which affects the size of the terminal cables. This also affects, and is affected by, the design of the building.

The general method to be employed in running from the pot-head rack to the main distributing frame depends usually on whether the two racks are on the same floor, or on adjacent floors, or on floors separated by intermediate stories.

Where they are on the same floor the terminal cables may be run in the most direct manner from the top of the pot-head rack to the top of the distributing frame and then fed down. Usually, however, these racks are not on the same floor. Where the main frame is on the floor immediately above that of the pot-head rack, the simplest

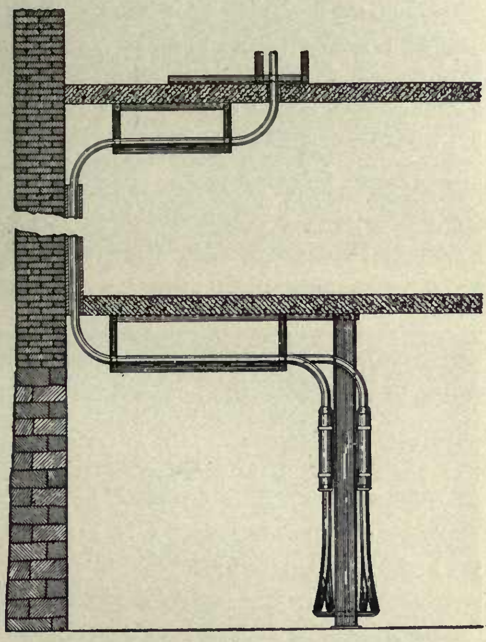


Fig- 620. Cables to Main Distirbuting Frame

way is to mount the main frame immediately above the pot-head rack and run the cables straight up to the main frame, as shown in Fig. 619. A good way of doing this is to provide a slot in the floor extending the entire length of the main frame, and care in disposing the longitudinal spacing of the pot-heads on the pot-head rack will result in each main cable being terminated directly under the corresponding vertical strips of the main frame.

Where there are intervening stories between the pot-head rack and the main frame, it is usually not possible to run the cable straight

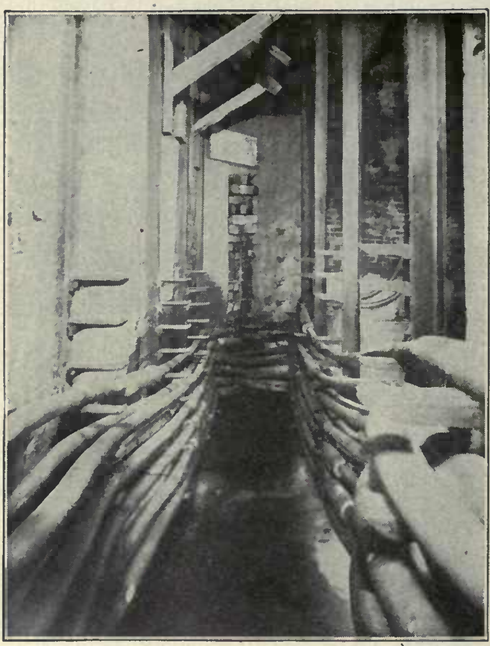


Fig. 621. Cable Entrance of the Grant Avenue Office of the San Francisco Home Telephone Company

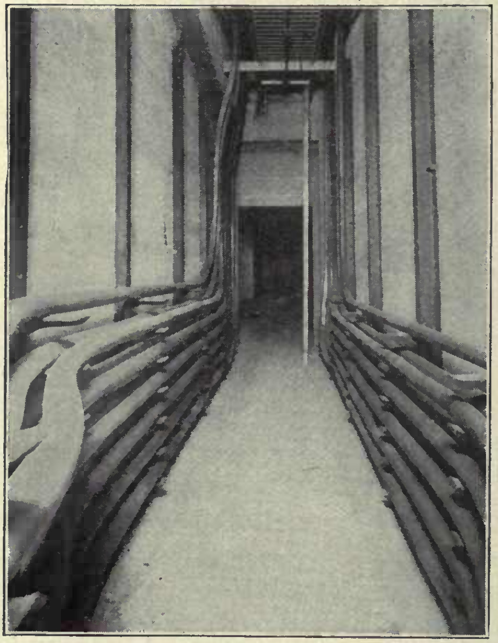


Fig. 622. Cable Entrance of the Grant Avenue Office of the San Francisco Home Telephone Company

up on account of interfering with the space on the intervening floors. One good way, which usually results in a minimum length of terminal cables, is to mount the pothead rack parallel with and near to one of the walls of the building and provide in this wall a sufficient number of ducts, either of iron pipe or fiber conduit, leading vertically to the distributing frame room. The terminal cables are led up from the pot-heads to a horizontal iron rack and passed over this to the lower ends of the wall ducts, through which they pass to the ceiling of the floor below the main frame, thence through an iron rack to a point beneath the main frame, and thence up through holes in the floor to the terminal strips which they are to feed. From this point the individual cables are led along the vertical members of the iron rack of the distributing frame to the proper horizontal member, and thence horizontally along that to the terminal strip. Such an arrangement, employing wall ducts, is shown in Fig. 620.

Where a cable shaft is employed rather than wall ducts, a good way is to build an iron rack or lattice work, extending from the pothead rack horizontally to the vertical shaft leading to the distributing frame room, the cables being supported in this shaft by strapping them at frequent intervals to iron supports.

In Figs. 621 and 622 are shown details of the cable entrance of the Grant Avenue office of the San Francisco Home Telephone Company. Fig 621 shows the cables passing from the conduit to the bottom of the cable shaft, and Fig. 622 is a view in the other direction, showing the cables turning up to enter this shaft. Note that in supporting the cables on the side walls no more than two vertical tiers are used.

CHAPTER XLVIII

SERVICE CONNECTIONS

In gas- and water-supply systems individual pipes are run from the main in the street to the consumer's premises, and these are called service connections. In electric-light and power-distributing systems, and in telephone systems, the service connections consist in individual pairs of wires leading from the line wires of the pole or conduit route to the subscriber's premises.

Telephony, unlike all the other public utility systems wherein the commodity distributed is furnished by means of wires or pipes extended from a central station, requires that the line supplying each subscriber, or party-line group of subscribers, be individualized the entire distance from the central station to the subscriber's premises. In water, gas and electric-light, and power systems, the service connector is ordinarily the only part of the supply line that is individual to the consumer.

Connections from Bare Wire Lines. Where a line drops off a bare wire lead to reach a subscriber, the service connection may be made by means of bare or insulated wires, strung from the main pole line to the house, where they terminate on brackets. If the line from which the connection is made is a party line, and the station is not the end one on the line, the service wires are merely tap-connected to the line wires. If the station is on an individual line or the end one on a party line, the service wires are merely a continuation of the line wires. In all cases the service wire should be properly dead-ended to resist stress, both on the line pole and at the house.

Connections from Cable Lines. In cable construction several methods may be employed for connecting the cable terminal with the subscriber's house wiring. These naturally fall into three classes: aërial or drop-wire distribution; wall or fence-wire distribution; and distribution from underground terminals.

Drop-Wire Distribution. A drop connection or drop is an aërial pair of wires strung from a distributing pole near the subscriber's premises to a point on his building, from which they lead to the terminals of the house protection apparatus and interior wiring. Drop wires may be bare, but modern practice has proven that they are better of insulated wire. In some installations the drop connection consists of two separate wires, one bare and the other insulated, the idea being that even if they swing together there will still be an insulating protection. Consensus of opinion now, however, is that both wires should be insulated, and there has resulted a form of wire known as drop wire, consisting of two rubber-covered and braided wires twisted together. As has been pointed out, this rubber-covered twisted-pair drop wire may be of iron, copper, or of copper-clad steel. It should always be of sufficient strength to be self-supporting in rather long spans, even under the most severe conditions of weather. Obviously, therefore, the climatic conditions affect the requirements as to its strength, and it may be said, therefore, that for northern climates, where sleet and wind storms are to be expected, the drop wire, if of copper, should not be smaller than No. 14 B. & S. gauge. In those climates where sleet is not to be expected and wind storms are not severe, No. 16 B. & S. gauge copper suffices. Owing to the low cost of iron wire, the saving in using smaller sizes than No. 14 is not enough to warrant doing so. No. 18 copper-clad steel wire may be made with such a proportion of steel as to have a strength approximately equal to a No. 16 hard-drawn copper, but where this bimetallic wire has been used for drop-wire purposes, it has usually been of No. 17 B. & S. gauge High conductivity in drop wires is not an essential and any of these wires may be considered as satisfactory in that respect. The great difficulty with iron wire for drop purposes is its liability to rust at the terminals and at exposed portions.

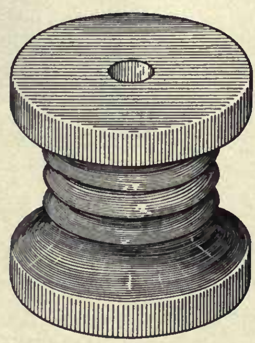


Fig. 623. Drop-Wire Insulator

Stringing Drop Wires. The attachment of the drop wire to the distributing pole and to the cable terminal, already shown in Fig. 570, is again referred to. Usually an iron bracket is bolted to the pole carrying one or more porcelain insulators. These porcelain insulators are preferably provided with double grooves to accommodate the twin wires. For dead-ending on distributing poles, the insulators are sometimes provided with two pairs of grooves, so that each may accommodate two drops. Such an insulator is shown in Fig. 623.

A common form of bracket, adapted to hold two of these insulators, is shown with the insulators attached in Fig. 624. Some trouble has been experienced in attaching the insulators to the brackets, due to the fact that if the nut was tightened sufficiently to bind and prevent its unscrewing, there was danger of cracking the insulator. It is for this reason that the four round leather washers are used.

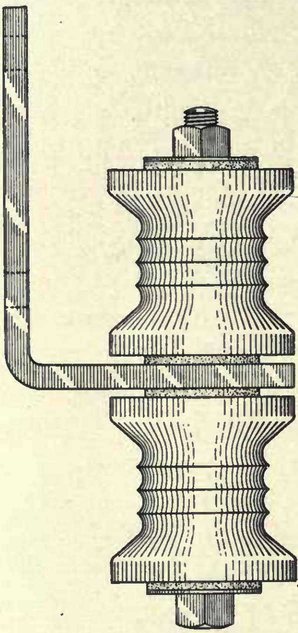


Fig. 624. Drop-Wire Insulators and Bracket

The method of tying the drop wire to such insulators deserves attention, since if this is improperly done the drop wires are likely to become crossed, even though a good grade of material is used. These knobs are used not only for attaching the wire to the distributing pole where the drop swings off, but also to intermediate poles—where such exist in the path from the distributing pole to the subscriber's premises. They are also attached to the house wall of the subscriber at the point where the span ends and at other points on the wall, in order to lead the wires along the house to the place where they pass through the wall.

The principal point to be remembered in making any of these ties to the insulators is that the two separate grooves are intended to hold separately the two wires of the pair. The two wires should not cross each other in passing around the grooves, but should lie as far as possible parallel with each other in the grooves.

The method of dead-ending the drop wire on the distributing pole is shown in Fig. 625. It will be seen that the drop is bent once around the insulator and then the free end of it is wrapped about five times around the portion that is to lead off into the span. On distributing poles, the wire may thus be wrapped about itself easily, because there is always a short end that is to lead up into the terminal box or can.

Where the drop wire is to be tied but not dead-ended on an intermediate insulator, as between two spans that are in the same straight line, or nearly so, the drop is laid in the insulator groove, but not passed around the insulator. It is tied in place by a tie wire cut

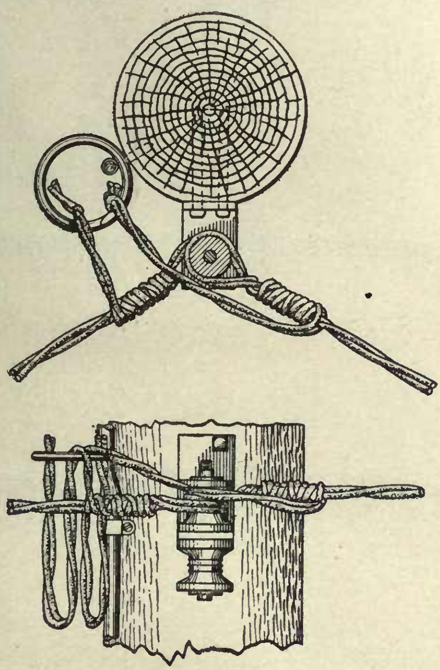


Fig. 625. Dead-Ending Drop Wire on Distributing Pole

from the scrap ends of the regular twisted pair drop wire. The method of making this tie is shown in four successive steps in Fig. 626.

At the point on the subscriber's wall where the span ends, it is necessary to dead-end the wire, but it is not usually feasible to make the same sort of dead-end tie that is illustrated in Fig. 625, because of the fact that it is not desirable to cut the wire at this point, as would be necessary in order to wrap it around itself. It is necessary, therefore, to dead-end the wire without wrapping it about itself, and the method of doing this is shown in Fig. 627. In this case the wire is wrapped once about the insulator and tied in place, as shown, by a tie wire of the same material which is also passed once around the insulator and then given about eight turns about the twisted pair. In both the regular tie and the house dead-end, each end of the tie wire, after wrapping, should be inserted between the two wires of the

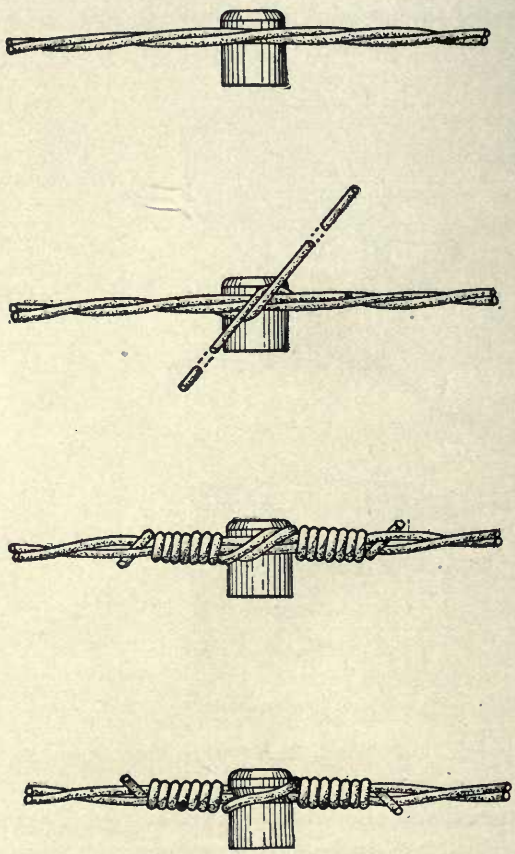


Fig. 626. Tie for Drop Wire

strand and then cut off. This prevents the tie wire from unwrapping.

At the distributing pole, after dead-ending the drop wire, the free end is looped down through a bridle ring screwed into the pole below the terminal, and its free end is passed up into the terminal can, where the wires are attached to the proper binding posts. The bridle ring used for this purpose is usually a 3-inch enameled iron ring with a screw shank for fastening it to the pole. The looping of the drop-wire ends down through these rings disposes of the slack in the drop-wire ends in a neat manner. This arrangement has already been

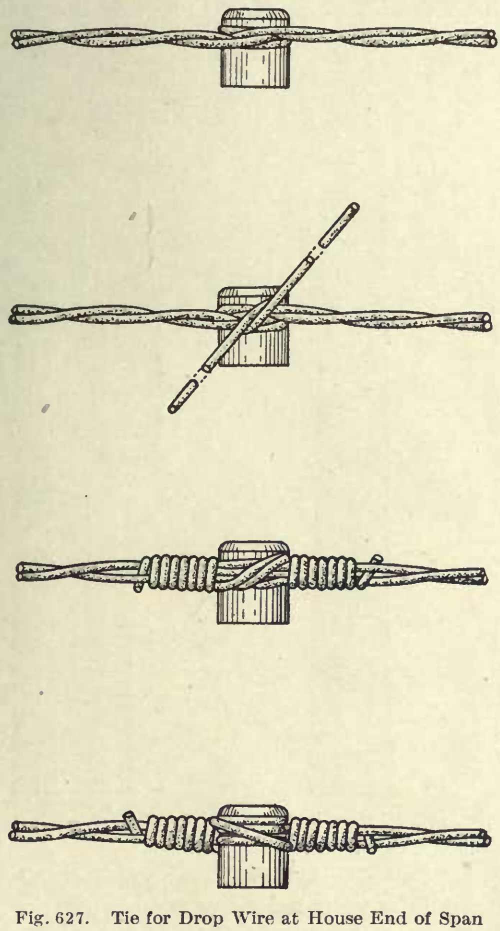


Fig. 627. Tie for Drop Wire at House End of Span

referred to in connection with Figs. 570 and 625. Another example is shown in detail in Fig. 628.

In Fig. 629 are shown the details of the connections of the drop wire to the outside wall of the house. Where the span leading to the house terminates, the house dead-end, shown in Fig. 627, should be used, and at all other insulators on the house, the regular tie of Fig. 626 should be used, these insulators being placed not further than 7 feet apart on horizontal runs, and not over 15 feet apart on vertical runs. The drip loop is provided just below the point where the wires enter the house to prevent moisture from following the wire into the house. The details of passing the wires through the wall are given in Fig. 630.

Splicing Drop Wire. It is preferable that continuous lengths of drop wire be used from the distributing pole to the subscriber's

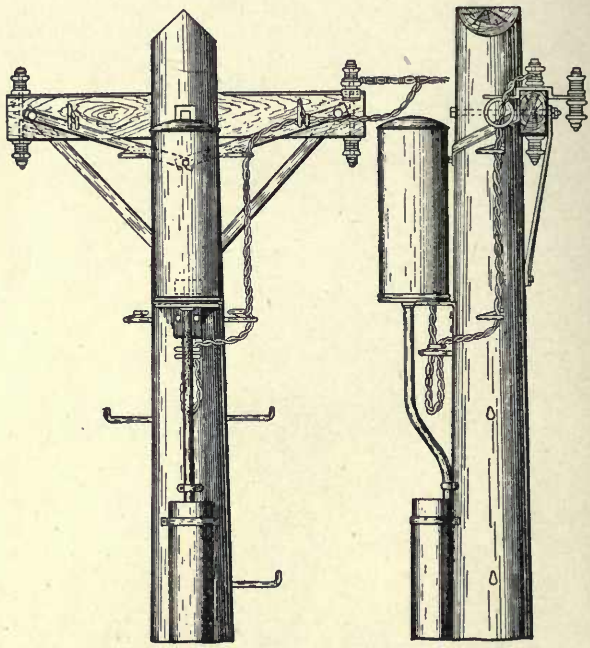


Fig. 628. Connecting Drop Wires to Cable Terminals

premises, but nevertheless economy of material makes other demands and a carefully prepared splice need cause no trouble. The method of splicing a twisted-pair drop wire is shown in Fig. 631. It is well not to use all of the scrap ends of the drop wire on any one connection, and this may be prevented by limiting the number of splices to two in any run of ordinary length.

Circle-Top Distribution. In districts where the buildings are of such a nature as to warrant the installation of individual underground terminals, it has been the practice in the past to provide, usually on the interior of the blocks, very high distributing poles on which the

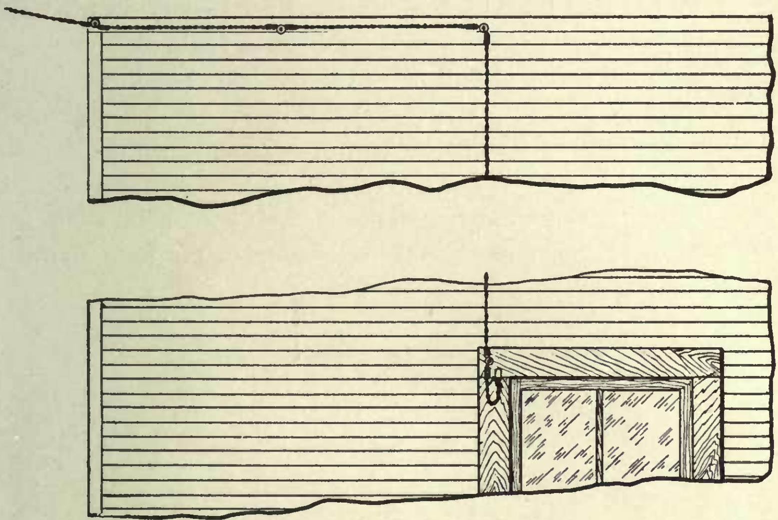


Fig. 629. Attaching Drop Wire to House

cable terminal was placed and from which the drop wires radiated to the various houses within reach, much like the ribs of an open umbrella. Often these poles are required to be of very great height and the drop-wire insulators are mounted on large rings encircling the pole and secured thereto by iron brackets. This is called "circle-top distribution," and an excellent example of it is shown in Fig. 632. The expense of these poles, the cost of up-keep, their equipment, and their general unsightliness, are all objectionable features.

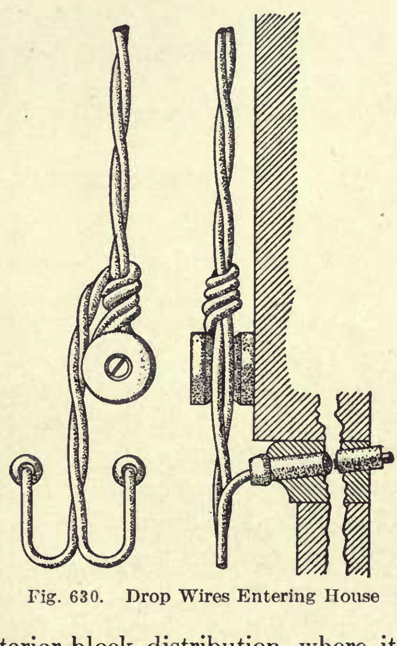


Fig. 630. Drop Wires Entering House

Rear-Wall or Fence Distribution. The better method of interior block distribution, where it is possible, is to terminate the cables on the walls of the houses, or on back fences, or on medium height poles near the rear walls or fences, and to lead from these terminals either paper cable or small gauge rubber-covered wire carried on rings, or both, along the walls or fences to the points of entrance to the various buildings.

Wall-Ring Wiring. Where the wall wiring is done by means of open wire rather than cables, a wire very similar to the ordinary drop wire, but of smaller gauge, is used. It is usually a No. 18 B. & S. gauge, rubber-covered and braided, twisted pair. The wire is carried along the walls in split bridle rings of the form shown in

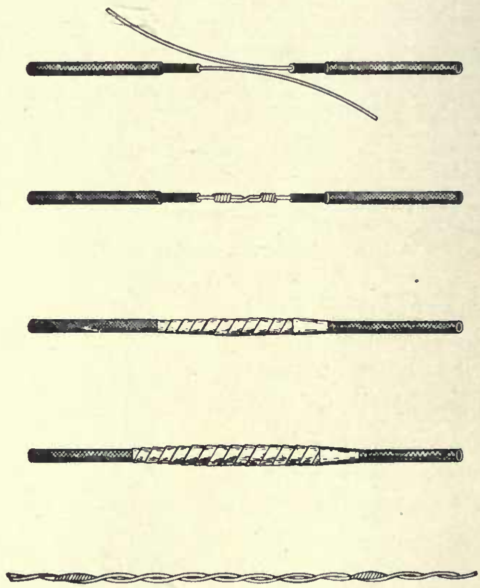


Fig. 631. Splicing Drop Wire

Fig. 633. The size of the ring is determined by the number of pairs of wires that will ultimately follow the routes, good practice in this respect being to use a 3-inch ring for all runs that will ultimately carry more than ten pairs and for the slack loop ring at all terminals; a $1\frac{1}{2}$-inch ring for all runs that will ultimately carry not less than three and not more than ten pairs; and a $\frac{5}{8}$-inch ring on all runs that will carry one, two, or three pairs. A $\frac{5}{8}$-inch ring is also well adapted for the final connection of the single pair at the point where the wires enter the building.

Where rings are to be secured to wooden walls, they are screwed directly into the wood. Where attached to brick, conerete or stone walls, a hole is drilled into the wall and this may be plugged with

Fig. 632. Circle-Top Distribution

wood, into which the ring is screwed, or it may be fitted with any one of several forms of standard expansion screw plugs that automatically tighten and hold against the interior of the hole. In all cases the rings should be turned so that they are at right angles to the direction of the run. When the run is horizontal the open sides of the split rings should be at the top, and at all corners the open side should be at the outer side of the bend. In horizontal runs the rings should be placed not over 4 feet and on vertical runs not more than 8 feet apart.

The method of mounting a terminal on a wall is shown in Fig. 634. This illustration not only shows the lead-covered cable leading up from the underground lateral to the terminal can, but it also shows the method of leading off the twisted-pair wall wires through the rings.

The method of dead-ending the individual pairs of wires at the bridle ring is shown in detail at the left of Fig. 634, while the method of running the wire through the wall of the house, preferably in the upper casement of the window, is shown in Fig. 635. Other details of wall-ring construction are shown in Fig. 636.

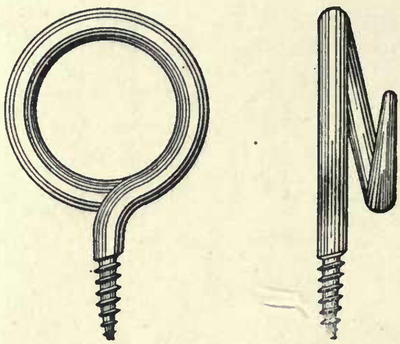


Fig. 633. Bridle Ring

Aërial Conduit. Often it is convenient to mount the cable terminal on a pole in the interior of the block so as to be able to reach the rear walls of several houses. Where this is done an aërial conduit is provided for

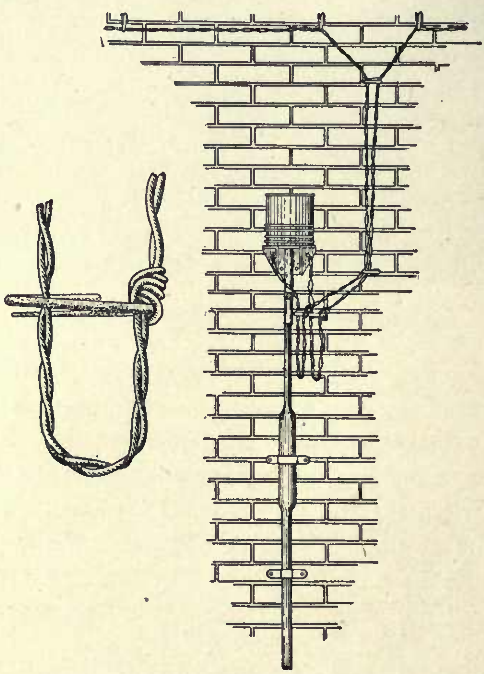


Fig. 634. Wall Terminal and Wiring

supporting the wires from the pole to the nearest wall of the house. This is readily done by extending a messenger wire from the pole to the house. As such construction is always relatively light, a No. 4 or No. 6 messenger wire is amply strong. The messenger wire may be dead-ended on the pole in the ordinary way, and on the house in a heavy screw-eye bolt. This messenger wire so run may support a lead-covered cable leading from the pole to a terminal on the house; and from this terminal on the house; the rubber bridle wires may be run, as already described. Usually, however, it is preferable to place the terminal can on the pole and to extend the bridle wires from it along the messenger wire. For this purpose aërial conduit rings are used, Fig. 637, which are clamped directly to the messenger wire so as to hang below it. They are usually spaced about 18 inches apart, and the bridle wires are carried through them along the messenger wire to the wall of the house. A general idea of this construction is given in Fig. 638.

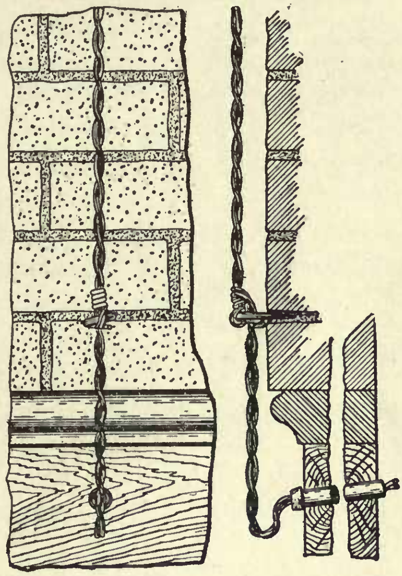


Fig. 635. Wall Wire Entering Building

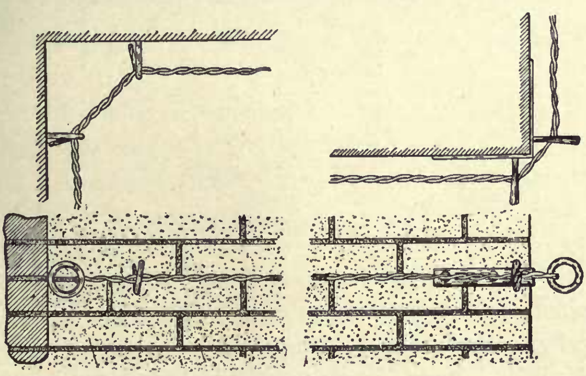


Fig. 636. Details of Wall Wiring

Fence Wiring. The same general methods that have been outlined for wall wiring will apply to fence wiring, except that on fences greater care must be taken to protect the wiring. Where the terminal is placed on the fence, it should be in as inconspicuous a place as possible and at the same time reasonably accessible to linemen, who should be able to reach it, if possible, without the necessity of annoying the occupants of the property on which the terminal is located. It should always be so placed that it will be least liable to injury by children walking or playing on the fences. Where necessary, it may be suitably housed in a wooden cabinet provided with lock and key. The underside of the upper fence stringer forms the best place for the bridle wires, and if a cable is also run along the fence for any distance, it is preferably run underneath the bottom stringer. Details of this construction are shown in Fig. 639. Where it is not possible to mount a fence cable

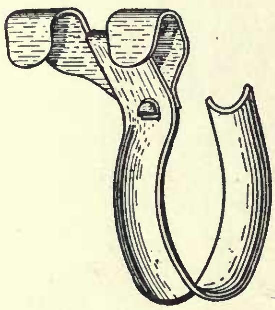


Fig. 637. Aërial Conduit Ring

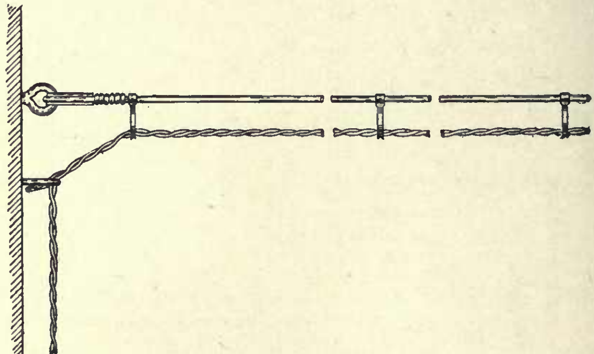


Fig. 638. Aërial Ring Conduit

under the stringer of the fence, it should be enclosed in a simple wooden moulding.

Back fences form almost the only available way of distributing wires and cables in some congested districts in large cities like New York and San Francisco, where back yards are small and where, in many cases, no alleys exist. This method allows a malicious or mischievous person to tamper with the cables or wires, but is not as unsightly as aërial block distribution.

Distribution from Underground Terminals in Buildings. Large office buildings are practically always found in localities fed by underground cables. The proper way of making the service connections in such buildings is to run an underground lateral from the nearby conduit manhole directly to the basement of the building, and to draw into this lateral a cable having a sufficient number of pairs to serve all the subscribers in that building. Some of the large office buildings in New York and Chicago have as many as 1200 cable pairs thus entering them directly from the underground conduits. In small office buildings and business blocks, the question as to whether the service connections shall be made directly from an interior terminal or by the rear-wall method must always be governed by the size of the

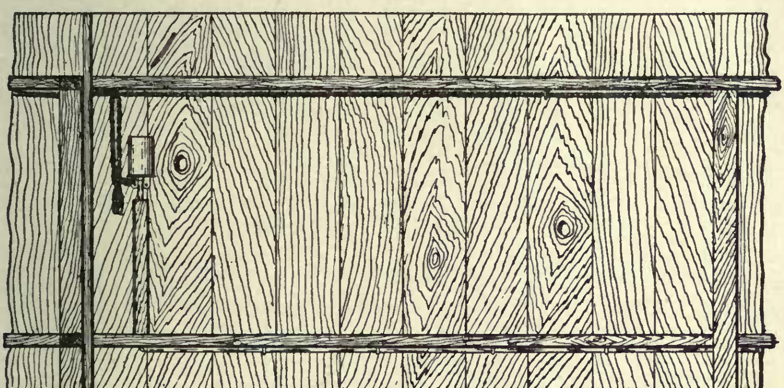


Fig. 639. Fence Wiring

building, by the ease of access to the basement of the building for the underground cable, by the provision of proper runways for the wires in the building, and by the character of the outside of the building as affecting the feasibility of using rear-wall wiring. Underground service connections are to be preferred, in many cases are the cheapest, and in other cases are the only practical way.

Where the distribution is from an underground terminal within the building, the cable leading into the building should be terminated at some point where it will not be liable to injury and where it will be reasonably accessible to the workmen of the telephone company. The same sort of a terminal that is employed for aërial cable work may be used for terminating the cables, unless they are of very great size, in which case special terminal racks are provided.

CHAPTER XLIX

SUBSCRIBERS' STATION WIRING

The simplest case of subscriber's station wiring is that of an unexposed open wire line, such as a private line in the open country, entering a dry wooden house to connect with a telephone. In this case the outdoor line is terminated on insulators on the outside of the house at such a point as to make the wiring to the telephone within as short as possible. A twisted pair of wires insulated with a good grade of rubber with a braid over each wire is then run into the house through a hole slanting inwardly upward and is carried to the instrument along vertical and horizontal lines of the woodwork of the house. It is attached to that woodwork by means of insulating nails or staples.

General Conditions. All telephones in subscribers' stations may be classified as exposed or unexposed, depending on the character of the line outside. Protectors are required at exposed stations, but none are required at unexposed stations.

The construction rules of governing fire-insurance bodies prescribe that the wiring of an exposed line shall be considered high-tension wiring up to the point of the protector, but that between the protector and the telephone the wiring may be considered as without exposure to hazard and may be run in any desired way.

The wires from the exposed line to the protector, therefore, if the latter is within the building, are to be supported on insulators. From the protector to the telephone, "inside wire" shall be used. As so much of the success of telephone service and the securing of low maintenance costs depend on the quality of inside wire, the following condensed specifications for such wire are offered:

> The wires shall be of No. 19 B. & S. gauge and shall be of soft copper, well tinned. Each tinned copper conductor shall be evenly and smoothly covered with an approved rubber insulating compound to an outside diameter not less than $\frac{3}{32}$-inch. The insulated covering shall

be flexible and not liable to deteriorate under ordinary conditions nor to act injuriously on the conductor. Each insulated conductor shall be covered with a close braid of cotton. This shall either be polished or shall be treated with a paint or compound, insoluble in water, and this shall not act injuriously on the insulating compound. The braid on one wire shall have a raised thread or an approved equivalent marker so that the wires may be easily distinguishable from each other. The two insulated braided conductors constituting a pair shall be twisted together. The twists shall be regular and uniform. The length of the twists shall be not less than 1¾-inches nor more than 2½ inches. The completed wire shall be capable of withstanding a pressure of 1,000 volts alternating current and shall have an insulation resistance of at least 200 megohms per mile at a temperature of 60° Fahrenheit. The resistance of each conductor shall not exceed 50 ohms per mile of completed wire at 60° Fahrenheit.

Where a protector is required, if the chosen type mounts inside the house, it shall be located as close to the entrance as possible. It shall be mounted on a wall 7 feet from the floor, shall be placed so as to avoid dampness and inflammable material, such as window shades and curtains, and never shall be mounted in a show window.

The ground wire from the protector shall, if possible, be run to a water pipe; if this is not possible, a gas pipe is next preferred, connection being best made between the meter and the street. A ground rod not less than 6 feet long driven into permanently damp earth is the third choice. A good ground clamp is the most convenient way of attaching a ground wire to a pipe, however, soldering the wire to the pipe is as good practice but less convenient.

Where a protector is not required because the line is unexposed, it is good practice to install a connection block in its place, as this is a handy way of joining the entrance wires to the inside wires. A connection block is merely a small slab of insulating material with binding posts on it. Two connected pairs of such posts may be used, or a single pair, each post taking one inside and one outside wire.

The inside wire of two insulated and braided conductors should be carried around rooms in picture mouldings where possible, if this does not require crossing open plastered walls. To reach wall telephones, it is generally possible to drop the wire from the picture moulding to the instrument within a plastered wall and to bring it out at the telephone so as not to show at all.

In carrying the inside wire along other woodwork than a picture moulding, the best fastening is an upholsterer's tack. This is a small, sharp-pointed steel nail with a large head of insulating material.

The stem of the tack is slipped between the two wires of the pair. Care should be taken never to drive the tack through the insulation. The next best fastener is a staple having a saddle of insulating material. For ground wires, which are single, staples are necessary. Neither ground wires nor twin wires shall have spirals in them. Ground wires carry away lightning best if entirely straight.

The more complicated cases of wiring office buildings, hotels, and apartment houses require some use of inside wire in these ways. It is not possible, however, to bring the outside lines to the telephones as simply as in the case of isolated houses. The preparation for wiring an office building or hotel should begin at the time the architect makes his first preliminary sketch, and telephone wires should be considered and arranged for during all the processes of planning and constructing the building. Owners, architects, building contractors, and wiremen should have exact knowledge of the needs of modern telephone installations. For this reason, the following fundamental matter is presented.

There are three classes of buildings which require particular attention in preparing for telephone service: Office Buildings; Hotels; and Apartment Houses.

Other buildings which require consideration are: Flats and Private Dwellings.

Office Buildings. Assume that office buildings will require about one telephone per office. While the number of telephones so figured often is exceeded, the excess stations are taken care of by private exchanges, having fewer lines to the central office than to local substations. Since the location of telephones cannot be determined in advance, it is necessary that a very flexible arrangement be provided and one that will permit wires to be run to *any* part of *every* room. Such an arrangement in nearly all cases can be obtained best by the use of raceway mouldings in halls, picture mouldings in rooms, and by the proper distribution of hall terminal boxes. These boxes are served by riser cables and provision is made for the riser cables to be carried vertically from the basement to the top floor.

Raceway Mouldings. Common and good forms of raceway mouldings are shown in Fig. 640. In the hall a larger moulding is required than in the individual rooms, the moulding in each room being connected with the hall moulding by a short piece of $\frac{3}{4}$-inch conduit which will make any subsequent boring of the walls unnecessary. Mouldings in adjacent offices should be similarly connected, in which case, the conduit shouldbe placed in the dividing wall as close to the hall as possible. This interconnection of room mouldings will be found particularly useful in wiring a suite of offices for a private exchange with a switchboard in some one room. The mouldings should be continuous along the entire length of a hall and around the walls of a room and preferably should be above all doors and window sashes, or, at the lowest, on a level with their tops.

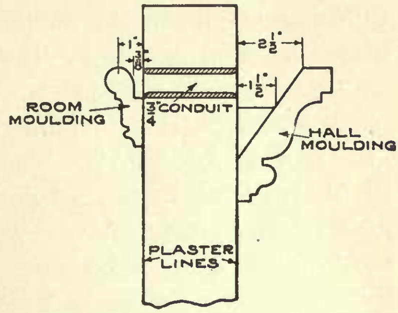


Fig. 640. Race-Way Mouldings

Ceiling Conduits. Where terminal boxes are not placed on both sides of the hall, the mouldings on each side should be connected by 1½-inch conduits, placed in the ceiling, as shown in Fig. 641. Where very long halls exist, even with terminal boxes on both

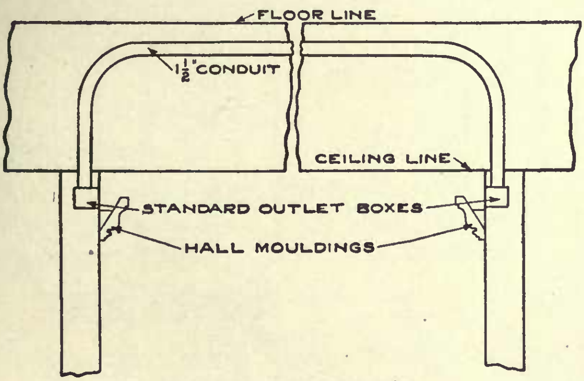


Fig. 641. Ceiling Conduits

sides, connecting conduits 1½ inches in diameter, and in duplicate, should be placed at intervals not exceeding 100 feet. The total length of a hall should be considered as that measured throughout its entire length on all sides of a building.

In placing conduit under these conditions and elsewhere, the usual precautions should be taken to round the exposed edges at the ends so as to remove all burrs which might injure the insulation of the wires or the covering of the cables.

Hall Terminal Boxes. It is distinctly desirable to use but one size of hall terminal box throughout a building. This can be done with ease, if the following simple rule is adhered to: *Always place enough boxes on each floor so that not more than ten to thirteen offices will be served from one box.*

A good form of hall terminal box suitable for the above arrangement is shown in Fig. 642. The boxes should be placed just below the hall moulding, the back of the box projecting up behind the moulding to afford a means of connection between the moulding and the box. In placing the boxes along a hall, an effort should be made to have the box as close as possible to the center of the group of offices which is to be served by the box.

In order to connect the terminal strips in the hall terminal boxes with the riser cable, the cable shaft, or closet accommodating the riser

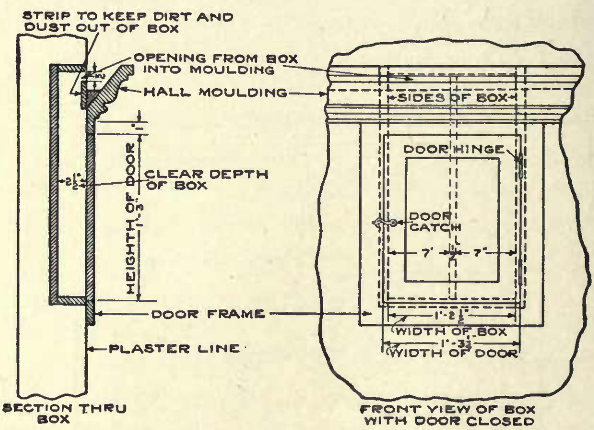


Fig. 642. Hall Terminal Box

cable, should itself be connected with the hall terminal box directly by means of the hall moulding, or by a special conduit-run, or directly by placing the hall terminal box in the shaft close to the hall moulding.

Hall terminal boxes should be located with reference to the offices they are to serve and, if a choice exists, the location of the riser-cable shafts should be made with reference to the location of the hall terminal boxes so as to reduce the length of distributing cable from the riser shaft to the hall distributing boxes to a minimum.

Riser-Cable Shafts. In all except the smallest buildings (four to five offices in the longest side) at least two riser-cable shafts should be provided for at diagonally opposite corners of the building. There

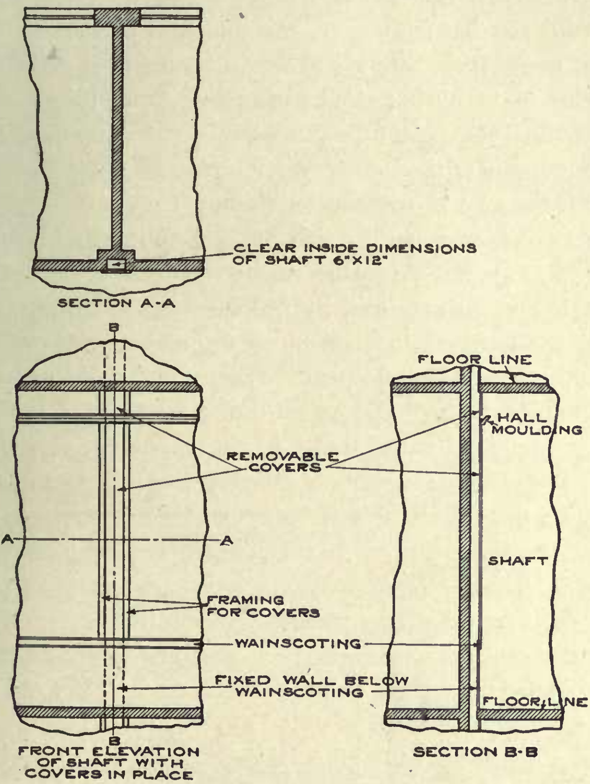


Fig. 643. Riser-Cable Shaft

should be as many shafts as necessary to keep the distance from the shaft to the farthest terminal box under 75 feet. Enclosed shafts are preferable to open ones, elevator ways and vents being classed as open shafts. Cables in open shafts, even though covered, are unsightly and in danger of injury.

Separate shafts of small dimensions are recommended and they may be located in some part of the hall walls so as to be nearly midway between the hall terminal boxes they serve. Such a shaft is shown in Fig. 643, in this particular case it being in the hall wall opposite a partition between offices. In many cases such a shaft may be recessed into a wall of the janitor's closet, elevator shaft, toilet room, or other space, so as to be inconspicuous. The shaft should have an inside dimension of *at least* 6 by 12 inches. It may well be somewhat larger. The long dimension preferably should be parallel with the hall; however, this position of the shaft may be reversed if necessary. The shaft shown is provided with a removable paneled cover on each floor, extending from the wainscoting to the ceiling, but cut at the hall moulding. If the location of the shaft permits, one of the hall terminal boxes, Fig. 642, may be placed in the shaft directly below the moulding.

As riser cables generally are not self-supporting, means must be provided to permit the cables to be strapped to the walls of the shaft. This may be arranged by sinking flush with the walls of the shaft near the top and the bottom of the opening on each floor, 2-inch by 4-inch wooden sleepers. Where tile walls are used, the sleepers may be omitted and toggle bolts used. It is not generally possible to extend all cable shafts to the basement, as the arrangement of the first floor generally is different from the rest of the floors; this condition may easily be met, however, by extending to the basement from the bottom of each cable shaft, two $3\frac{1}{2}$-inch conduits.

Cable in Elevator Shaft. Where it is not possible to construct separate shafts for telephone purposes, other shafts—such as elevator shafts, pipe shafts, and vents—may be used, providing they are within a reasonable distance of the hall terminal boxes. They are distinctly not the best way, however.

When an elevator shaft must be used, provision should be made at each floor so that the distributing cables may be run from the riser cable to the hall distributing boxes. This may be accomplished either by running the hall moulding to the shaft or by connecting the shaft to the hall moulding by a conduit run. Where possible, the riser cable should be enclosed, both for appearance and for protection. This being done by means of a small box with removable doors, extending vertically from the basement to the top floor. This box should have an internal cross-section approximately 6 by 12 inches.

Combined Pipe-and-Wire Shaft Where a combined pipe-and-wire shaft is to be used, an effort should be made to separate the telephone wire portion from the rest by a substantial partition, preferably fireproof. Telephone cables and wires may not be kept close to steam pipes. Provision should be made so that access may be had to the cable at each floor. The shaft should be properly connected

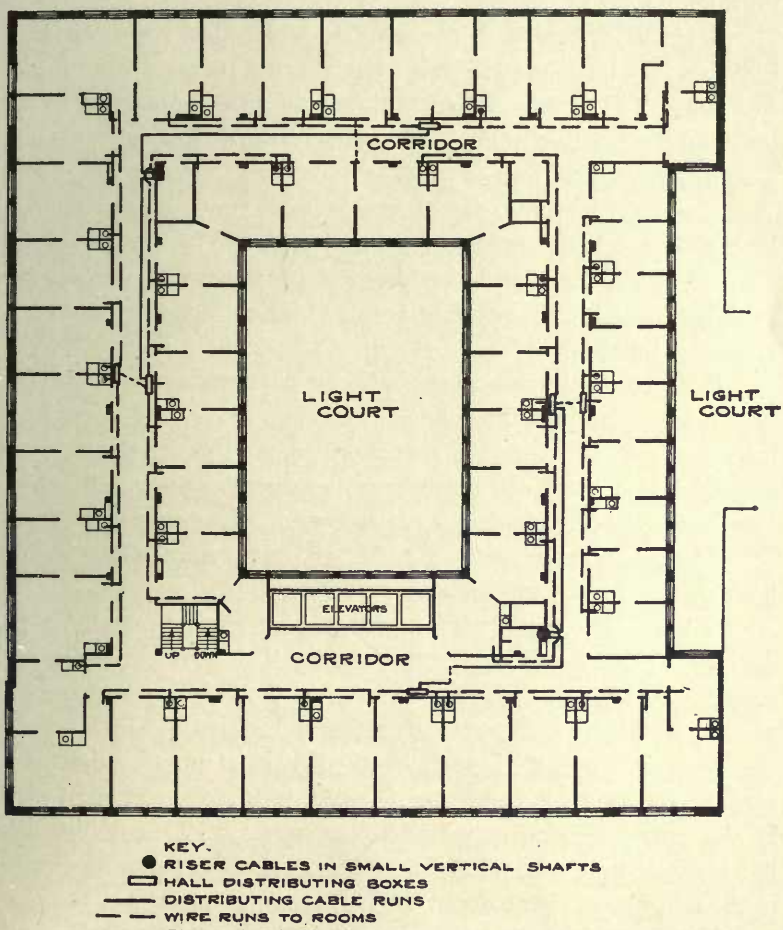


Fig. 644. Office Building Wiring

with the hall moulding or to the distributing boxes. A separate door for each part of the shaft is not necessary.

Cable in Vent Shafts. Where vent shafts exist in suitable locations, they should be treated the same as elevator shafts, the cable being accessible at each floor. As lead-covered cables are used in riser shafts, it is not necessary that the vent shaft should be waterproof. Care should be taken, however, that the connection to the hall moulding is waterproof on the hall side. Where conduit is used, this result may be obtained by slanting the conduit up from the outside.

Main Distributing Terminals. In order that wires within the building may be connected to the outside wires coming from the central office, it is necessary that both sets of wires be carried to some common distributing point. The place at which this occurs is either a main terminal cabinet or main terminal room.

The main terminal, except for special reasons, always should be located in the basement and the location should be dry and not too close to steam pipes and the like, but convenient to vertical riser-cable shafts and to the point or points at which the service cables will enter the building.

If the vertical riser-cable shafts do not terminate at the main distributing terminal they should be connected to the latter by $3\frac{1}{2}$-inch conduits, two conduits being run to each shaft. Should it be evident that a shaft will never have to accommodate a full cable of four hundred pairs of wires, smaller conduits may be used.

Typical Arrangement. Fig. 644 shows a typical office building floor plan, laid out for wiring.

Hotels. The entire telephone traffic of hotels generally is handled by a private-exchange switchboard. This switchboard must be connected with practically every room in the hotel and with a telephone central office, the latter by a few trunk lines. The location of the telephone outlet in each room of a hotel may be determined readily; therefore, it is always possible to install permanent wiring at the outset for the entire telephone system. This distinguishes hotel wiring from office-building wiring, since the permanent wiring in the latter must terminate at the hall terminal boxes.

In a degree, the wiring of a hotel for telephone purposes is similar to wiring it for electric lights, the difference being that for telephone service a separate pair of conductors must be carried to each telephone, while in electric-light work, all lights may be connected in one way or another to a single source of current.

The method of wiring best suited to the average hotel is: A riser cable, which is installed at a convenient point, is properly connected at each floor by smaller cables to suitable floor distributing boxes. From the proper box a pair of twisted wires is run to each telephone in each room. More than one riser cable may be needed in a large hotel. As in office buildings, the economy of such a system will depend very largely upon the care exercised in choosing the locations of the riser-cable shafts and the floor distributing boxes, which locations should be such that the length of conduit, wire, and cable runs will be a minimum.

The first thing to do in preparing wiring plans for a hotel is to decide upon the location of the private exchange switchboard. A good location generally is found in or close to the office. This, in most cases, brings the switchboard on the first floor and in occasional cases on the second or third floors.

All house lines, incoming and outgoing trunks from and to the central office, and all lines to the private exchange switchboard should end at the main distributing terminal. The terminal affords a means of cross-connection, so that any room line or trunk line may be connected as desired to a chosen circuit in the private exchange switchboard. It will be seen that in this way the number of wires between the private exchange switchboard and the main distributing terminal will be large, and to reduce cost to a minimum the distance between the main distributing terminal and the switchboard should be made as short as possible.

Arrangement of Apparatus. In hotels of moderate size, not exceeding 150 rooms, it is good practice to arrange for a main distributing terminal directly at the rear of, or close to, the private exchange switchboard. Where this is not advisable, and in the larger hotels, the main distributing terminal should be located in a separate room. This room, in the larger hotels, will also be required to care for certain power apparatus and other telephone accessories in addition to the wiring.

Where the switchboard is located on the first floor, an ideal location for the terminal room is directly below it in the basement. Where the private exchange is not located on the first floor, the terminal room, from a cost viewpoint, should be located on the same floor as the switchboard. Where a separate room—or a room used in conjunction with electric fuse cutouts, etc.—is to accommodate the main distributing terminal, a cabinet is not necessary. If the terminal must be located in a hall or other room, or at the back of the switchboard so as to be exposed to general view, a cabinet should be provided which should be approximately 1 foot deep in the clear. The entire front of the cabinet should be fitted with removable doors, and its design should harmonize with its surroundings. Provision also should be made to carry the incoming wires from the point where they enter the building to the distributing cabinet. A 2-inch conduit generally will suffice for this purpose.

Location of Outlets. If ordinary wall telephone sets are to be used in rooms, the telephone outlet, consisting of an ordinary conduit outlet box, should be placed 4 feet 10 inches above the floor. If sets mounted flush with the wall are to be used, a special conduit outlet box is required.

Where portable telephones are used, the outlets in most cases may be located with advantage in the baseboard. This location and the outlet box required must be considered special and should be given special consideration in each case. It is often desirable to arrange for telephone service in dining rooms and grills, from part or all of the tables and such provision requires the use of floor or wall outlet boxes and special apparatus.

From the individual outlet or outlets in each room, there should be run to the proper floor distributing box a twisted pair of No. 19 B. & S. gauge, braided, rubber-covered, tinned, soft copper wire. Where a separate circuit is run to each outlet—the usual case—a third or ground wire is not necessary unless coin-prepayment or other special service is desired; in the latter case, a third wire tap should be brought out at each outlet. The third wire taps from all outlets should be spliced to a common wire at the distributing box or other convenient point. For mechanical reasons this common ground wire should not be smaller than No. 12 B. & S. gauge and should be of the best quality of braided, rubber-covered, tinned, soft copper wire. At each floor distributing box, the wires from the various outlets should be connected to the distributing cable, preferably by means of suitable binding posts mounted on strips of suitable insulating material.

Distributing Cables. The distributing cables from the riser-cable shafts should be lead-covered and should consist of a number of twisted pairs of No. 22 B. & S. gauge, double silk- and cotton-insulated, soft, tinned, copper wires. The size of the distributing cable is determined by the number of outlets it is to serve. An extra pair or so should be allowed where possible. This will naturally follow where a 15-pair cable serves from twelve to fourteen rooms.

Even where one conduit serves more than one distributing box, only one cable should be placed in a conduit where practicable.

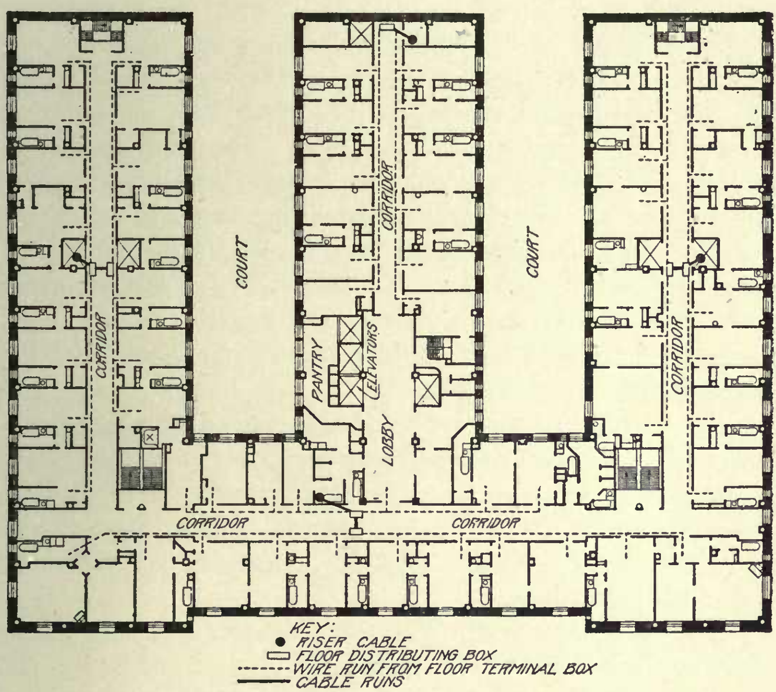


Fig. 645. Hotel Wiring

This may be done in most cases by tapering the cable at each box so that only the wires actually required will be carried ahead. At the riser-cable shaft or shafts, the distributing cables should be permanently spliced to the riser cable or cables, as the case may be.

Riser Cables. The capacity of the riser cable or cables should be made to equal the combined capacity of the distributing cables unless there is an unusually large number of dead wires in the latter. In case this number is large, the capacity of the riser cable or cables may be decreased as required and certain of the dead wires in the distributing cables on each of the floors connected to the same conductors in the riser cable or left dead, if desirable.

In hotels of not over five or six stories, the riser cable should preferably be of the same kind as the distributing cables; namely, lead-covered, with No. 22 B. & S. gauge, double silk- and cotton-insulated wires. The distributing cables then may be spliced to the riser cables at each floor.

In the larger hotels, especially where a large number of rooms are to be served on each floor, the first cost may be materially reduced by using lead-covered cables with paper-insulated conductors such as are used in underground conduits. Where this type of riser cable is used, it is better to make one splice to the distributing cables at every fourth or fifth floor, thus paralleling certain of the distributing cables for a floor or so, rather than to splice the distributing cable to the riser cable at each floor. The reason for this is that splices to paper cables are expensive to make and must be made with great care, since the paper insulation of the conductors will not stand rough usage or exposure to moisture.

To convey the riser cables to the main distributing terminal where silk and cotton riser cables are used, they are attached directly to the terminal strips on the main terminal rack, the exposed insulation first being dipped in hot beeswax. Where paper-insulated cables are used, the cable must be pot-headed before being attached to the terminals.

Typical Arrangement. Fig. 645 illustrates an actual example of the method of wiring for hotels.

Apartment Houses. The following notes refer in particular to those apartment houses which are of sufficient size, or of such a type as to warrant a private exchange. The requirements of this class of apartment houses are similar to the requirements of hotels.

In apartment houses, one telephone generally is required for each apartment. This makes the ratio of telephones to rooms considerably less than in hotels. It is for this reason that the method of wiring best suited for hotels is not generally the most economical or the best suited for apartment houses, except in cases of very large buildings or where the arrangement of the apartments on each floor is irregular.

In most apartment houses, the apartments on the several floors are arranged similarly. Should the telephones in each vertical tier of apartments be located in the same relative position, it will be seen that one vertical riser conduit running from the basement to the top floor can be made to serve all telephones in each tier of apartments, and in many cases, one conduit can be made to serve *more* than one tier of apartments.

Most of the preceding, relative to the location of the private exchange switchboard and the main distributing terminal in hotels, applies equally well to their location in large apartment houses.

Conduits and Outlets. Care should be taken not to overlook the conduit that may be required between the main distributing terminal and the private exchange switchboard. The size of this conduit will depend on the size of the cable it is to accommodate. Where possible, the conduit also should be run from the main distributing terminal to the point at which the service wires will enter. A 2-inch conduit generally is sufficient for this purpose.

To permit the use of the system above described, it is essential that there be an outlet in each apartment of each vertical tier, in line with the common vertical riser conduit. In most cases, the telephone may be located at this outlet. Should another location be desirable in certain apartments, an additional outlet box should be installed at the desired location and connected to the outlet box referred to above by a suitable run of conduit. Whether the outlet box is to be of standard or special design such as required for flush sets, or whether it is to be located for a wall set, or a portable set, will depend upon the type of instrument desired.

The size of each of the vertical riser conduits, which is determined by the number of wires it is to accommodate, may be tapered from floor to floor as the number of wires to be carried by the conduit decreases. All riser conduits should be carried to the main distributing terminal.

Main Distributing Terminal. The type of main distributing terminal best suited to most apartment houses is one which mounts in a cabinet, the size of which is determined by the number of apartments the terminal is to serve.

The telephone outlet in each apartment should be connected to the main distributing terminal by a twisted pair of No. 19 B. & S.

gauge, rubber-covered wires, which wires may be fished easily through the conduit after the latter has been installed. In some of the larger apartments, it will be found economical to splice the individual wires, at the bottom of each vertical conduit, to a lead-covered cable containing a proper number of No. 22 B. & S. gauge double silk- and cotton-insulated wires, thus conveying the circuits from the splices

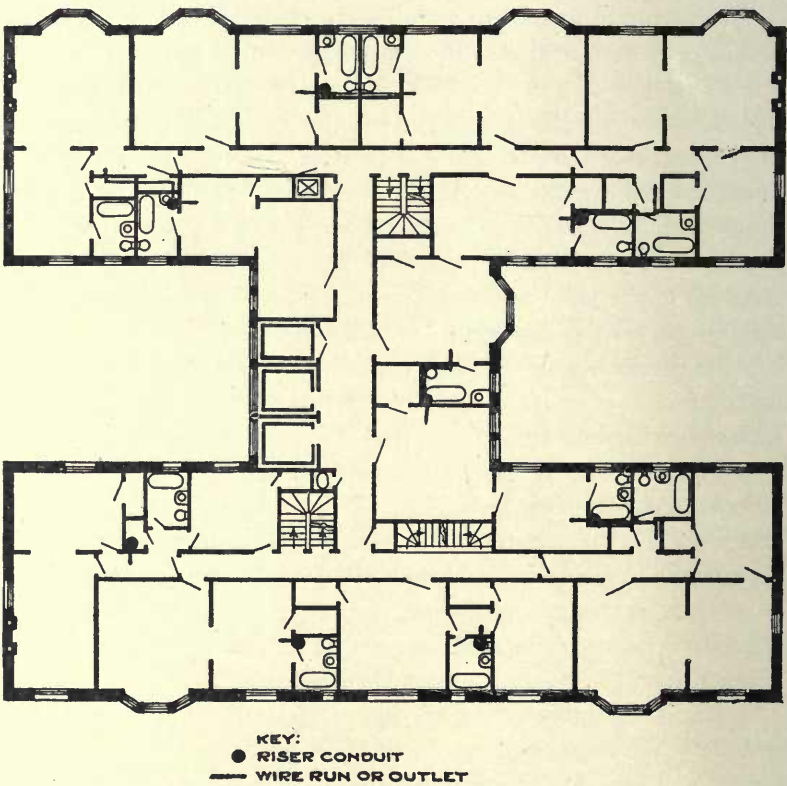


Fig. 646. Apartment House Wiring

to the main distributing terminal in the cable. Similar cable should be used to connect the main distributing terminal to the private exchange switchboard.

Typical Arrangement. Fig. 646 illustrates the wiring of a typical apartment house. In this case, a number of risers have been located so as to serve more than one apartment each.

Flats. Small apartment houses may be considered as flats, in that both classes of buildings do not, as a rule, require private exchanges. It may be said further that intercommunication between such apartments or flats generally is not necessary and sometimes is undesirable.

Location of Outlets. The location of each telephone outlet having been determined, there should be run to each outlet from the predetermined common distributing point a pair of No. 19 B. & S. gauge, braided, rubber-covered copper wires.

Distributing Point. The common distributing point preferably should be located in the basement. Should the building be served by an underground system, further provision for wiring need not be made unless the basement walls are finished, in which case conduits should be run through the finished portions of the basement, avoiding the necessity of carrying exposed wire or cable through a finished room. Should the building be served by an aërial lead, either at the front or at the rear of the building, two conduits should be run from the common distributing point to a point or points on the front or on the rear of the building, directly opposite the aërial leads from which the service wires or cables will be taken.

In small buildings of not over six or eight apartments, a distributing cabinet is not necessary. In larger buildings, a distributing cabinet should be arranged for at the common distributing point. It should have a removable door, hinged or otherwise, and should be approximately 6 inches deep.

Special Facilities. When desired, special facilities for local service can be provided which will permit a caller in the vestibule to ring and speak with the occupant of any apartment or with the janitor. The occupant of each apartment also may call the janitor or be called by him. To provide for such a system of course will require some additional wiring and special apparatus, but such apparatus does away with the usual tin speaking tube and push button.

Private Dwellings. The setting of the protectors and instruments, and the running of the wires may be carried out in private dwellings in accordance with the instructions already given. Whether or not concealed wiring is to be used will depend on the character of the dwelling and the desires of the owner.

CHAPTER L

ELECTROLYSIS OF UNDERGROUND CABLES

The practical result of the electrolytic hazards described in Chapter XVIII is, that if currents are allowed to flow away from cable sheaths or other metallic property in the presence of moisture for a long enough time, the metals will be injured. Fig. 647 is a

Fig. 647. Part of Cable Sheath Corroded by Electrolysis

photograph of a piece of cable sheath from which current at a pressure of 5 volts flowed to moist earth for a few months. If it had flowed a few months longer, the pitting would have perforated the sheath and moisture would have entered the cable core.

Early Controversy. As the principal, if not the only cause, of this hazard is the return current from ground return electric railways, it will be instructive briefly to recall certain phases of a controversy between telephone and electric-railway interests in the early days of each of these industries. It was not known then that this controversy involved the electrolytic hazard, and it was fought out on other lines; but the point of particular interest is that, had the controversy been decided the other way, electrolysis of underground cables would not be a serious enough matter to write about here.

It has been stated that all telephone lines were single-wire circuits in the beginning of practical telephone development, and for a number of years thereafter. It was the advent of electric light and electric street-car systems, particularly the latter, which made grounded circuits unsuitable for the best telephone service, the high-tension circuits while in operation making these single-wire telephone circuits noisy, and the street-railway systems causing not only noises but false signals as well, the annunciators of the subscribers' lines being frequently dropped by stray currents flowing over the lines.

As the street-car systems became more extensive in the cities, and particularly as their traffic grew heavier, the difficulties from these two troubles became quite serious. No remedy was discovered to be reasonably possible so far as changing the street-car system was concerned, except to provide each car line with two trolley wires, and each car with two trolley poles, making the street-car system wholly metallic circuit, the rails not being used at all for the return of the current to the power station. Such systems have been installed abroad, and such was the plan adopted in Cincinnati, Ohio. In that city, grounded telephone lines were successfully operated for a considerable time after the establishment of the electric-traction system. So long as the car trucks and wheels were kept insulated from the electric circuit of the motors, the telephone lines passing or ending near the trolley line were free from disturbances. If, by any defect in the car, a cross occurred between some part of the motor circuit and the truck, the progress of that car through the streets could be traced by one listening upon the telephone lines, and it was by means of this detective work of the telephone system that such defective cars were located, the listening subscribers observing from their windows the numbers of the noisy cars as they passed by. These cars were then withdrawn from service and repaired. The double trolley system with its distinct freedom from being the cause of trouble is still extensively in service in Cincinnati.

The existence of a so thoroughly possible traction system with its absence from disturbances to the telephone system caused legal action to be instituted in Ohio, wherein it was contended by the telephone company that as the traction interests possessed a means of operating their cars without interfering with the telephone system, the former should apply that method, or be compelled to continue it if they had applied it. The decision of the lower courts was favorable to this contention, and it seemed at that time as if the single-trolley rail-return traction system must disappear.

Court Decisions. In the higher courts this decision was reversed, it being held that the telephone company did not possess such a right to the use of the streets and the earth under the street, as to permit it to interfere with the proper use of the streets for transit and transportation. The ruling in effect was that the telephone company did not own the earth, as some phases of the attitude of the original monopolists have indicated they were inclined to believe. From this time the growth of single-trolley traction systems continued without further opposition from the telephone interests, and the burden of relief lay upon the latter.

McCluer System. One of the measures of relief was that devised by McCluer of Richmond, Virginia, and consisted in the simple expedient of providing for each main and branch route of the telephone system, a copper return wire to which the telephones of that district were connected, instead of being connected to ground. For a given route of 100 lines, for example, there would be 100 line wires plus one common return wire. The office of this was merely to provide a return path to the central office quite as the ground had provided such a path before, and its success depended upon its being kept clear of ground. In a sense, an exchange having single-wire lines and a common return wire on each route—the other returns being united in the central office—might be called a *metallic-circuit system,* because if the circuit is not grounded in any degree it must necessarily be metallic. In the accepted sense, however, a system utilizing a common return is only to be called metallic circuit by an excess of courtesy, because it partakes in a large degree of the disadvantages of a grounded system, the chief disadvantage being the lack of similarity in the two sides of the line, one side being its actual line wire, and the other the common return. As the latter has many lines connected to it, and as it is usually of copper and the line wire frequently of steel or of iron, the conductivity and electrostatic capacity of the two sides of a given line were distinctly unlike. The common return wire did, however, successfully cure the trouble due to the falling of drops from stray traction currents. These troubles, as they were due wholly to currents flowing between separated points of the earth, would no longer exist when the use of the earth as a return had been abandoned.

Metallic Circuits and Cables. Following this partial cure of new difficulties, the existence of metallic-circuit long-distance lines assisted in introducing the present general practice of making all subscribers' lines of two wires, with the consequent advantages, assuming proper transposition, of complete balance, complete quietness, and absence from false signals. This made it further advantageous to combine many lines in one cable, even though it must be of considerable length, because the complete balance of the subscribers' metallic circuit rendered it free from cross-talk troubles as well as from inductive noises. When it became possible to place many wires in one cable, it was further possible to place the cables underground, and such practice became general.

Electrolysis Troubles. In 1895, I. H. Farnham, chief engineer of the New England Telephone Company, observed the beginning of an epidemic of underground-cable troubles. In all of these new troubles, the difficulty was a failure of the underground cable due to loss of insulation, and the loss of insulation was found to be the result of the entrance of moisture due to an unaccountable appearance of holes in the lead sheath. With characteristic thoroughness, Farnham investigated all the elements accompanying this new trouble and conducted a series of experiments which led him finally to discover that the cause was the eating away of the lead sheath of the underground cable at a certain point, or at certain points in its length, which destruction of the sheath was due to the passage of current from the sheath to the earth in the presence of moisture, as has already been stated.

Causes. The corrosion of a lead sheath by currents passing from it to the earth must not be confused with any electrical use of the conductors of the cable, as it is entirely independent of such actions. The reasons the lead sheath is attacked at all are several: First, the existence of a single-trolley traction system, using the rails of the track as a return for current, does more than that statement implies. Whatever may be the condition of the soil in any city, the rails laid upon the earth will be assisted in carrying current by the earth's mass itself. This is true, however well the rails may be supplemented by copper return wires connected to them at intervals. Second, the cable sheaths themselves, being formed of a considerable amount of lead, a fairly good conductor, and laid in quite good contact with the earth itself, necessarily assist the rails and the rail-return in carrying current toward the power station. Perhaps this is as well told by saying that in any traction system, an examination of the territory covered will show that different points in the territory have different potentials with relation to the earth at the power station; and it is obvious that where differences of potential exist, and these are connected to each other by a conductor, current will flow. The amount of current which will flow is an immediate result of the amount of the difference of potential and of the conductivity of the connecting conductor, which in this case is the cable sheath. It is further evident that the difference of potential depends largely upon the number of cars which are in use at a given time, upon their location, and upon the amount of current they are drawing from the power station.

In almost all underground situations, moisture is present, and in addition has dissolved in it salts or acids of various kinds, which assist in the electrolytic process. A simple experiment of passing current from a piece of lead through moist earth to another conductor will establish the certainty of pitting the lead, while no such effect whatever results when the current is passed from a conductor through the moist earth to the lead.

Underground Conditions. Some idea of the conditions to which an underground cable is subjected may be gained from Fig. 648, in which it is assumed that, as is usual, the negative pole of the electric-railway power-station generator is connected to the rail and, therefore, to the earth, and the positive pole to the trolley wire; and that the telephone cable passes through the territory in such a way that one part of it is nearer the power station than the other. Indeed, it is not essential that this condition exist, because, due to the existence of other pipes and to natural conditions of the earth, a cable may be laid in such a way as to be always equally distant from the power station, and yet be subjected to the carrying of return current, because it passes through regions having different potentials with relation to the power station and, therefore, to each other. It is evident that, in a condition such as is shown in Fig. 648, no destruction of the cable sheath would take place at the point where current enters, near the ends of the portion shown, but that its sheath would be attacked in a greater or less degree at a point nearer the power station where the current is indicated as leaving the sheath.

An idea of the relative conditions of this destruction may be gained from the statement that a few volts difference of potential between two points of the cable sheath will cause a large current to flow therein, the resistance of the sheath being so very low. The

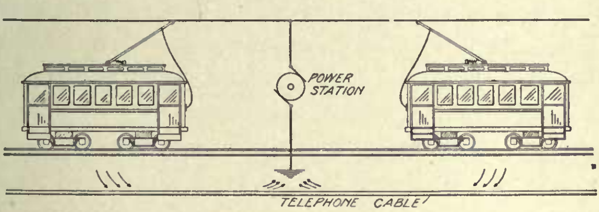


Fig. 648. Conditions Causing Electrolysis

destruction at the point where the current leaves it can be accomplished with a difference of potential between the sheath and the surrounding earth of less than one volt. In many cities there are differences of potential between different parts of the city of as high as twenty volts.

Remedies. As it has been accepted that single-trolley systems may be used and that differences of potential between points in cities must be expected, the prevention of cable-sheath damage must evidently come from work done upon the cable system itself. If the cable sheaths could be of some non-conducting material; or if the cables could be carried in dry and non-conducting underground pipes; or if the current entering the cables might be carried by their sheaths and caused to leave at a point where there was no moisture contact; or if some easily renewable metallic mass could be attached to the cable at each point where it has had a tendency to be destroyed, the problem might be considered solved.

Insulating Joints. It has not been found possible at all as yet to enclose the cable wires in anything but a metal sheath; nor is it generally feasible to occasionally insert insulating joints in the cable sheaths, which, while they seal the core satisfactorily, interrupt the continuity of the metal sheath. This remedy is being used with apparent success in a few places, and if it proves that it may be applied with practical certainty as to the tightness of the joints, it should result in at least a very considerable reduction of electrolytic hazard.

Moisture-Proof Conduits. To enclose cables having continuous metal sheaths in wholly dry and insulating conduits has been the fond dream of manufacturers and constructors, but so far as proof has been given, it is yet unrealized. Conduit material of paper or other fiber, saturated with asphaltic or bituminous compounds, may be presumed to be of better insulating character than clay-conduit material; but when in the earth, exposed at manholes, it has not been shown that a conduit system of this kind really and completely protects the cables from electrolytic damage.

Bonding. To attach to the cable sheaths at danger points some metal intended to be destroyed, is a precaution which is a practical one, with the simple objection that such an attached mass will itself be destroyed in time and will require replacing. The ideal cure is, of course, one which is applied once for all.

In general, the method that is employed is to provide dry metallic paths over which the current may flow from sheaths tending to be positive to other things, instead of flowing from them through moisture. Its application is called "bonding," as metallic bonds are provided as substitutes for moisture paths. This is the method that survives in general practice.

Two steps are required in applying a system of cable bonding: First, determine the areas of the city in which bonds are needed, and second, apply them and test the result. The first is done by a system of observations to determine the amount and the sign of the potential of each cable to the surrounding earth and things in it and on it. These things are, for example, the near-by rails of the traction system, water pipes, gas pipes, and other cables. It is convenient to record these observations on maps. Usually the cables in a region surrounding each power station of the traction system will be found positive to the negative bus-bar of that power station. Outside this critical area surrounding each power station, the cables usually will be found negative to the rails and to other conductors in their neighborhood.

Cables so negative are not in danger of corrosion, but cables which are positive are in danger of corrosion. Guided by the map record, copper bonds are attached to the cable sheaths at one end and

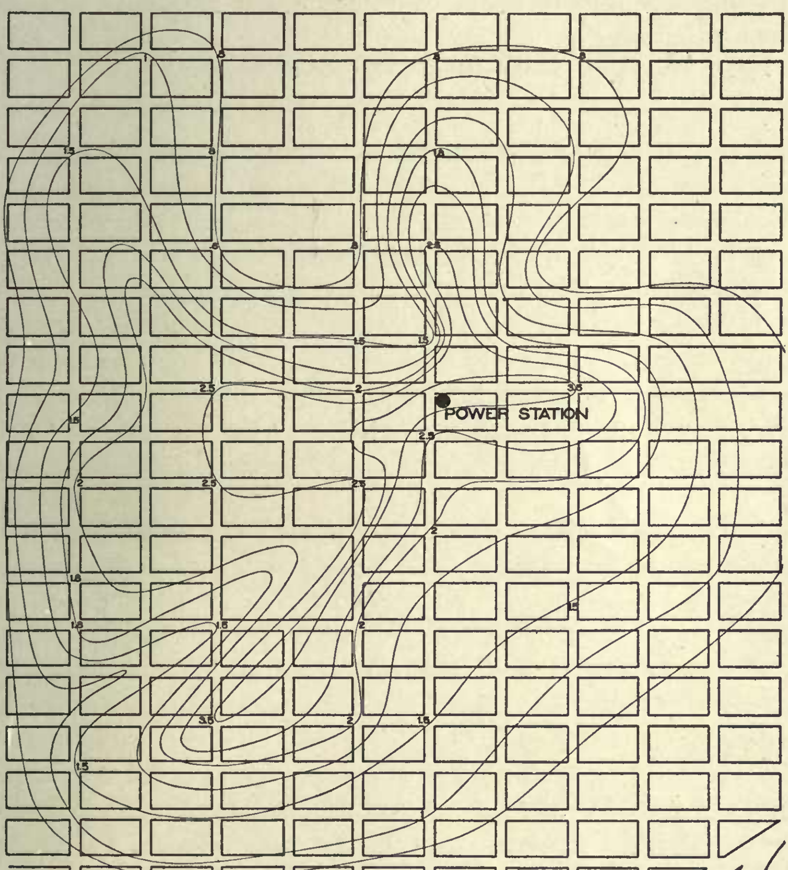


Fig. 649. Potential Map Surrounding Power Station

at the other to the negative bus-bar of the station or to something leading to it. Many traction companies use negative feeders to supplement their rails, as well as positive feeders to supplement their trolley wires. These negative feeders, therefore are admirable circuits to which to carry cable bonds. Bonding to the rails themselves is less likely to be permanently useful.

Fig. 649 is a map of a portion of a city in which lines join the points of equal cable potential and of similar sign. If copper enough be used in bonds between the cables of this area and the negative bus-bar of the power station of this area, these danger-indicating potentials may be reduced within negligible limits. A regular system of re-inspection and re-arrangement is imperative to keep them so.

CHAPTER LI

DEVELOPMENT STUDIES

A development study is an examination of the physical, commercial, and social conditions of a region to determine its present and future need of telephone service. Consciously or otherwise, a development study always is made before the construction of a new telephone system or part of a system. This study may be very simple, confining itself merely to a forecast as to how many telephones shall be arranged for at the time a very small switchboard, or even a single telephone, is placed in a village. Or the study may be very elaborate, as in the case of an entire reconstruction of the central offices, the equipments, and the wire plant of a large exchange covering many districts.

Long-Distance or Toll Line. Development studies address themselves to determining telephonic needs in and between cities and towns. The building of a long-distance line between two points, known to have little communication with each other because of small population and little mutual interest, might be assumed to be so simple a matter as not to warrant an investigation deserving the name "development study." No one would build such a line, however, without giving *some* thought as to whether one or two circuits should be erected at the outset. No one should build such a line without giving some thought as to whether the number of circuits to be required at a future time will be few or many. For if the general growth of the region should indicate that forty or fifty pairs of wires would be needed on that line during the life of the poles, good judgment would indicate that the poles chosen should be large enough and heavy enough to carry that many pairs. If it were obvious at the outset that the pole line never would need to carry more than three or four pairs within its life of twelve to fifteen years, it would be unwise to use heavy poles.

Long-distance development studies, therefore, are seen to address themselves largely to the amount of traffic which may be expected to develop in the future and to undertake to make such forecasts as will enable a conclusion to be reached as to the type of construction most economical for the case. If a development study in some form be not made, or if incorrect conclusions be drawn, the line may be built too light and have to be supplemented or rebuilt while its poles are still good; if it be built too heavy, it will carry throughout its life a greater investment than its earning warrants. A money loss occurs in both cases. Development studies are intended to limit these money losses as much as possible.

Exchange. If one should say: "Here is a town of one thousand inhabitants; let us install one hundred and twenty-five telephones, which will just about meet present needs," he would have made a development study. If the estimate should prove to be correct, he would have made a development study with little labor and at low cost. If the nature of the town should be that seventy-five telephones were all it could support at the outset, the development study would have been too sanguine, and its carrying-out too costly.

The construction and reconstruction of exchanges in cities over about twenty-five thousand inhabitants involves investments large enough to warrant the expense for painstaking care in examining the conditions as they are, forecasting conditions as they will be, and reaching conclusions from both. Experience in such study is increasing the knowledge and skill in the forecasting required. That phase of telephone engineering today has reached as high a development and those practicing it are as dextrous as are found in transportation and other forms of public service.

Scope of Study. An exchange development study undertakes first to determine what will be the population of the city at some selected future time; the distribution of that population over the area of the city; how many telephones it will require; where they will be located; how much traffic they will originate, and how much and what kind of wire plant, equipment, and housing will be necessary to handle that traffic.

The future date for which population, telephones, and traffic are to be forecasted usually is fifteen or twenty years from the time of the study. The further ahead the forecasting is done, the less accurate it will be. The intention is to have the time long enough to include the useful life of much of the property.

Estimates of future population are made by determining what the population has been during the past. In the United States and Canada, this is easier in the East than in the West, because the cities are older, have more recorded data, and also because they now grow more steadily.

Ratio of Telephones to Population. The ratio of the number of telephones to the population may be determined from the history of the exchange as it exists, although few elaborate development studies are made in cities having no telephones whatever. Notwithstanding the fact that the ratio of telephones to population has been increasing in most cities, a forecast may be made to estimate what that ratio will be at a future time. The product of this ratio and the estimated population will give at once a forecast of the telephones which may be expected at the future date.

House Count. Setting aside this general forecast for later reference, a "house count" is undertaken. A house count is, as its name implies, a count of the buildings in a city and is accompanied by an estimate of the telephone-using ability of the occupants. As the city is canvassed, the estimators determine, block by block, not only the character of the present population, but the probable tendency of the future population, its amount, and its distribution. As the study is made, it is customary to enter on a map, figures denoting the present possibilities, those in five years, and those in fifteen or twenty years.

Ratio of Telephones to Buildings. In residence areas of the best class, it is estimated that each residence will have one telephone at the ultimate time. In residence areas of other classes, some fraction of a telephone per residence is estimated. In business areas the sizes of office buildings are recorded and an estimate of future telephones is made from the probable number of ultimate offices. The ability of offices, hotels, and apartment houses to utilize private exchanges is estimated upon.

Comparison of Estimates. The result of a house count is an estimate of the ultimate telephones, and this now may be compared with the first estimate, which was the product of the forecast of the population and the ratio of telephones. It is likely that the two estimates will not agree. If they are widely at variance, one or the other may be re-studied until they harmonize. When the two estimates have been harmonized, the house-count record is taken as the distribution of telephones for which the future plant is to be designed. The first step is to determine the proper number of office districts and central offices within them.

Single-Office District. In manual practice, one central office usually is chosen for reasonably compact cities requiring under ten thousand lines at the ultimate time. By "ultimate time" is meant fifteen or twenty years hence or other term, depending on the chosen period of study. Ten thousand lines can be handled in a single multiple board without undue smallness of jacks and plugs.

If the city, or a part of it, has very great congestion, two or more ten-thousand-line manual switchboards may be placed in a single office. These conditions are unusual and are less likely to be found in America than in other countries.

Single vs. Multi-Office Districts. The greater the number of central offices in a city, the smaller the total length of subscribers' lines. For example, a city having ten thousand lines centering in a single office might have such an area as to make the average length of line two miles; this will require a total of twenty thousand miles of subscribers' lines, if these all are carried to a central office. If the city were divided into fifty districts of two hundred lines each, the average length of line might be one-tenth mile, requiring only one thousand miles of subscribers' lines. So far as subscribers' lines are concerned, therefore, the subdivision of the city into fifty districts instead of one has saved ninety-five per cent of wire.

But it is necessary to interconnect the fifty offices by means of trunk lines, and two kinds of circumstances determine whether these trunk lines will require much or little of the wire which has been saved from subscribers' lines by making so many districts—(1) the amount of traffic originated by the subscribers and requiring to be carried by the trunks; (2) the topographic form of the area of the city. In almost all practical cases, the more office districts there are, the fewer total miles of wire will be required for both subscribers' lines and trunks, because trunks *can* carry so many more messages than subscribers' lines *do* carry.

Multi-Office Districts. With any arrangement of offices, where there are more than one, the number of trunk lines varies directly as the number of calls originated by the subscribers. While the variation is direct, the ratio of originating calls to trunk lines is not, of course, a fixed one. As was shown in the chapter on Telephone Traffic, the call-carrying ability of trunks varies with the number of trunks in a group; the number of calls trunked out of an office depends partly on its size relative to the total number of lines in the city and partly on considerations local to the district of that office. The greater the number of offices in the city, therefore, the larger the proportion of calls trunked out of each and the greater the number of trunks which must be provided. For both reasons, the greater the saving in subscribers' lines by increasing the number of districts, the greater the cost of trunk lines.

The cost of maintaining, operating, and supervising manual equipments is greater with many offices than with few, the number of lines served being the same. The increase of cost, of maintenance, and of operation is less rapid with automatic equipment when the number of offices is increased.

Number of Office Districts. The operation of determining the proper number of central-office districts for a city is experimental. It is usually done by plotting the distribution of ultimate telephones on a map, arbitrarily dividing the city into districts, and successively comparing the arrangements with each other as to investment costs (*first costs*) and costs of owning, maintaining, and using the several arrangements (*annual costs*).

As the number of districts is increased in this experimental study, the first costs of subscribers' and trunk lines fall. Very likely this will be found to be true of first costs of manual equipment also, due to the lessening of the number of multiple jacks required. Costs of power plants and other things which vary with the number of offices will tend to increase equipment costs. When several arrangements with different numbers of districts have been made, one of them will be found to have the lowest annual cost when all elements of interest on investment and costs of operating and maintaining are included. Perhaps this lowest annual cost will be for one office rather than for several. If two arrangements of different numbers of districts are equal in annual costs, the one having the lower first cost shall be chosen because of that hazard of changing styles which is of such strong influence in telephony.

Central-Office Locations. The most economical district arrangement having been determined, a point is located in each district where the least wire will be required for the lines. Taking as an example a rectangular district in which the ultimate telephones are evenly distributed, the proper office location for the least wire would be at the crossing of the diagonals of the rectangle.

But districts are likely not to be rectangular in shape, and it is also probable that the ultimate telephones will not be uniformly distributed; hence this simple method of determining the ideal place for the central office is usually not feasible. For irregular shapes and developments of districts the ideal location for the central office is determined by dividing the district by two straight lines at right angles with each other in such manner that each line will bisect the total number of stations to be reached. The intersection of the two lines so placed is the ideal location in that it results in the minimum amount of wire. In such a determination trunk lines leading to other offices should be given the same weight as so many subscribers' stations.

It is not always possible to locate the central office at the ideal district center for greatest wire economy—for the excessive cost of property at the center might more than overbalance the added wire cost involved in having the central office elsewhere. The principal purpose of development studies is to teach one how to decide just such questions. It is obvious that when the study has shown where the central office *should* be, the next step is to learn where it *can* be, and to lay out the conduit plan and other details of the distributing system in harmony with the possible central-office position.

Conduit and Pole-Line Routes. Central-office locations being determined for each district, conduit routes are laid out. Speaking generally, it is good practice to provide a main or "backbone" conduit passing the determined central-office point, this main run having cross-routes extending from it at right angles. A good plan is to run these cross-routes on each alternate street, causing them to follow alleys if alleys exist. The cross-section of each conduit run is then determined from the house-count map, providing ducts enough in each run to accommodate the ultimate subscribers' lines to the central office, allowing also for trunk lines and such extra ducts as may be required for municipal purposes. In practice it is found that conduits of many ducts will accommodate more wires per duct in the average than conduits of fewer ducts; and in forecasting the number of ducts a conduit requires, more allowance has to be made for possible error in estimating the smaller runs.

Pole lines then are laid out in the area which surrounds the underground district. Distribution from conduits within the underground district is laid out to fit the local requirements, whether they call for direct entrances into buildings, distribution from terminals on back walls and fences, or distribution from poles in alleys or on private property within the blocks.

Ultimate Sizes. Central-office buildings and conduits when originally built usually should be of their ultimate sizes. It is generally not economical to add stories to a central-office building, although in some very large cities, where enormous development is expected and where real-estate values are high, the buildings are sometimes planned with foundations and walls of sufficient strength to sustain additional stories in the future. In cities of ordinary size, it may be economical to provide for extending the ground area of the central-office building, but it is not economical to reopen a conduit line in order to increase its numbers of ducts. When a conduit line is filled, it is often best to lay its relief ducts in the next parallel street.

A cable plan, made consequent to the completion of the conduit and pole-line plans, undertakes to show the general arrangement of ultimate cables and the exact arrangement of immediate cables. It is of advantage to utilize a definite system of multiple-cable distribution. One of the basic principles of such a system is that it undertakes to cause the number of wires leaving a central office to grow steadily as the wire requirements grow, while the terminal facilities of those wires are more generous at the outset and grow less rapidly.

As a practical example of what is meant, four thousand wires might leave a central office and by branching appear in twelve thousand terminal building posts or soldering clips. These twelve thousand available points could receive drop wires or back-wall wires or be connected by jumpers to cables in buildings. As the requirements of the district increase, additional wires will be run from the central offices, but most of them will be joined to the existing twelve thousand terminal points. Under ideal conditions no increase in the terminal points might be required during all the time when the four thousand wires were increasing to twelve thousand wires. At the latter time, in such a case, there would be no longer any multiple distribution, each wire from the central office going to one, and only one, terminal binding post.

Subdivision of Exchange Districts. In automatic practice it is becoming possible to furnish an acceptable telephone service with two kinds of districting in the same exchange. Assume a city to be divided into certain major districts, each containing a central office and a full complement of selector switches. Assume each of these major districts to be divided into a further number of minor districts, each containing merely individual line switches and connector switches. Each subscriber's line, with this arrangement, will have a district-office line switch. This line switch will have access to a plurality of trunks leading to the major office, terminating therein in a first selector. All second or third selectors, as the case may be, in major offices will have trunks leading to connectors in the minor offices.

By this arrangement practically all power-plant devices are located in the major offices. The smaller the minor districts, the shorter the average length of subscribers' lines will be, and the more minor districts the greater the trunk mileage leading from minor to major centers. Unless the character of the apparatus makes it require too much human attention, the saving in wire plant by this method will more than overcome the expenses which are added by the greater subdivision.

Broadly speaking, there is no reason why this major- and minor-district method is not applicable to manual practice. A full utilization of the economics of minor districting, however, requires that some automatic apparatus supplement the manual apparatus. The minor district centers, in such an arrangement, will have some counterpart of line switches and connectors; the major centers may contain manual switchboards which will make connections between lines as at present, but all the lines will be trunks.

Undoubtedly one of the most promising fields of development now offered to the telephone engineer is in the greater use of this sub-district plan of working and in the devising of systems of switching and operating adapted fully to harmonize therewith.

CHAPTER LII

CARE OF PLANT

Maintenance and Depreciation. Whatever be the cost or the value of a telephone property at the outset, its value at a later time depends on the care which is given to it as well as on the extent and kind of additions which are made to it. Circumstances may determine that the additions may be slight. Age affects inanimate telephone property as surely as it affects life. Economy and effectiveness in the care of a plant constitute the largest technical task in the management of a growing telephone system.

No element or general division of a telephone plant ever is as good again as it was on the day it was put into service. Each thing has some useful life; it may wear out, break, or be destroyed by accident, or it may lose its relative usefulness by the invention of something better. The economic loss due to the changing of styles in the art of telephony has been enormous. Viewing the art broadly, and particularly the ultimate good of the telephone-using public, most of the sacrifices in value by the adoption of newer and better things and methods have been warranted.

No amount of expenditure in maintenance charges can ever keep things new. One plan of maintenance may be so comprehensive and so exhaustive as nearly to do that, yet it may cost so much as to be most unwise to use. Another plan or way of executing a plan may spend too little and bring sections of the property too soon to their time of required replacement. The problems of deciding upon and carrying into effect wise methods of plant-care are as grave as those of good design, construction, and management.

Maintenance expense, properly viewed, is a cost for keeping property in as nearly as may be its original condition without replacement or reconstruction. The term "current repair" expresses the same thought. When a property has been maintained—kept in a proper state of repair for a certain length of time—its condition becomes such that economy requires making it over or putting something else in its place. These acts are respectively reconstruction and replacement. Neither is at all the same as maintenance or current repair.

The reason a property is replaced or reconstructed is because it has lessened in usefulness to a critical degree and a more useful or usable property needs to be put in its place or needs to be made out of it. "Lessening in value" is only another way of saying "depreciation." Speaking broadly, all telephone properties except real estate depreciate in value as time passes. The price of copper may advance, yet copper wire in use in lines usually depreciates in value as time passes. Insulated, outdoor copper wire depreciates in value steadily from the time of its erection, principally because rubber insulating materials and cotton braids are destroyed by the actions of air, sunlight, and moisture. Wood poles may last fifteen or twenty years before requiring to be replaced by others. When so replaced, those which have rotted at their lower ends may be cut off and used again. Such expense as was required to keep the poles in serviceable condition before replacement is maintenance cost. Such expense as was required to replace them, less the value of the poles replaced, is replacement cost. The shrinking in values of properties generally, due to the passage of time, is a depreciation expense. The cost of keeping them in usable condition while they shrink in value by the passage of time is a maintenance expense.

The hazards which passing time brings to bear upon telephone properties are principally those of decay, wear, and adjustment. Good design and construction limit these actions. Good maintenance practice repairs damage caused by decay, replaces parts made inefficient by wear, and restores adjustment.

The quality of telephone service is intimately connected with maintenance methods and maintenance costs. When an element needs repair it should be repaired so as to stay so and with as short a service-interruption as possible. The fundamental rules of maintenance are: *Be thorough* and *Be prompt.*

Thoroughness of understanding begets thoroughness of execution; knowledge of the functions (and reasons for functions) of apparatus and circuits begets a love of workmanlike handicraft. Workmanlike repair endures; slovenly repair has to be done over.

The largest reason for telephone service is time-saving. Multiple and automatic switchboards are the outcome of effort toward promptness in getting lines connected and disconnected. Promptness in restoring service is of as great importance as promptness in giving it.

The following are some general kinds of troubles and their remedies.

Outside Plant. *Supports.* Pole lines suffer principally by decay of pole butts; decay of cross-arms; gnawing of poles by horses; abrasion of poles by wheel-hubs; corrosion of anchors by electrolysis and by rust; and, in general, supports suffer by accidents. The preventive measures are creosoting; strip guards against gnawing, plate guards against wheels; strain insulators against electrolysis and good galvanizing against rust. Corrective measures are obvious.

Conduits. Underground structures suffer principally from the work of others than the owners. The most effective maintenance measure is watchfulness, seconded by prompt support of conduit lines undermined by excavation. Keep idle ducts plugged; if otherwise, sand, soil, and small stones will wash in. Watch manhole covers. Replace broken ones promptly. Clean out scrap left after cable splicing. It has value, and is a hazard if left in.

Open Wire. Bare wires on insulators suffer principally from two causes: slack and foliage. Slack wires cross with each other by wind. The tension on all wires of a span should be uniform. This lessens likelihood of crossing. The allowable tension is controlled by the temperatures of the region. Wires in foliage have low insulation, making their lines noisy and otherwise less efficient. Trim the trees, insulate those spans, or put the wires in cables. Open wires suffer from grounding by contact with suspension strand and guys. Clear such troubles by *permanent* measures. Twin drop wires (twisted pairs) under heavy strain, where wires overlie at supports, cut through rubber insulation and short-circuit the pair. Clear the cause by placing the wires side by side at such points of support.

Cables. Aërial cables suffer from punctures, bullets, beetle-borings, burns, and cracking. Such openings in the sheaths let in water from the air or from rain. Water destroys the insulating quality of the paper wrapping of the wires. Such a fault is called a "wet cross." It is repaired by stripping off the sheath as far as the core is wet, pouring on melted paraffin till it flows off without bubbling, and putting on a lead sleeve, split lengthwise to allow it to be placed over the uncut core. The split is soldered up and the ends wiped to the cable sheath.

Preventive measures are few. Arrange aërial cables so they do not bend and unbend by change of temperature, or by swaying. Do not place them where they will be subject to vibration. Be sure cables are firmly supported where they enter terminals. Keep them clear of contact with power circuits. Limit the flow of earth currents over them.

Underground cables are subject to the same "wet cross" troubles when sheaths are damaged. They are less exposed to punctures and flexures. They are more exposed to electrolytic corrosion. Keep them so connected to traction systems of distribution that little such current *leaves* them in the presence of moisture. Make and remake observations on these conditions. Change the corrective means as the conditions change. Watch the sheaths in danger areas. Support the cables in workmanlike fashion in manholes. Let each splice be freely accessible. Keep inflammable things out of cable shafts, vaults, and runways.

Subscribers' Equipment. In wall sets, receiver cords are the perishable element. Test them at every visit. In common-battery sets having magneto receivers in a wholly local induction-coil circuit, an open receiver cord means the subscriber can be heard but can not hear. In most other circuits, it means impairment or prevention of both hearing and talking. In portable sets, broken transmitter mouthpieces and receiver shells are chief troubles. Replace them promptly, look for unusual causes of falling of the set, and advise a suitable support. Inspect other things at every such visit. Recommend change of entire set when its appearance is such that you feel that *you* should have a new one if it were in *your* premises. But perhaps you could clean it somewhat and make a change unnecessary. The most practical sanitary mouthpiece is an ordinary one, frequently washed with soap and water. A patron often copies so good a habit. Clean carbon arresters on suspicion, understand thoroughly the proper functions and relations of the telephone set, and the rules of repair *always* will be obvious.

Manual Office Equipment. Cords are a source of trouble in central offices, as in subscribers' sets. Test them regularly. Tinsel cords become "scratchy" by breaking gradually; wire and metal-ribbon cords break abruptly. Breaks in a switchboard cord usually occur near the plug. Cut off the defective end and refit the plug.

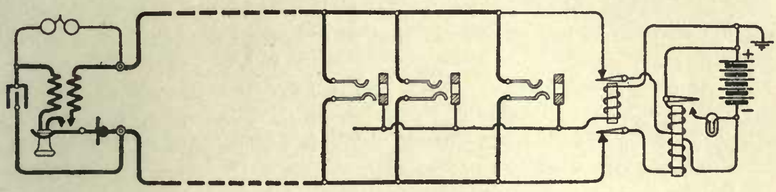


Fig. 650. Relay Multiple-Board Line Circuit

Put a good cord in place of a defective one, repair the latter ready for use, and keep up the process. The key shelf of a switchboard is the operator's workbench. It is not a repair shop. Use good tools and keep them in order.

Manual and automatic central-office equipments are growing more alike in their fundamental circuits. Understand them. All troubles are consequences of causes. Know the causes.

Because of its wide use, and because it is typical of all manual switchboards, the American Telephone and Telegraph Company's

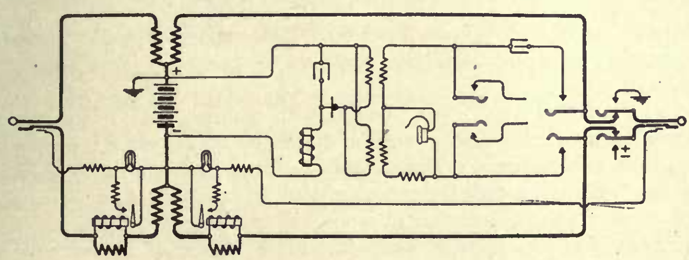


Fig. 651. Relay Multiple-Board Cord Circuit

multiple equipment is shown in Figs. 650 and 651. Some of the principal troubles and remedies follow. A study of the circuits in figure and in fact will be of more value to the student than reading many chapters in a book. In the cases of trouble, the causes given are several in each instance. Any one of them *may* be the cause. The tests are to show which *is* the cause.

Line lamp does not glow when subscriber calls. Lamp burnt out. Lamp terminals do not make contact with lamp socket springs. Line-relay lamp contact does not close. Line relay defective. Line is open. Test the line at the main distributing frame, determining whether the trouble is in or out. Test line relay. Examine lamp and socket.

Line lamp does not go out when operator answers. Cut-off relay defective; contacts of cut-off relay do not open. Test-strand of answering cord is open, failing to operate cut-off relay. Try several cords. Examine the common path for current to test-strands of that switchboard position. Test cut-off relay.

Line lamp glows steadily, though the subscriber is not calling. Line is short-circuited. Negative side of line is grounded. Line relay is out of adjustment, closing lamp circuit though relay is not energized. Test the line in and out at main distributing frame.

Line lamp glows when subscriber calls but operator can not hear subscriber. Defective subscriber's set; receiver cord broken; defective receiver. Answering jack defective; wiring to answering jack open. Try answering in multiple. If successful, answering jack trouble is proved. If unsuccessful in multiple, test from main distributing frame.

Line lamp glows when subscriber is being called. Line relay is not cut off because test-strand of calling cord is open; or supervisory lamp of calling cord is open; or cut-off relay is defective.

Supervisory lamp of calling cord does not glow when calling plug is inserted. Line in use, busy test absent or ignored. Line is short-circuited or negative wire grounded. Supervisory lamp of calling cord defective. Supervisory relay of calling cord has contact closed though relay is not energized. Try other cords. Test line.

Line tests busy when it is not busy. Improper local or foreign potential on test wire, giving differences of potential between test rings and plug tips Test wire is crossed.

Line does not test busy when it is busy. Test wire grounded. Test-strand of cord open at position where line is in use. Supervisory lamp open at that position.

Line open in multiple. Test the line with regular cords; begin at section nearest main distributing frame; normal operation ceases when the open point is passed. To test for open without using the line, bridge a receiver in series with battery between successive points of wire in trouble. Clicks will not be heard when open point is included in series with receiver and battery.

Line or test wires crossed in multiple. Place tone or clicks on the crossed wires so the cross will shunt the interrupted current. Bridge a receiver across the crossed wires at different points. Sound will be heard *least plainly* nearest the cross. Watch for solder, wire clippings, and bent terminals in jacks.

Operator can not ring. Trouble in ringing current supply or in ringing branch to operator's position, because it is open, short-circuited, or grounded.

Operator can not hear or speak. Defective receiver cord, transmitter cord, plug, or jack of operator's set. Listening key troubles. If confined to one cord circuit, the latter. If common to all, the former.

Permanent signals. This is a colloquial term given to the condition where the line lamp glows even though the subscriber is not calling. As the subscriber's call is shown by the lighting of the lamp, he can not call if current enough is passing through his line relay to hold it closed. Permanent signals may show when the line is otherwise operative, that is, a subscriber may be called and may talk, though his line may be short-circuited through a resistance low enough to operate the line relay.

In such cases, partial service may be given by transferring the line to a hospital board or other arrangement having a relay with a lamp on its back contact, which lamp will light when the trouble is cleared, thus advising that the line may be restored to service on the multiple board. Calls for lines so in trouble may be referred to positions so equipped and such calls often can be completed when they would fail if handled in the regular manner.

Automatic Systems. Systems of the Automatic Electric Company vary in nature. Those requiring successive contacts between the line wires and ground in order to operate selectors and connectors are called *three-wire systems.* Those requiring successive makes and breaks in the line to operate selectors and connectors are called *two-wire systems.* No ground connections at subscribers' stations are required in the two-wire systems.

In early types of automatic systems, each subscriber's line is connected permanently to an individual first selector. Second and third selectors and connectors are common devices, being chosen for use when required. In later types of automatic systems, individual line switches less elaborate than first selectors are permanently connected to subscribers' lines, and selectors and connectors are chosen when required. All selectors and connectors of the Automatic Electric Company's systems, either two-wire or three-wire, with or without individual line switches, are of one general type as to mechanical motions. In all of them the connection between the calling and called portions of the line is made by metal wipers (seeking contact-pieces), which pass over sets of punchings (waiting contact-pieces), stopping on a desired or an available set.

The mechanical motions of selectors and connectors are two: vertical and rotary. The wipers make no connection with contacts during vertical motions; they sweep over contacts during rotary motions. Most selectors and connectors change their functions several times during a set of operations of connecting and releasing. These changes principally are caused by motions of a side switch or its equivalent. A side switch is a device adapted to repeal one set of electrical conditions and establish another. Each position of a side switch represents the conditions of one particular set of functions.

Wipers carried by the shaft of a selector or connector are either four or six in number. Always they represent three conductors.

The analogy is close between line circuits in automatic systems and in multiple manual systems. Each has two line wires and a test wire. The latter in automatic systems is called the *private wire* and like the test wire in manual systems, it is local to the office. Its principal duty is to guard a line in use against intrusion by another line calling it. In some automatic systems it is called a *guard wire.* The bank of private (guard, test) wires usually is mounted above the bank or banks of line wires. Line wires may be in one bank of 100 pairs or two banks of 50 pairs each.

Opens, crosses, and grounds in automatic multiples may be tested for the same as in manual multiples. These problems usually are simpler in automatic systems, as the multiples are limited to 100 lines (300 wires).

Selector and connector switches require their shafts to be kept clean and lubricated. Wipers are required to be kept adjusted so as to engage and disengage contacts freely. Side switches require adjustment tight enough to ensure good contacts in each position, yet weak enough to move freely; these two requirements being opposed, a compromise is necessary. Better side switches or equivalents would avoid this compromise. Fine graphite on side switches is a great help and causes no trouble.

Automatic equipments require that switches be kept *warm, dry,* and *clean.* If the switches be cooler than the air around them, they will condense water from the air for the same reason that dew forms Moist switches operate less freely than dry ones. Freedom from dust is essential in all telephone equipment.

Soldering. Soldering is the most important handicraft of the telephone repairman. The first rule in using soldering tools is that the tip of the copper, or "iron" as it is called, shall be kept clean and well tinned. By the latter is meant that the surface of the copper shall be kept evenly coated with solder thoroughly united with it. Good work is impossible unless this tinning exists, and it cannot exist unless the iron be kept reasonably smooth and free from corroded spots. From time to time the iron must be dressed up by filing, and occasionally during use should either be dipped in sal ammoniac solution for an instant or wiped on a pad of cotton waste which is saturated wtih sal ammoniac solution. This tends to clean off the copper oxides which gather on the metal and thus "insulate" it from tinning. The copper must be hot when dipped in or wiped on the sal ammoniac solution, and there should be some solder on the iron at the time; it will be found to spread easily, with a little rubbing, all over the surface of the tip.

With a clean, hot copper it is easy to solder together two pieces of metal already coated with solder, unless they be so large that they cannot be well heated by the copper. If both parts are tinned or coated with solder, then the only flux required to make the applied solder flow is rosin, and in telephone work most soldering is done with solder already provided with powdered rosin in it. Good results cannot be expected in soldering untinned metals together with rosin only, so that it is unwise to use untinned copper wire in connection with switchboard apparatus. The reason for using no other flux than rosin about apparatus is that none has been discovered which will serve its purpose as a soldering flux and leave the insulating parts in any sufficient state of insulating quality after the work is done. Many fluxes also tend to corrode the wires and apparatus parts after the soldering has been done.

The code of the National Board of Fire Underwriters specifies a flux composed of chloride of zinc, alcohol, glycerine, and water. This is a good material for soldering untinned surfaces, as it is easily applied and remains in place, causes the solder to flow freely, and is not the most corrosive of chemical fluxes after the soldering is done. But useful as this flux may be in such work as mending tinware and patching up mechanical devices, it is *absolutely to be prohibited* in the soldering of conductors to each other and to apparatus in telephone systems. Equal condemnation must be given to all forms of *paste* and *soldering sticks,* none of which is more suitable in these particulars than is the chloride of zinc solution.

If parts of apparatus can be soldered together and then washed before assembling, there is no more hurtfulness in using acid or alkaline soldering fluxes than in the use of chemical solutions in the process of plating. But one must appreciate exactness of division between a rosin flux on the one hand, and all other fluxes on the other, as being suitable and unsuitable, respectively, for use in soldering conductors in the assembling and repairing of telephone apparatus.

CHAPTER LIII

TESTING

Electrical tests are used to determine the qualities of working lines and apparatus, the same fundamental principles being applied also to the latter during the process of manufacture.

Implements. Tests of lines are made by voltmeters and galvanometers. In both, one magnetic field is created by the current and another by a permanent magnet. In the D'Arsonval galvanometer and in the commercial direct-current voltmeters of the same type a suspended or pivoted coil moves in the field of a permanent magnet. In the Thomson type of galvanometer, however, a suspended permanent magnet moves in the field of a coil. In all three cases, the current in the coil moves an index pointer which, in voltmeters, is a flattened aluminum wire, while in galvanometers, it is such a flattened aluminum wire or it is a beam of light reflected upon a scale or into a telescope. Voltmeters have scales graduated in volts and fractions of volts while galvanometers have scales arbitrarily graduated.

Although magnetic voltmeters do not measure true differences of potential, they do measure currents. But currents are consequences of differences of potential, so a magnetic voltmeter measures volts within close limits of error if the resistance of the voltmeter coil is high, relative to the resistance of the circuit external to it. Electrostatic voltmeters measure true differences of potential, but they are not commercial for low pressures.

Faults. Voltmeter tests of telephone lines cover all necessary measurements except accurate *location* of faults, and tests for acceptance of cables and line materials. They are adapted for the use of the wire chief of an office, as they are more rapid than galvanometer tests. Wire chief's tests cover:

Insulation resistance (grounds)
Continuity (breaks; opens)
Crosses

Conductor resistance
Discharge capacity
Foreign currents (earth potentials)
Talking, ringing, and adjustments

These tests usually are made from the wire chief's desk, which has voltmeter, relay, sounder, and key circuits, and, in automatic equipments, has test switches for observing the performance of impulse-sending mechanisms (calling devices).

Galvanometer tests cover:

Conductor resistance
Insulation resistance
Capacity
Opens
Grounds
Crosses

The last three are "faults." Finding them is "fault location."

Continuity. Figs. 652 and 653 are tests for continuity. If the wire under test is continuous, the voltmeter will show almost the full voltage of the test battery. Consider the pair tested in Fig. 652

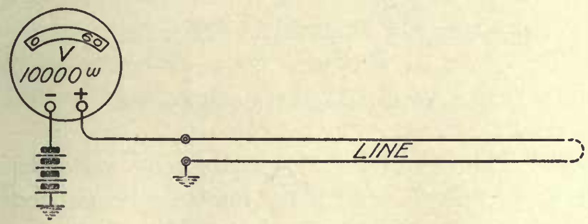


Fig. 652. Test for Continuity

to be open at the distant end; the test then is for insulation between the upper wire and all grounds. Its insulation is inversely as the deflection—high if the deflection be small, low if the deflection be large. If the deflection be half the full voltage of the test battery, the insulation of the tested wire is the same as the resistance of the voltmeter. In the case cited, if the test battery is of 60 volts, the deflection through the wire 30 volts, and the voltmeter's resistance 10,000 ohms, the insulation resistance of the wire is 10,000 ohms.

Insulation. Tests for insulation and continuity are made also by means of a relay and sounder. With a fixed voltage and adjustment of relay, the sounder of Fig. 654 will respond for insulations below a certain amount.

Foreign Potentials. Foreign potentials are read on the voltmeter by the circuit of Fig. 655. Be sure the potential to be read is

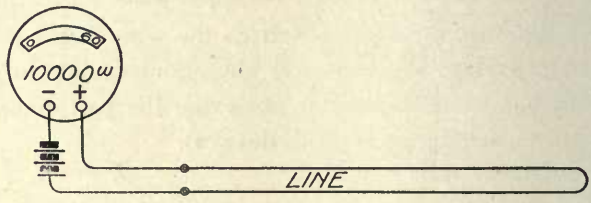


Fig. 653. Test for Continuity

not greatly in excess of the voltmeter's scale. A lamp of higher voltage is a convenient device for a first test, for if it is damaged, the

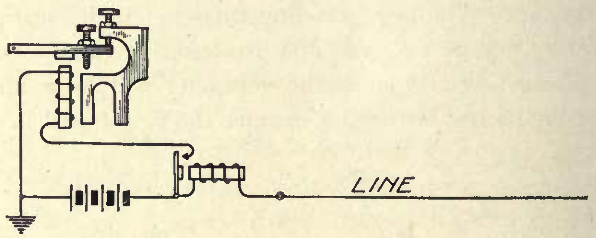


Fig. 654. Sounder Test for Insulation

loss is small. The key of Fig. 655 enables the voltmeter's connection to the line to be reversed if the foreign potential requires it.

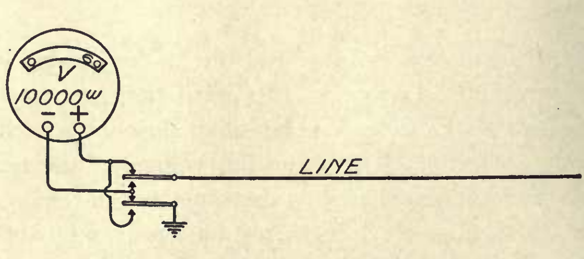


Fig. 655. Test for Foreign Potentials

Capacity. Capacities of lines usually are measured by galvanometer methods. Often it is useful, however, to check the condition of a line by taking a discharge reading on a voltmeter. The condenser in the subscriber's telephone, if the line is in good condition, will give a large deflection on the voltmeter. If the line is not in good condition, the deflection will be less. The key of Fig. 656, when depressed, allows the battery to charge the line and the condenser.

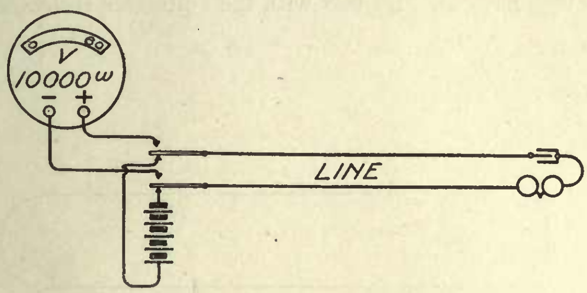


Fig. 656. Discharge Test for Capacity

When the key is released, the condenser and the line discharge through the voltmeter, the degree of deflection indicating the capacity. This method is used for measuring the capacities of condensers as they are made.

Opens. Open wires in cables may be measured in the same manner as are capacities. A good wire being available, the discharges from the open and the good wire may be compared, their lengths being as their discharges. Fig. 657 shows a simple method using

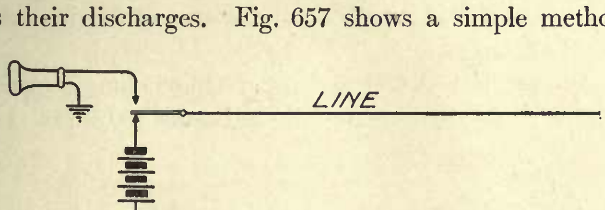


Fig. 657. Telephone Test for Capacity

a telephone receiver. The larger the capacity, the louder the click when the key is released. Expert workmen can estimate the distance to a break by this simple test.

Resistance. Resistance of a wire or loop is measurable by voltmeter methods. The process is: Read test-battery voltage E. Read voltage with line in series D, as in Fig. 658. Let R be the line resistance desired and V the voltmeter's resistance. Then

$$R = V\left(\frac{E-D}{D}\right)$$

which in words is: *Deduct voltage with line in series from full test-battery voltage; multiply this remainder by the resistance of the voltmeter; divide by the voltage with line in series. The result is the line resistance.* In Fig. 658 with the voltmeter resistance 10,000,

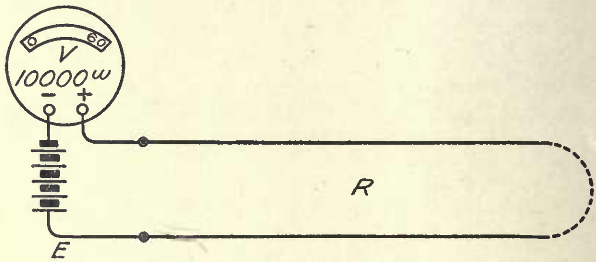


Fig. 658. Test for Resistance

consider test-battery voltage to be 60; deflection through line, 25. Then the line resistance is 14,000 ohms.

Low resistances are more accurately measured with low-resistance voltmeters. That is, it is obvious that the full test-battery voltage and that through, say, 300 ohms of line wire, would give similar deflections on a 10,000-ohm voltmeter, but when the voltmeter is shunted so as to give it an effective resistance of the desired amount, this difficulty disappears.

For example, in Fig. 659, a shunt of 416.66 ohms is placed across a 10,000-ohm meter, making the joint resistance 400 ohms. Using this

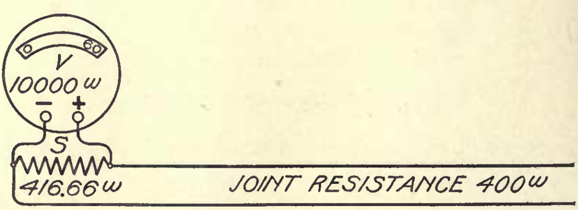


Fig. 659. Shunted Voltmeter

as in Fig. 660, a lower resistance may be measured with greater accuracy than with the unshunted instrument. Assume the test-battery deflection to be 40 and the deflection through the line to be 25; then, by the formula given, the line resistance is six-tenths of 400, or 240. With the unshunted voltmeter the deflections would have been much closer together, viz, 40 and 39.06, making the difference—.94 volt—less easy to read accurately than in the case of Fig. 660 for the same line resistance.

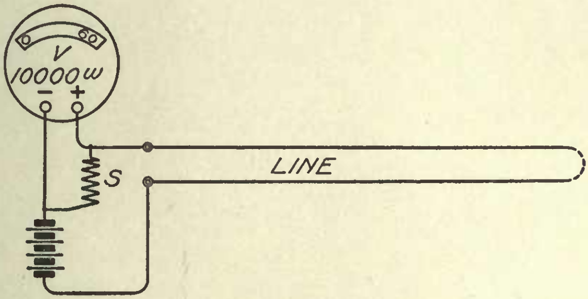


Fig. 660. Loop Resistance Test

Crosses. Tests for crosses, as in Fig. 661, are made by observing one of the suspected wires while ground (or the pole of the battery not joined to the voltmeter) is applied to the other suspected wire. If the ends of the crossed wires are in offices equipped for testing in this way, as in the case of trunks, both can measure resistance including the cross. The loop resistance of a good pair being known accurately from records or actual test, it is easy to know just where the cross lies. For instance, assume that the loop resistance of the wire is 160 ohms. One wire chief measures the loop through the cross to be 1,195 ohms; the other finds it 1,125 ohms. Each has included all the wire from his office to the cross, and the cross itself also. Each has measured a different part of the loop but the same

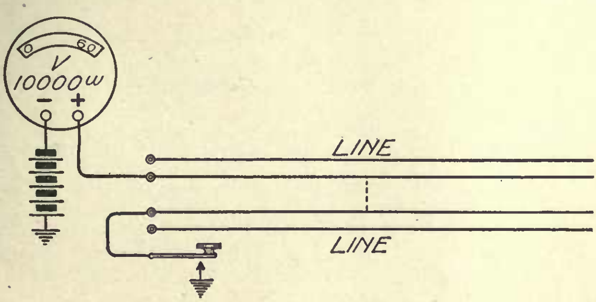


Fig. 661. Test for Cross

cross. The difference between the resistances observed by the two wire chiefs is 70 ohms. This is the difference between the two parts of the loop. The sum of the two parts is 160 ohms, for that is the known whole loop resistance. The sum being 160 and the difference 70, the two parts must be, respectively, half of (*160 plus 70*) and half of (*160 less 70*), or 115 and 45. These are the loop resistances to the cross from the two offices.

Wire-Chiefs' Desks. Facilities for the tests illustrated in Figs. 652 to 661 are combined in modern wire-chiefs' desks. The voltmeter, sounder, and telephone set, in such equipments, are associated with cords, plugs, lamps, and keys so that all the tests are available quickly.

Tone Methods. Mutual inductive action enables grounds to be located with great accuracy by means of the simple apparatus of Fig. 662. This method was first used by power companies for the loca-

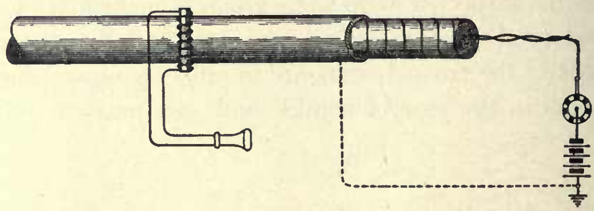


Fig. 662. Fault Location with "Jigger"

tion of such faults in underground cables. It has been re-invented in several forms for telephone purposes, marketed as a trade secret, and published by at least three persons—L. R. Hoffmann, William Maver, Jr., and Donald McNicol. The exploring device is called by many a "jigger"

The apparatus consists of two parts: a tone-producer—indicated in the figure as a commutator interrupting a battery circuit—and a receiver joined to an exploring coil. The latter is held with its turns parallel to the cable. The tone on the grounded wire can not be heard in the receiver beyond the fault, but can be heard between the fault and the end where the tone is applied.

Identification. Identifying the conductors of a cable is the kind of testing most often necessary in construction and installation. The methods are simple. In testing an aërial or underground cable for the identity of its conductors, connect the wires to the office terminal first. Identify the various groups of pairs and connect them in a recorded order. These groups are the fixed parts into which the whole number of pairs is divided, and their existence greatly simplifies the work of testing out. A telephone receiver, a buzzer, a vibrating bell, or a polarized ringer, may be used to identify the wire upon which the testing current is placed; the latter naturally should be that of a battery or generator, depending on which of the detecting devices is chosen. As pair by pair of the cable is identified, it is placed in position on the terminal to which it is to be fixed, and when a given group or the whole cable has been tested out, the whole test should be repeated rapidly to discover any error which may have crept in. In order to make the identification of pairs rapid and easy, switchboard cables are laid up of pairs in which one wire of each differs in color or marking from the rest.

Cable Testing. When an aërial or underground cable is placed in position and terminated, the tests for identifying the conductors will have shown whether any of the wires are open and whether any of them are crossed with each other. The fact that they are open or grounded on the sheath will be shown by a failure to get the testing potential from the distant end. The fact that they are crossed together will be shown in the first or final test for identification by the fact that current is received over more than one wire when it is sent from the distant end on only one. For this reason the final test should be made, running over the whole group in checking the identification of each conductor.

Cable Quality. When this part of the work has been completed, it is necessary to know whether the conductors are in good condition and whether they comply with the guarantee of the manufacturer. This guarantee, or requirement of the specifications under which the cable was made, provides that it shall have an insulation resistance not below a certain number of megohms per mile and an electrostatic capacity not above a certain fraction of a microfarad per mile. The insulation resistance per mile is simply the resistance of the insulating material, and with reference to testing and the quality of lines is often referred to as "insulation." Because it is simpler, insulation resistance is usually expressed in megohms. The insulation resistance ordinarily required by specifications and usually guaranteed by manufacturers, is 500 megohms per mile or more, and it is not difficult to make and install cables which will have much more than this degree of insulation resistance.

The method of finding out the amount of insulation resistance of a cable is, in principle, simpler than that of finding the resistance of a wire and simply involves the allowing of the current to flow through a galvanometer into the wire under test, from which it will then flow through the insulation resistance to the earth or to the cable sheath. In all the accompanying drawings of testing methods a ground is shown. It is to be understood that the sheath of the cable may be considered to be that ground in case it is the testing of cable conductors which is considered with reference to the drawing.

Thomson Galvanometer. Because the insulation resistance of cable conductors in reasonably short lengths is very high, and because the potentials to be used in testing must be kept within reasonable limits for conditions of safety, the galvanometer for insulation-resistance tests must be of high sensibility. The first successful form of high sensibility galvanometer was that designed by Lord Kelvin and was used for receiving signals over the early Atlantic cables. He changed the form of earlier galvanometers having a compass needle and a coil, by making the needle very light, suspending it by a single fiber of unspun silk, attaching a very light silvered glass mirror to the needle, and surrounding it with a large coil of very fine wire. This arrangement makes it possible for very feeble currents in the wire to move the needle and the mirror in some degree. In addition to these advantages the mirror reflected a beam of light upon a scale, thus multiplying the mirror's movement. As a beam of light so used as a pointer is always straight, as it can be of considerable length, as it has no weight, and as the angle of the mirror's movement is always doubled, the Thomson reflecting galvanometer was a remarkable step forward. It enabled things to be done which could not be done before—and this is the measure of the value of invention.

D'Arsonval Galvanometer. For two reasons the Thomson galvanometer is a particularly annoying device. The silk-fiber suspension of the mirror system is so delicate that it often is found to be broken at the critical moment of use, also the instrument is sensitive to mechanical vibration and to external magnetism. D'Arsonval reversed the arrangement of elements of the Thomson instrument, and used a light *movable* coil and a powerful *fixed* magnet. The coil can be suspended in different ways, but always by means of wires or other conductors, so that current may be carried to the coil even though it is movable. A mirror carried by the coil throws a beam of light upon a scale, or allows the use of a telescope, which is pointed at the mirror, and receives the *reflection* of a scale, usually attached to the telescope stand. The telescope forms a magnified, inverted image and hence the scale is marked with reversed figures and is placed in an inverted position on the stand. What the observer sees, therefore, is some portion of the scale, erect and non-reversed. The sensibility of this type of galvanometer is not as great as that of the Thomson form, but its many advantages make it the best existing form.

Galvanometer Shunts. For all purposes of measuring insulation resistance, the galvanometer must have a means of reducing the current passing through it; this is accomplished in the use of a shunt. Commercial galvanometer shunts are small resistance boxes containing coils, of resistances proportional to that of the galvanometer. A common form has four coils in one box, with arrangements for selecting any one of the four, the resistances of the coils being respectively 1/9, 1/99, 1/999, and 1/9999, of the galvanometer resistance. When the galvanometer is shunted by one or the other of these coils, 1/10, 1/100, 1/1000, or 1/10000 of the current will pass through the galvanometer coil, and the remainder through the shunt.

Insulation Resistance. In addition to the device already mentioned, other essential things for insulation-resistance tests are, a key which normally short-circuits the galvanometer, some kind of a switch, a battery or other source of potential, and a standard high resistance. The arrangement of these parts is shown in Fig. 663, and the method of using such an arrangement is as follows: First find the deflection which the galvanometer will give through the standard high resistance of known amount; then the deflection with the same battery through the insulation resistance to be measured. If the standard high resistance were of many megohms, this comparison would be simple. However, as a standard resistance of many megohms would be expensive and bulky, it is customary to have the standard resistance 100,000 ohms, which is 1/10 megohm, and to make a preliminary test-reading through that resistance with the assistance of the galvanometer shunts. Making such a test-reading to determine conditions for testing the unknown insulation resistance is called "getting a constant."

To find this constant, place the switch in Fig. 663 in the proper position, use the largest shunt, press the short-circuit key and observe the deflection; if it is very small, release the short-circuit key and choose the next lower shunt; again press the short-circuit key and observe the deflection; if the deflection is on the scale, and is fairly large, note it as soon as it is well settled; if not, take a lower shunt

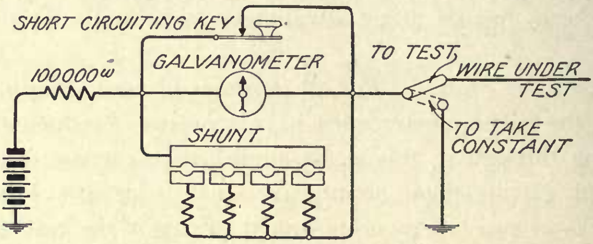


Fig. 663. Insulation Test

and when a satisfactorily large reading is secured multiply it by the multiplying value of the shunt and by the resistance in megohms of the standard. For example, suppose the following conditions to exit:

Shunt, 1/999

This will let only 1/1000 of the current through the galvanometer; the multiplying value of this shunt is 1000.

Standard resistance, 100,000 ohms (1/10 megohm)

Deflection, 85 scale divisions

The constant is, therefore, $85 \times 1000 \times 1/10 = 8{,}500$

That is, the insulation resistance through which the same battery would give one scale division deflection is 8,500 megohms. The result of this preliminary operation is to give a constant number which may be used through a series of tests and which only needs to be re-secured at intervals to make sure the conditions have not changed.

The constant secured, throw the switch shown in Fig. 663 to the position required for testing, select a shunt, depress the short-circuit key, hold it down one minute, note the deflection, and if necessary repeat the process, selecting lower and lower shunts or cutting out the shunt altogether. In most cases the first trial will tell whether any shunt is necessary. Suppose that with no shunt a reading of five divisions is secured. The insulation resistance of the wire under test will then be found at once by dividing the constant 8,500 by the observed deflection 5, giving 1,700 megohms as the actual insulation resistance of the wire under test. Similarly, if the deflection with no shunt had been found to be 10 scale divisions, the insulation resistance of the wire would have been 850 megohms. If the wire had been in such condition as to give 15 scale divisions with the $\frac{1}{9}$ shunt on the galvanometer, the multiplying power of that shunt tells us that 150 scale divisions would have been given with no shunt. Therefore, the insulation resistance in such a case would be 8,500 divided by 150, which equals $56\frac{2}{3}$ megohms, the insulation resistance of that conductor.

In all these cases the observer was getting the insulation resistance of the wire irrespective of its length, and it is necessary to know the result in megohms per mile, as the guarantee and the specifications were written in such terms. When it is remembered that the reason the insulation resistance is not immeasurably high is that current is leaking from the conductor through its insulating material, it will be seen that with other conditions equal, the longer the wire the lower its insulation resistance; so that the insulation resistance of one mile of such wire will be greater than that of two miles or less than that of a fraction of one mile. To determine the insulation resistance per mile, therefore, of any conductor, learn its actual insulation resistance as described, and multiply this result by the length of the conductor in miles. For example, in the case first cited, having an actual insulation resistance of 1,700 megohms, suppose the length to be $\frac{3}{8}$ mile. Multiply 1,700 megohms by $\frac{3}{8}$ and the result, 637.5 megohms, is the insulation resistance of that conductor per mile.

In case short lengths of cable, found by preliminary tests to have high insulation resistance, are to be tested merely to discover whether the manufacture and erection can be passed, a number of wires can be tested at once, thus shortening the operation greatly. Taking the case of the cable which had a conductor testing 1,700 megonms actual insulation resistance, if 50 pairs (or 100 conductors) had been tested at once, the result would have been 17 megohms instead of 1,700 megohms, assuming the character of all the wires to be the same.

In all measurements of cables for insulation resistance it is customary to test each wire against all the rest grounded with the sheath. If the wires are tested in groups, all except the group under test should be connected with the sheath and to ground. Measurement of insulation resistance by means of galvanometers and voltmeters is the most usual way.

The "Megger":—A device known as a "megger" nas come into some use and deserves more. It consists of a hand-driven generator, a coil moving in a permanent field, a pointer, and certain stationary coils, not required to be adjusted. The circuit whose insulation is

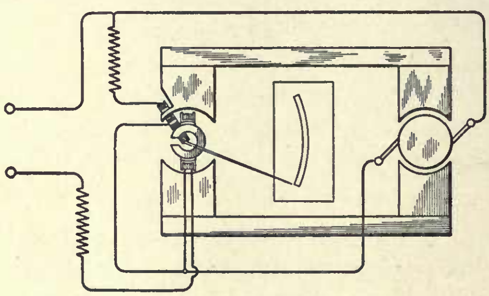


Fig. 664. The Megger

required is connected to the external terminals of Fig. 664, and the generator driven, when the resistance is read directly on the scale. The megger reads directly in terms of ohms or megohms; its pointer is dead-beat; the handle may be turned as fast as wished, a friction clutch slipping beyond a critical speed. The results given by the megger require no calculation whatever to know the resistance of the circuit connected to the test terminals.

Capacity. The second thing required to be known in testing cables for general condition is the electrostatic capacity of each wire. Specifications usually call for an average mutual capacity of about .065 microfarad per mile more or less. As it is of advantage to have the insulation resistance as high as possible, it is also of advantage to have the capacity as low as possible. A statement of the mutual capacity of a wire and its mate is merely a statement of how large a condenser the two wires form. As two wires with the insulating material between them do form a condenser, although one of small capacity, the effect is to short-circuit the voice currents in the line to just that extent, acting as if the wires had no such quality, but that a condenser—small perhaps, but none the less a condenser—had been bridged across the pair. If the pairs were used not for talking but for telegraphy, or some other electrical use with direct current, the capacity would have a less harmful effect, as alternating currents pass through condensers with much freedom, and the voice currents sent over the line will pass through the condenser formed by the wires and thus be lost from usefulness at the distant end.

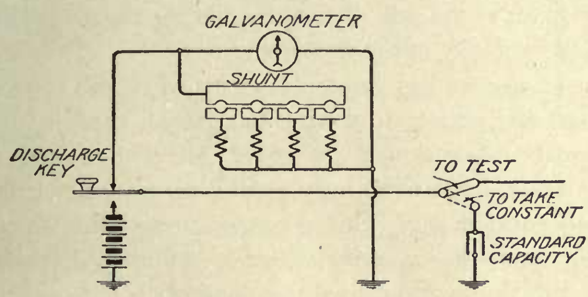


Fig. 665. Capacity Test

In Fig. 665 are shown the conditions for capacity tests, using the principal items shown in Fig. 663 for insulation tests. The discharge key is one which has two contacts, one above and one below, and is usually arranged so that it may be locked in the lower position and released quickly when desired. The condenser is one of accurately known capacity and is usually either of $\frac{1}{3}$ microfarad or is adjustable in small fractions up to about $\frac{1}{2}$ microfarad. For tests such as we are now considering, the $\frac{1}{3}$ microfarad standard is as good as any and is cheaper than the adjustable form. The procedure for capacity measurements is as follows:

Place the switch in the position to take the constant; depress the discharge key, holding or leaving it down for a few seconds, thus causing the battery to charge the condenser. Release the discharge key and note the galvanometer deflection. If but two or three cells of dry battery are used, the deflection will be on the scale with no shunt, and the galvanometer movement simply makes one steady swing, then stopping and returning to zero. The figure thus found is the deflection which $\frac{1}{3}$ microfarad will give with no shunt and with the battery used. Throw the switch to the testing position, depress the discharge key for a few seconds, and release as before, noting the deflection now given. The capacity of the wire under test is now found by multiplying $\frac{1}{3}$ microfarad by the last deflection and dividing by the first.

For example: Suppose the deflection to get the constant were 50 scale divisions with the $\frac{1}{9}$ shunt; as this shunt has a multiplying power of ten, the deflection is equal to 500 scale divisions with no shunt; suppose the test deflection were two divisions with no shunt; then $\frac{1}{3}$ microfarad times 2, divided by 500, equals .00133 microfarad, which is the capacity of the wire under test.

As a condenser has greater capacity when the conducting surface is increased, so a pair of wires has greater capacity as its length is greater, if other things are equal. Insulation and separation being the same, large wires have greater capacity per length of pair than small ones; size, length, and separation of the wires of a pair being the same, the capacity is lower or higher, depending on the kind of insulating material used. Dry paper is the standard insulating material for telephone cables, because lower capacity is secured with it than with any other convenient material.

Fig. 665 shows conditions for capacity between a wire and earth. To measure capacity between two wires (mutual capacity), connect one wire as shown and the other, instead of to the ground, to all three of the points shown grounded in the figure.

It often is necessary to practice insulation tests on lines which are not yet brought into a building and as one may have to go from town to town on such work, it is of advantage to have the testing outfit light enough to be portable, and strong enough to stand handling and shipment. Improvement is still going on in testing apparatus, although it was reasonably well developed long before the invention of the telephone. Much instruction may be had from the catalogues of instrument makers, and the student is recommended to study them.

Testing Sets. A typical form of insulation testing sets is that made by Nalder Brothers, London. The arrangement of the parts and the circuit are shown in Fig. 666. A notable feature is the absence of keys. The only parts requiring to be moved by hand are two switches, one controlling the taking of the constant and the actual testing, and the other applying the galvanometer shunt in its varying degrees. The shunt is subdivided in smaller units than usual, and the switch method enables it to be used with much greater speed than if the plug form were chosen. With such a set, the operation is to take the constant by throwing the main switch to the left and moving the shunt switch until the largest deflection which will be on the scale, is found. Suppose that this deflection is 320; sup-

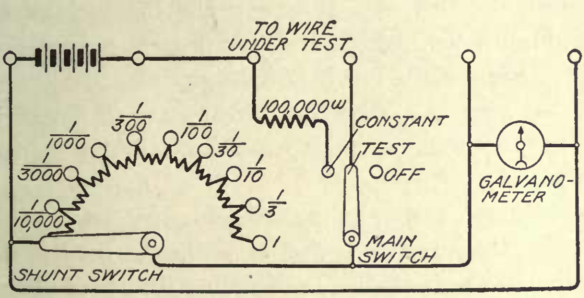


Fig. 666. Insulation Test

pose the shunt to be on the 1/1000 point at that time; then the constant will be 32,000, because the resistance through which the constant was taken was 1/10 megohm ($320 \times 1000 \times .1 = 32{,}000$); throwing the switch to the position marked "test", deflections may be taken on the various wires and their insulation found at once by dividing 32,000 by the observed deflection, multiplied by the shunt multiplier used. For instance, if after taking the constant as above, one were to test a wire upon which the shunt switch stopped at the 1/10 point, giving a deflection of 64 divisions, 640 would represent the deflection which would have been given with no shunt, and this is contained in 32,000, fifty times; therefore, the insulation of the wire under test is 50 megohms. For convenience in other tests the galvanometer terminals are brought out to binding posts, as well as being permanently wired into the circuit of the set.

A minor, but attractive feature of this set is its compactness; the reading of the galvanometer deflection is by means of a telescope, through which the worker sees the image on a scale rather than by watching the movement of a spot of light on a scale. The telescope is small—only about $3\frac{1}{2}$ inches long—and the scale is short and finely graduated, however, the high power of the telescope enables the divisions to be clearly read.

In any of the reflecting types, the use of the apparatus requires reasonably intelligent care not to pass large currents through the windings. With such precautions, pressures of several hundred volts may be used with safety.

In Fig. 663, the 100,000-ohm standard resistance is left in the circuit during the test as well as when taking the constant. This prevents injury to the apparatus by getting on a very poorly insulated or grounded wire, and it is customary to arrange sets in this way for that reason. Where it is necessary to get very accurate results, 1/10 megohm must be deducted from the result when the test is completed.

Loss-of-Charge Test. In the foregoing method of testing insulation resistance, the principle is that of sending current to the conductor and through the insulation, and noting the effect of that current on some movable thing under its influence. In a method described by Carhart and Patterson in "Electrical Measurements," and by Gray in "Absolute Measurements in Electricity and Magnetism," another principle is involved. It is that of loss of charge, and is practiced by charging the conductor under test to a definite potential, allowing a known time to elapse, then testing to see what potential remains. An insulated conductor must form a condenser with reference to something, even if it hangs in air and the other condenser conductor is the earth. But if the conductor under test is not perfectly insulated, the potential to which it is charged must diminish by the leaking away of the charge, so that after a known time the loss may be known by observing how much is left. A calculation then will tell what insulation resistance exists to allow that loss with the known time and charge. The method has the practical advantage that a sensitive millivoltmeter is a suitable instrument for the purpose and is readily portable. A direct-current power-source may be used for the charge. If much work is done with the method tables or curves may be laid out, thus enabling the observer to omit calculations and to read insulations at once.

Varley Loop Test for Grounds. Two of the three things which may happen to working wires are—becoming grounded and becoming crossed with other wires. Both of these troubles may be located by means of the Varley loop test, the circuit of which is shown in Fig. 667. There are many methods of making ground locations, but of them all the Varley test and the similar one designed by Murray are those best adapted for general use, principally because they are free from errors which might result from the existence of earth potentials. The

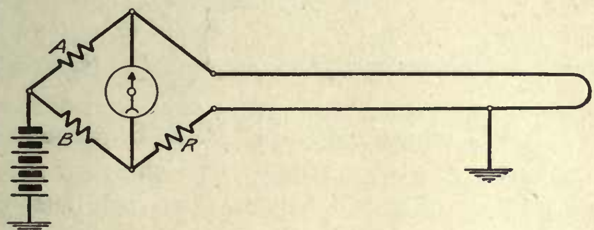


Fig. 667. Varley Loop Test for Grounds

pieces of apparatus used in the Varley test are the usual Wheatstone bridge, rheostat, and galvanometer. It is not necessary that the latter be of the reflecting type, although in some cases it may be found convenient to use one of that sort.

Referring to Fig. 667, showing the Varley tests for grounds, the arrangement is of the Wheatstone-bridge type, in which it is intended that the current from the battery shall flow through two paths, and at the time of completing the test shall cause no deflection of the galvanometer. In the figure, *A* and *B* are the two bridge resistances; *R* is the rheostat (the resistance of which may be varied at will by plugs or switches); the battery, galvanometer, and ground can be recognized by form. The test requires that in addition to the wire having the ground fault on it, an extra wire shall be provided which is clear of faults. Fortunately, in telephone work, wires generally go in pairs, and one often is good when the other is bad. The two wires must be directly connected at the distant end.

If the two wires are alike, and if the resistance of the bridge arms *A* and *B* are equal to each other, the galvanometer will show no deflection when the resistance in the rheostat R is equal to twice the resistance from the ground to the distant end. This is the simplest form of the test, and on a long line may give valuable help in knowing just about where to find the ground. The rheostat being adjustable in ohms, however, one cannot get results to fractions of an ohm unless the bridge arms are in another ratio than equal. And as the result, in integral ohms, may be half an ohm wrong, with No. 10 B. & S. gauge wire the location may be wrong by 500 feet or so. If this will do well enough, it is simplest to remember the test by the following rule, suitable when the two wires are alike:

Use equal bridge arms; adjust the rheostat till no deflection, or the least deflection, exists; divide the resistance cut in at the rheostat by two; the result is the resistance from the ground to the distant end of the line.

No. 10 B. & S. gauge and No. 12 N. B. S. gauge hard-drawn copper wire have a resistance, roughly, of 5 ohms per mile of wire, or 10 ohms per mile of metallic circuit. For such lines, which are common for toll service, this rule is quick and good:

With equal bridge arms, balance as usual; divide the resulting rheostat resistance by 10 (or point off the right-hand figure); the result is the distance in miles from the ground to the further end of the line.

Varley Loop Test for Crosses. The Varley test for crosses, Fig. 668, is the same as for grounds, except for a slight difference in

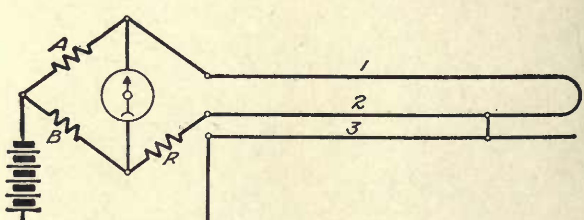


Fig. 668. Varley Loop Test for Crosses

the arrangement of the wires under test. The battery is connected to one of the crossed conductors *3;* the rheostat is connected to the other, *2;* a good wire *1* is connected to the set as in the test for ground, and is looped to the crossed wire *2* at the distant end. The further operations are by the rules given for grounds.

The Varley test with bridge arms of a ratio other than equality will give results to such a fraction of an ohm as may be desired. As the apparatus is usually made, bridge-arm relations may be selected so that A is to B as 10 is to 1, or 100 to 1, or 1,000 to 1, or the reverse. Suppose the arrangements are such that B is greater than A, say, 10 to 100 times, and the two wires in the test are of equal resistance. Then, having adjusted the resistance in the rheostat until there is no deflection in the galvanometer, the equation of the resistance *from the observing point to the ground* is

$$X = \frac{2BC - AR}{A + B}$$

in which C is the resistance of one wire to the distant end. Stated in other terms, the resistance to the fault may be determined thus:

Multiply the resistance of bridge arm B by that of the good wire, and double the result; subtract from this the product of the resistances of arm A and of the rheostat; divide the remainder by the sum of arms A and B.

As a practical example: A line 35 miles long is made of two copper wires of 175 ohms each, and one has a ground on it at some place unknown; the bridge arms, in testing, are 10 for A and 100 for B; a balance is reached with 2,015 ohms in the rheostat. Then, by the rule, 100 times 175 times 2 = 35,000; subtracting 10 times 2,015 leaves 14,850; dividing by 100 plus 10 equals 135; this is the resistance in ohms to the fault. In the case of a cross, the result is figured in the same way.

If the records tell the resistance of all principal lines under good conditions, the location of the fault can be accurately figured. It is hardly enough to know the theoretical resistance per mile of the size of wire used. The actual resistance ought to be known and used.

Murray Loop Tests for Grounds. The Murray loop test is similar to the Varley loop test in its freedom from error due to earth currents. It differs from it in that the bridge ratio is varied instead of the rheostat being varied with fixed bridge ratio.

A dial form of bridge is most convenient for the Murray loop test, one type of which is illustrated in Fig. 669. The dial, the arm of which swings one end of the testing battery, has 101 points in the circle; a resistance coil of 1 ohm is connected across each gap between points; there are thus 100 such coils. The coil A is of the same resistance, 100 ohms, as the total of the 100 coils in the circle. Then with a loop of one good wire and the faulty one, the dial lever is turned till the galvanometer deflection is nothing. If the ground is one ohm or more from the extreme further end of the looped wires, at least one step from zero will be required to balance the needle. The amount the switch is turned from zero is marked C in the figure; the remainder of the circle is marked B; the loop resistance may be called L. Then the equation is

$$X = L \frac{B}{B + C + A}$$

but $B + C + A$ equals the sum of all resistance in the set, or, in this case, 200 ohms. Hence

Multiply the loop resistance by the steps between the switch and the end; divide by 200. The result is the resistance in ohms from the point of testing to the fault.

To trace the following case with the aid of Fig. 669 will aid in clinching the principle in one's mind: Loop resistance, 84 ohms;

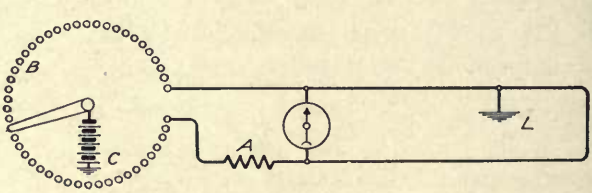


Fig. 669. Dial Set for Murray Loop Test for Grounds

distance switch lacks of reaching the end, 68 coils; then the resistance to the fault is 68 times 84 ohms divided by 200, equaling 28.56 ohms. From this the distance can be computed in feet or miles as desired.

Capacity Tests for Opens. Besides being grounded and crossed with other wires, lines may become open. A break in a wire, if it is a bare aërial one on poles, may result in one or both ends becoming grounded. In some cases, the location of the break can be located by a method for grounds. In some other cases, one of the ends may be crossed with another wire, and the method for locating a cross may enable the location to be made. In cables, however, opens are often merely breaks with no ground or cross to assist the test, in which case the test must be based on a comparison of electrostatic capacities.

By applying a capacity test to the broken wire, and also to a good wire of the same size, route, and of similar surroundings, a comparison of the two results will give the length of the defective piece. The good wire must be open at the distant end. Suppose that a toll line 45 miles long, of two No. 10 B. & S. gauge wires, has one wire broken; this wire is found by test to be clear of ground at the break.

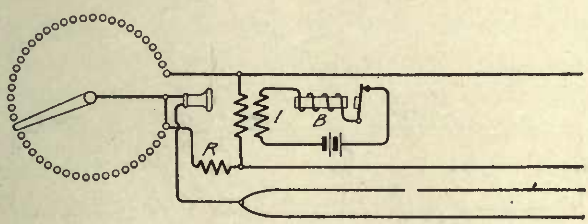


Fig. 670. Dial Set for Tests for Opens

A test for capacity on the good wire, opened at the distant end, gives .2925 microfarads for the whole piece; a test on the broken wire gives .1172 microfarads; then the distance to the break, in miles, is 45 times .1172, divided by .2925, equaling 18 miles and a little over—to be exact, 18 miles, 163 feet. In a word, the rule for the distance to the break is: *Multiply the length of the good wire by the ratio between the bad wire and good wire capacities.*

Another method for locating a break in a conductor, particularly adaptable to conductors in cables, utilizes the apparatus of Fig. 670. For use in locating breaks, the set is associated with a telephone receiver instead of a galvanometer. The current from the battery is supplied to the conductors under test in the form of an alternating current which is generated by means of an induction coil *I* and a buzzer *B*. The resistance *R* is a fixed non-inductive one, and the dial is composed of 100 equal coils connected between the steps, the total dial resistance being the same as that of the fixed resistance. The cable conductor which is broken is joined with its mate at one of the terminals of the set, and two wires of another pair of the same size and length are connected to the set at the terminals of the secondary of the induction coil. Listening in the receiver, the dial lever is turned until silence is reached, or as near silence as is found possible. Then the distance from the point of observation to the break is found by multiplying the total length of the cable under test by the number of ohms between the switch lever

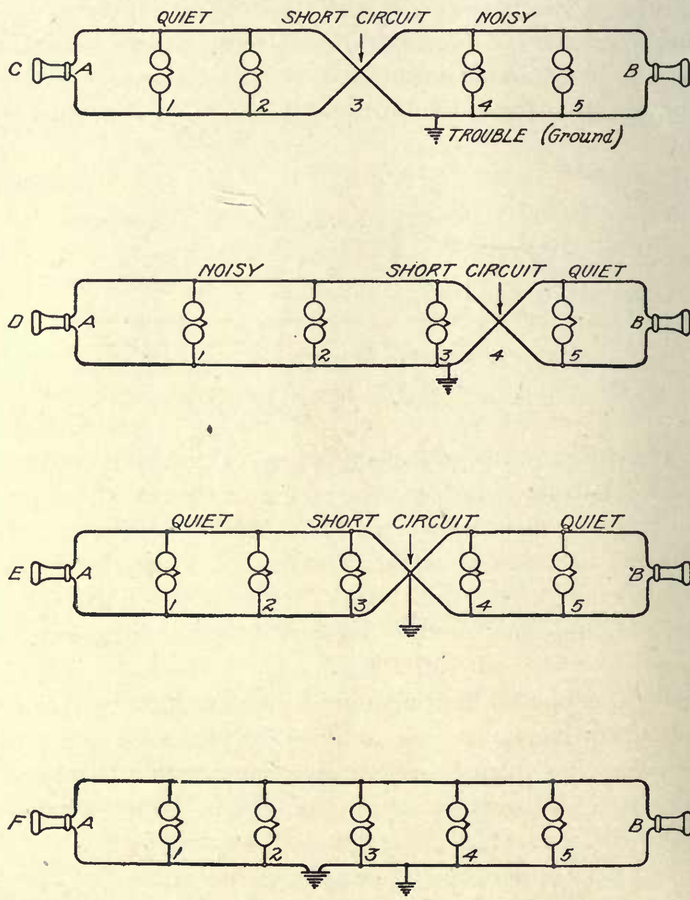


Fig. 671. Short-Circuiting Tests

and the end, dividing by 200. In this, as in any capacity test for the location of a break, the wires involved in the test must be open at the distant end.

Listening Tests. When both wires of a long-distance line are equal in resistance, insulation, and capacity of each to the earth and other things, the line is quiet. When one or more of these conditions is changed from the equality, the line is noisy. Only very short lines are quiet when unbalanced, unless in regions where no power circuits exist.

If one wire of a long line is open, grounded, or crossed with another wire, even if the latter is open at both ends, the long line is unbalanced. Long-distance wire chiefs become very expert in detecting the causes and locations of faults by the sounds they hear when lines are noisy, and by the behavior of the noises under changes in the line's connections.

In general, make listening tests while the line is short-circuited at various places. The fault, if an open, a ground, or a cross, is beyond the point short-circuited, if doing so makes it quiet. The Middleton Brothers describe the facts graphically, as in Fig. 671. Four cases are shown, *C, D, E,* and *F.* In case *C*, placing a short circuit at the point indicated quieted the line for observer *A;* that is, when the ground lay beyond the short circuit, the line was quiet. In case *D*, the line is quiet for *B*, noisy for *A*. In case *E*, the ground and short circuit are at the same point; the line is quiet for both *A* and *B*. In case *F*, short circuit at *2* quiets for *A;* short circuit at *4* quiets for *B;* short circuit at *3* will quiet for neither. A double fault exists, a difficult condition for bridge location, but easy for listening tests.

Quiet local lines may be connected to quiet long-distance lines making a noisy connection. A fault on the local line is indicated. Inserting a repeating coil quiets the connection, but impairs transmission. Short-circuiting the local line at successive points, further and further from the connecting point, will quiet the long-distance line, until the fault is passed.

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