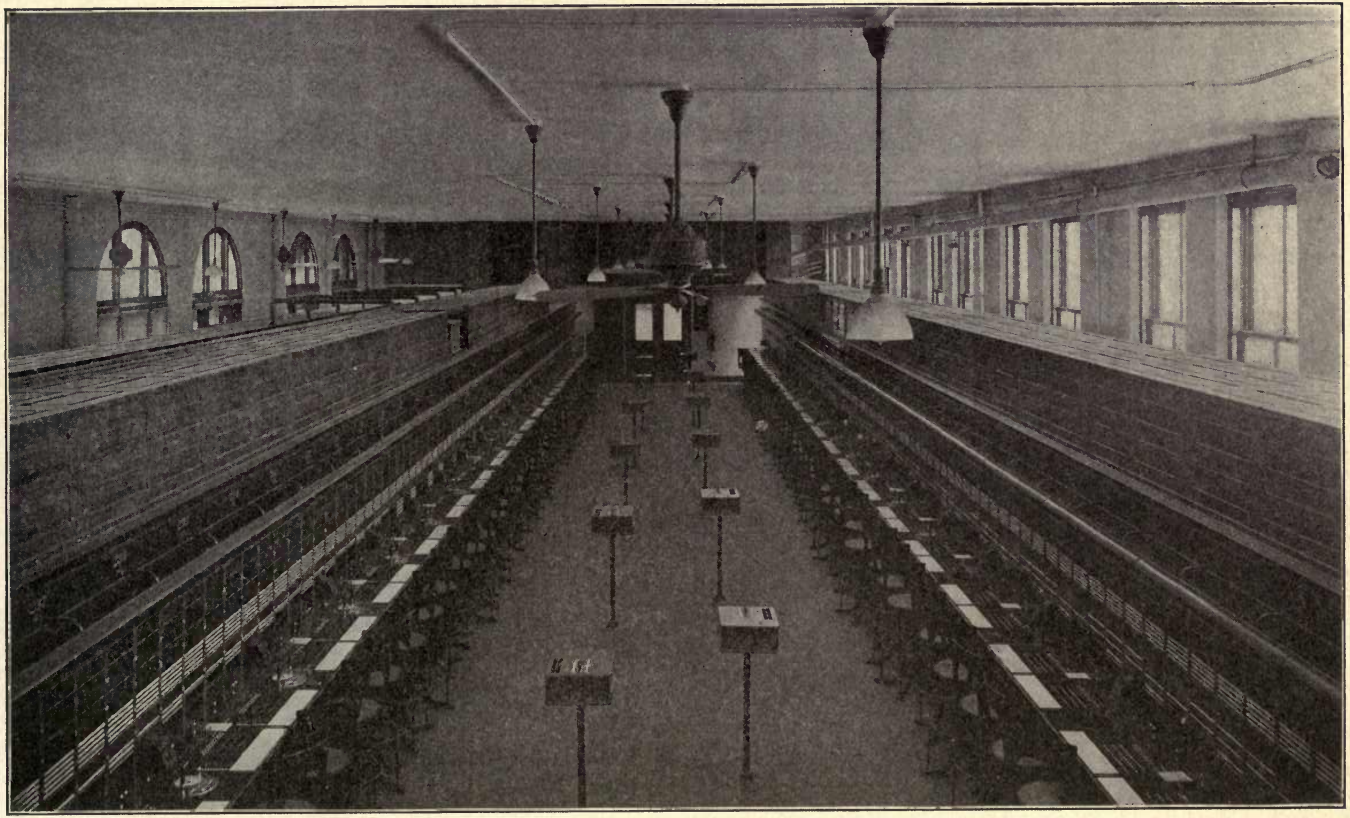

Frontispiece. — Toll Board of the American Telephone & Telegraph Company, at Philadelphia, Pa.

TOLL TELEPHONE PRACTICE

BY
J. BERNHARD THIESS, B.S., LL.B.
AND
GUY A. JOY, B.E.

WITH AN INTRODUCTORY CHAPTER BY
FRANK F. FOWLE, S.B.

273 ILLUSTRATIONS

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PREFACE

THE art of telephony has now progressed so far in its development that great difficulty accompanies any attempt to present it as a whole in exhaustive form, in any treatise of reasonable length. This statement, in the belief of the authors, will be almost universally accepted by all who are broadly familiar with the subject, and thus seems to justify the present volume which deals alone with toll practice. While the field of interest naturally diminishes as the scope of the subject becomes limited, it is still the hope of the authors that in departing from previous general customs and attempting a comprehensive treatment of only a portion of the art, their labors will receive some appreciation.

The theoretical portions of the subject have been treated as far as possible from a non-mathematical point of view, with the object of appealing not only to the engineer and the student, but as well to those whose training has been essentially practical. For the same reason purely theoretical considerations have been treated, where possible, in connection with their practical applications, with the further object of holding the reader's interest.

The authors wish to acknowledge the contribution of the introductory chapter by Mr. Frank F. Fowle, and also many helpful suggestions in the preparation of the manuscript. They also wish to acknowledge their indebtedness to Mr. J. E. Hilbish, who collaborated in numerous original articles which have been used in whole or in part. Many authorities have been consulted on all phases of the subject, to whom the authors tender their thanks.

J. B. T.
G. A. J.

CHICAGO, ILL., MAY, 1912.

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CHAPTER I

INTRODUCTION

The enormous expansion in the use of the telephone in America, dating from the contemporaneous inventions of Alexander Graham Bell and Elisha Gray in 1876, down to the present development of some 8,000,000 stations, is a matter of open history. Immediately succeeding the discoveries of Bell and Gray, there was a period of struggle to open the way for commercial development, which advanced but slowly up to 1895. The entire art during those two decades was in the control of the monopoly interests which acquired the fundamental patents. It was necessary, in establishing telephone communication on a commercial basis, to develop the art and at the same time educate the public to a realization of its great usefulness and economic value. That the development advanced slowly during the first decade was natural and to have been expected; that it did not advance more rapidly in the second decade is attributable in part to the lack of competitive stimulation.

At the opening of the third decade, about 1895, the fundamental patents were expiring and the field was thrown open to competition. That phase of the commercial development which really commands amazement began at this time and the succeeding yearly expansion increased at a rate not anticipated even by the most optimistic forecasts. The rate of growth at the present time appears to be unchecked and a state of development approaching saturation is unquestionably beyond the immediate future.

The independent or competitive interests which entered the field, at the period just mentioned, share the credit with the Bell companies for the technical development of the art; and to their efforts is due about one-half of the present commercial development, in the number of stations. Their influence has been felt least, perhaps, in the New

England and Eastern States, while in the middle West they have represented a very large share of the whole development in many instances. Lacking as a whole the benefits of a strong central organization or the extensive support of large financial interests, they have occupied, nevertheless, a most prominent part in spreading the benefits of telephone service. The early Bell development was confined practically to the cities and towns, and to building up a toll system. The independent companies brought about a marked change in this respect, owing to the demands for service in large numbers of undeveloped territories. Financed by local capital and managed by local interests in most cases, they commenced at once to develop the smaller cities and towns, and rural districts in particular. The growth of independent service spread also to the larger towns and cities and produced competition, thereby reducing rates and stimulating development. The exceedingly rapid growth of the service during the past fifteen years is due in great measure to competitive influences, and in part, of course, to the educational influence of the Bell service prior to this period. The adoption of modern or aggressive business methods in campaigning for new subscribers, by progressive managements on both sides, has also had an important influence on the development; but such methods, of course, are largely inspired by competition, or the fear of it.

It is hardly necessary to point out that the state of the telephone art to-day is exceedingly complex and no apology is necessary for attempting to present a comprehensive treatment of some particular branch of it. This is somewhat of a departure from previous treatments of telephony, but seems well warranted under present conditions. It has been recognized for a long time that toll systems are not merely an adjunct to local service, but an integral and necessary part of any general system. Isolated local service has a value much impaired in contrast with combined local and toll service; in fact, the former is an illogical condition of development, except in very remote and unimportant communities, and must ultimately give way to the latter. Toll service, as distinguished from local, is a natural division of the general subject and seems to be well past the point where it merits such consideration as the authors have given it in this volume.

A word of explanation here in regard to terminology, before entering upon the historical phase, seems to be in place. Common usage among telephone men has led to the general classification of telephone service under four headings, as follows: local, suburban, toll and long distance. These are named in the order of advancing distance or length of haul, respectively. The last three fall within the scope of the present treatment, inasmuch as they comprise all that part of telephone service which is not local, or exchange service. Any telephone call which is not local bears a special or toll charge and broadly may be termed a toll call; hence it seems proper to use the term "toll" to embrace all service of this class, whether it be suburban, toll, or long distance in the narrow sense. It is hoped that this view of the matter will meet with general approval. The term "toll" has been employed as a rule in its broad sense, throughout this volume; where special usage makes this impossible the proper construction will be duly apparent, if not explained. The ordinary meanings of these terms are fairly obvious, from their names; in Bell practice the terms "suburban" and "toll" are often used synonymously, but suburban business is always short haul, comparatively, while toll business may be long haul but not exceeding 100 miles. The term "long distance" in Bell practice implies any haul exceeding 100 miles and in many cases the toll and the long distance business are handled at different switchboards, particularly in the larger cities. The terms "toll" and "long distance" do not have this distinction in independent practice and are commonly synonymous.

The history of toll development contains much that is instructive and of special interest, from various standpoints. The idea of communication over long distances has always appealed to man's imagination and no doubt has greatly stimulated the interest in this branch of the art.

The pioneer work was very largely carried out by the Bell companies, of course, because they enjoyed a monopoly of the business for the two decades next succeeding the announcement of the basic discoveries. But the slow commercial progress postponed any serious attempts to establish toll service until 1885. At the outset such service was in practically no demand at all and the problems to be solved had scarcely been approached. Among the very earliest attempts to converse over telephone lines of any considerable length were those made between Boston, Mass., and Providence, R. I. The distance between these cities is about 40 miles and the circuits then employed were single overhead wires with earth return. It speedily developed that cross talk was a commercial barrier to the use of more than one such line at a time, when two or more were carried closely parallel to each other on the same supports, for such a distance.

These results seemingly interposed a barrier to long-distance telephony until it was proposed to try the remedy of metallic lines. About this time a company was formed to engage in furnishing long-distance telephone service, under certain privileges and restrictions from the interests which owned the Bell and other fundamental patents. This corporation was the American Telephone and Telegraph Company, which was formally organized in 1885. The same year it commenced to build the first important long-distance line, between New York and Philadelphia, a distance of 90 miles. This line was built for metallic circuits and was completed in 1886. But the original difficulty again appeared and only one metallic circuit could be used commercially at one time, because of the cross talk. The credit for overcoming this obstacle to commercial success belongs very largely, if not entirely, to John A. Barrett, who at that time was the electrician for the company. Barrett developed, step by step, a scheme of transpositions which made it feasible to use all the circuits simultaneously in commercial service. This marked the commercial opening of toll development and the building of toll lines connecting other cities was forthwith undertaken.

At the same time, and in fact prior to that period, independent investigators had been attracted to this field, both in America and abroad. Before the advent of toll telephone service the telegraph was the only means of rapid long-distance communication. The telegraph had already achieved considerable commercial importance and had so far advanced that various schemes for multiplexing a single wire had been reduced to a practical basis. The next logical step was the discovery of suitable means for telephoning and telegraphing simultaneously over a single wire. Van Rysselberghe, a Belgian, had invented a system which accomplished this result and came to America in 1885 to demonstrate his method on the lines of the Baltimore and Ohio Telegraph Company. Many successful experiments were conducted and it was clearly shown that telegraphic impulses or signals could easily be modified so as to become substantially inaudible in the telephone receivers which were employed for simultaneous transmission. Among the successful tests made at that time were those between Baltimore and Cumberland, Md., a distance of 178 miles; and between Coeman's, N. Y., and Fostoria, O. These experiments culminated in a test between New York and Chicago which is of special interest historically, as being without doubt the longest circuit actually spoken over until 1893, when commercial service was opened between these cities. The test was made in 1886, between stations at 63 Broadway, New York, and the Palmer House in Chicago. The circuit was metallic, employing the ordinary copper wires then in use and followed the routes of the West Shore Railroad and the New York, Chicago and St. Louis (Nickel Plate) Railroad. Simultaneous transmission was successfully carried on, although the volume telephonically was very small and inadequate for commercial purposes.

Another independent investigator, Rosebrugh, had successfully anticipated Van Rysselberghe's claims in this country, although his efforts had been directed mainly toward a system of duplex telephony. Rosebrugh's patents were disposed of to the Bell interests and further development of what is now known as the composite system was carried out later under the direction of Frank A. Pickernell, who became Engineer of the American Telephone and Telegraph Company. In that work no method was found for ringing over the telephone circuit simultaneously, without interference, and the apparatus was developed for simplex or single morse transmission exclusively.

The discovery of the well-known phantom circuit principle was made by Frank Jacobs, although it was regarded for some time as a method of multiplex telephony. Jacobs' plan permitted as many independent telephone circuits as there were wires, in theory, all of which were metallic circuits except one. Thus, from two wires he obtained two independent circuits, one metallic and one grounded; from four wires he obtained three metallic circuits and one grounded circuit, and so on, each time doubling the number of wires. The principle is derived fundamentally from a balanced Wheatstone bridge. Its practical application has been limited to two cases, one of which is the first or simplest case where one metallic circuit and one grounded circuit are derived from two wires, and the other is a limited use of the second case, in which three metallic circuits are derived from four wires. It is one of the familiar facts of history that useful inventions frequently languish for some years before their commercial importance is at all recognized, and in this case there was no exception. The commercial use of the phantom principle had hardly commenced by 1900, but has spread rapidly since that time.

The construction of commercial toll lines commenced rapidly after the successful solution of the difficulties encountered with the New York-Philadelphia line. Lines were completed between Boston and New York and between New York and Buffalo, connecting with many intermediate cities, in 1888; the Chicago-Milwaukee line was finished in 1889 and a line was extended from Philadelphia to Washington, D. C., in the same year. Many lines were built each year thereafter and the development is still progressing at the present time.

One of the most important events was the opening of the New York-Chicago line in 1893, which attracted much attention and marked the arrival of long-distance commercial service in the full sense. This was the first instance of the employment of heavy copper line conductors, weighing 435 pounds per mile. There was naturally much uncertainty over the outcome of this pioneer attempt to give commercial service between two cities nearly 1000 miles apart. The success which attended it is very remarkable in view of the fact that there was little to rely upon in the way of proven theory and no great range of experience from which to deduce empirical results. Service between all the large cities east of the Missouri and Mississippi rivers soon followed.

Shortly after this time, about 1895, the independent telephone companies entered the field, as a result of the expiration of fundamental patents. In a commercial sense this event was of the most far-reaching importance because it directed the development as a whole into new channels and brought telephone service into communities which otherwise would have gone without it for some years to come, in some cases perhaps indefinitely. The independent companies have built up no single great toll system as yet, although there are a number of systems which reach considerable proportions and cover several states. The independent toll systems taken as a whole, and consolidated, however, would constitute a very comprehensive network. The contributions to the art from independent sources, as regards toll practice, relate chiefly to equipment and operating methods. This seems but natural in view of their exclusion from all participation in the development until a comparatively late stage.

In 1898, Barrett produced an improved transposition system which has been standard ever since, except for modifications to permit the use of transposed phantom circuits. A very important contribution to this branch of development was made by John J. Carty, who described many of his researches in a paper presented before the American Institute of Electrical Engineers in 1891. Barrett's improved system has been widely used on the lines of the American Telephone and Telegraph Company.

The advances in cable development up to this time had been chiefly in the reduction of electrostatic capacity, which was made possible by the so-called dry-core paper cable. The conductors employed hitherto had been selected largely with reference to the needs of local service. No. 19 Brown and Sharpe gauge had been adopted and used as the standard. It was not appreciated until some years later that such conductors were uneconomical for use in long toll circuits, although it was known that their efficiency was low. The practice abroad advanced more rapidly in this respect and the use of large gauge toll cables was undertaken somewhat earlier. At the present time it is well known that the proper gauge of conductors for toll cables is settled by the characteristics of the lines of which they form a part, according to definite laws.

The year 1900 was marked by the announcement of Dr. Michael Pupin's method of improving transmission, by means of inductance loading. This invention is of immense commercial value and has been widely applied, with greatly beneficial results. The greatest relative improvement was obtained by its application to cable circuits, but material gains are obtained on long open-wire lines if the insulation is kept sufficiently high. It is a curious circumstance that Oliver Heaviside suggested the possibility of inductance loading in 1893, when pointing out the benefits of large inductance under the assumption that it was uniformly distributed. It is quite possible that Heaviside's suggestion was responsible for the later discovery of a successful method of artificial loading. Heaviside himself, so far as known, never solved the problem. It is even more interesting to know that his suggestion was actually given a trial in this country before Pupin's work was announced, but the trial resulted in a total failure because the loading coils were of exceedingly large inductance and situated a great many miles apart on the circuit. A contemporary investigator in this field, with Pupin, was Dr. George A. Campbell, who was working under the direction of the American Telephone and Telegraph Company. The latter company acquired Pupin's patents and an interference suit between Pupin and Campbell was subsequently decided in the former's favor.

One of the direct results of Pupin's discovery is the ability to construct underground toll lines of considerable length and high efficiency. Such lines are now operating between New York and Philadelphia, New York and New Haven, Conn., and between Chicago and Milwaukee; other lines of the same character are projected. The application to open-wire lines at first seemed successful, but a great difficulty was encountered in low insulation during periods of mist, fog, or rainfall. A superior type of insulator, very recently produced, has overcome this objection and loaded open-wire lines seem now to be entirely successful. The most recent development is the application of loading to phantom circuits; the slight superiority of a phantom circuit over its component physical circuits and the large gain due to loading, results, in the case of No. 8 B. W. G. copper circuits, in what is probably the most efficient long-distance circuit ever utilized commercially. It has been announced that such a circuit will comprise part of a New York-Denver connection, when that service is opened to the public.

Within the last few years there have been several important improvements in composite systems, due very largely to the work of J. M. Fell and W. E. Athearn. In order to signal for telephonic purposes over a composited circuit it was formerly necessary to sacrifice one of the two morse circuits, but Fell's composite ringer has removed the necessity of this, by means of a high-frequency signalling system. This improvement results in a considerable gain in wire efficiency. The composite system was originally developed for simplex or single morse working, but Athearn found it feasible to introduce duplex working after refining the composite system and developing an improved duplex equipment; in fact, duplex operation is superior to single working. Quadruplex working is also feasible for limited distances. These developments have brought the total wire efficiency to a remarkably high point; the ability to employ two wires for commercial metallic toll service, to signal back and forth between operators and to work a full telegraph duplex on each wire without interference, is indeed a great achievement.

Many investigators have sought for a successful telephone repeater, one that would work in either direction automatically without regard to circuit conditions and preserve the quality or clearness of transmitted speech, and at the same time give a substantial increase in volume. No one has yet achieved this result, although many have been partially successful. Probably the most notable results have been obtained by Herbert E. Shreeve, who developed a successful repeater for limited use, under the direction of the American Telephone and Telegraph Company. Shreeve, in 1905, was granted a patent on a repeater which has been in commercial service and gives quite satisfactory results under certain limitations. One of the necessary conditions was a substantial balance, electrically, between the outgoing lines on each side of the repeater, in order to eliminate any tendency to " howl." Experience shows that this repeater is a comparatively sensitive apparatus and requires the most careful maintenance. But now that the repeater problem has actually been solved for certain conditions of service, it is reasonable to hope that future research will widen its usefulness materially.

The most recent developments in toll cable practice have made it possible to bring phantom circuits into such cables without unbalance or cross talk. This is accomplished by forming the core in a rather unusual manner. Twisted pairs are made up in the ordinary way and then two such pairs are twisted together to form a phantom circuit element. These elements are laid up in reversed spiral layers after the usual manner, and single twisted pairs are frequently interspersed to make use of space which otherwise would be wasted. When physical or phantom circuits are intended for loading, the requirements for perfection of electrical balance are particularly severe and demand the greatest care in manufacture.

During this progress of development there has been a marked change in switchboard practice and in the office equipments generally. The latter developments have appeared gradually and in fact constitute a long process of evolution. The numerous improvements have been contributed from many sources and it is difficult to separate the distinct steps. The early types of board were non-multiple entirely and equipped throughout with magneto apparatus. The advent of automatic lamp signals quickly followed the introduction of the common-battery system in local service. The multiple type of board appeared somewhat later, in response to the need of operating flexibility in large installations. The introduction of the multiple board also made it possible to economize operating labor, during hours of reduced traffic, to a much greater extent than before. There has been a great change in keyboard practice, also, of which the tendency is toward more efficient operation through the reduction of labor and the improvement of supervision.

The contemporary development of toll test and morse boards has likewise been an evolutionary process. The early boards were entirely of the cord type and were comparatively inflexible with respect to the needs of a large office. The modern boards are of the cordless type, except for small installations, and are provided with automatic signals and means for supervision. They are also more systematically arranged and equipped with a view to flexibility of layout. The general progress in methods of installation has likewise been marked, following in the wake of advance in this respect in local office installations. Passing mention should be made of the introduction of various labor-saving devices, prominent among which is the pneumatic ticket carrier. Belt carriers have been used to some extent and are still in service in a few instances, but the latest equipments are usually provided with the pneumatic system.

CHAPTER II

RURAL TELEPHONE EQUIPMENT

TELEPHONE development in its early stages was confined for the most part to the cities and large towns. The growth in these communities was so rapid and required so much capital that the development of rural districts did not commence until a later date. At the time the fundamental Bell patents expired the keen competition inaugurated by the independent companies began almost at once to stimulate this important phase of development.

These independent companies were comprised, in a great number of instances, of farmers and country merchants. As a result of their almost universal inexperience in building or operating such plants, the construction of the early rural systems was crude in many respects. The class of service expected, however, was much below that necessary to give satisfaction to subscribers in urban districts and, moreover, the necessity for rigid economy was frequently imperative. The kind of service actually obtained was usually sufficient to the needs, at least for a time. Service that now would not be tolerated was then often welcomed as of great benefit, in contrast to the entire absence of any kind of communication, except the telegraph, but a short time before.

As a means of keeping down the cost of such plants, the farmers often contributed the poles for line construction, using native timber of many kinds; and furthermore, gave extensively of their time to assist in the work of construction. The cash purchases were usually limited to switchboards, wire and telephone sets. These conditions contributed to low cost and low rates. If the service was imperfect and slow, it should be remembered that a delay of a few minutes is not of great consequence in business transactions in such communities, where the stress of city life is so little in evidence.

But conditions as they were a decade ago, have been undergoing a marked change, and the increase in prosperity among farmers, as well as their greater enlightenment and experience, have produced a demand for better service. The present tendency is toward better equipment and construction in most instances. The early mistakes necessarily exerted a lingering influence on the service, because they generally related to the construction of the plant and were hence too costly to be eliminated until the approach of the natural reconstruction period.

The efficiency of a plant from a service standpoint is largely settled as soon as the construction is complete. The early errors that were made in laying out and building these plants, and their costly effects, may be observed still in many sections of the country. The practice of coöperative construction without regard to proper methods or standards is now widely recognized to be undesirable. Yet many hundreds of rural plants were built wholly or partly in this way. It was often the rule, for example, to require country subscribers to build their own lines up to the boundary of a restricted exchange area or zone, at which point the telephone company or association assumed the construction and ownership of the plant. The type of line construction obtainable under this plan in most instances was far below a proper standard, owing to the inexperience of those who built such lines and the rigid economy generally practiced. Thus we find in our western country some very crude conditions, such for example as barbed-wire fence lines. Even when fences were not resorted to, the character of pole lines was often of such a character as to be a public inconvenience, or even a menace. Native timber was used almost exclusively and the bark as a rule left on; the sizes as to length and diameter were extremely irregular in many cases. Again, the timber was sometimes so hard or so crooked that linemen's spurs were useless and pole climbing as an art reverted to old-fashioned methods.

In this connection a description of a line observed by the authors in eastern Nebraska may be of interest. The timber used for poles was osage hedge and is not only excessively crooked but also very hard. At the top of each pole was nailed a loop of wire which served in lieu of an insulator and the line wire was strung loosely through these loops. No apparent attempt had been made to avoid trees or foliage, which grew up and around the line wire in dense profusion. Whether the service over this line, in good weather and bad, was of a satisfactory character, will be left to the reader's imagination.

Farmers who have had experience in the ownership of these rural lines are often glad to turn them over to the telephone company, at least ultimately. The maintenance of poor construction at a standard of high efficiency is an expensive matter and the telephone company which succeeds to the ownership of these lines will probably replace them as soon as feasible by standard construction. A company making this change will naturally use its toll routes as far as feasible, at least where toll and rural lines were once parallel on the same right-of-way. The need for entirely new pole lines may be confined to short stretches, if the toll route is followed wherever it is economical to make use of it. Even though the toll line does not follow the most direct route for rural distribution, it may still be economical to use it. This method of reaching rural subscribers is resorted to quite extensively.

When new lines are under consideration, the company will find it economical to make use of good construction from the first, because such a course is essential not only to good service, but to low maintenance costs as well. By a proper policy at the outset much subsequent trouble from dissatisfied subscribers will be avoided. A satisfied subscriber is the most efficient publicity agent and his good will is a matter of concern.

When the early rural systems were built there was almost complete freedom from inductive disturbances of any kind. Grounded lines in consequence obtained favor because of their economy in first cost and annual charges; that is the only reason, in fact, for employing them at all and they have made possible a great deal of development that otherwise could not have sustained the rates necessary to meet the cost of service. The rapid development of electric light and power service, electric railways and high-tension transmission has worked much injury on telephone service of such character. Even at this time, however, there are many communities where the service is not disturbed by such influences. But the tendency is always toward complications of this kind, owing to encroachments of the character just mentioned.

There are two schemes by means of which this trouble may be solved. One is to make the entire line metallic; the other is to string the line metallic for a distance well beyond the disturbing field, where it should terminate in one winding of a repeating coil, the two terminals of the other winding of the coil being wired to ground and the single line wire, respectively. Either of these schemes will eliminate the noise on the line, but the latter remedy has the disadvantage of reducing the efficiency of speech transmission due to the insertion of the repeating coil, and should not be attempted on a circuit having subscribers who are likely to use long toll lines. Either of these plans for improving service will of necessity involve additional expense; but at the same time they are likely to pay for themselves in the long run in indirect ways, such as making it easier to get new subscribers and toll business, and reducing maintenance expense.

NOMENCLATURE OF EQUIPMENT

The nomenclature employed in discussing telephone equipment has become well established in most respects. It does not seem necessary to give here a glossary of terms in common use among telephone men; but in regard to certain equipment there has crept in some ambiguity of terms that might give rise to misunderstanding if it were not explained. It is quite natural that local usages of terms should not have identical meanings, in every instance, throughout the country.

The principal variance in usage occurs in designating the three springs of a switchboard jack and the three conductors or terminals of a plug. The designation which the authors have used is the one believed to be in greatest use; it is shown in Fig. 1. The terms "tip," "ring" and "sleeve" are clearly indicated and defined in the figure and this usage has been employed throughout.

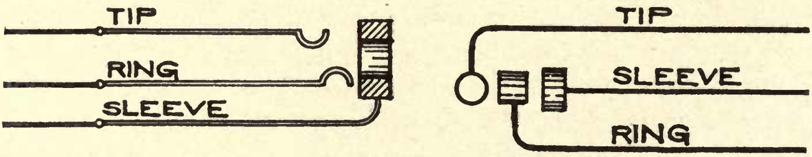


Fig. 1. — Standard Plug and Jack Designations.

In other respects there seems to be no terms in general use and hereafter employed which are not well known, or explained as they arise.

Subscriber's Instrument. — Telephone sets for use in rural lines should be chosen from the instruments especially designed for this particular class of service. They have distinctive features and limitations, and it is not to be expected that such service can be properly handled with any kind of an instrument. Some telephone companies practice false economy in assigning to rural lines, instruments which are too nearly worn out or antiquated for town service, instead of sending them to the scrap heap. It is right and proper for the business managers to see that the waste of material is no greater than necessary; but in their efforts toward economy they lose money for the company in many instances by operating with old and inefficient apparatus.

Some of the most essential points to be provided for in the design of the rural telephone are that the bell should readily respond to the ringing current placed on the line by the operator; that the instrument shall be equipped with a hand generator of sufficient power to easily operate the switchboard signal; and that the set shall talk properly, *i.e.* transmit and receive talking current so that the parties at opposite ends of any connection whose length is within the probability of operating conditions, can converse with ease. These points are naturally just as essential in all other telephones; but for the class of service under consideration they are much harder to attain, and so should be insisted upon with great vigor. High quality is demanded for these instruments because the rural line is longer and of poorer construction than the city line. Then again, there is very often a tendency to overload the country line by putting on as many as twenty-five or even thirty telephones, each one of which lowers the talking and signaling efficiency of the circuit.

As experience has proven that the permanent insertion of low-wound ringer coils in series with the line gives results vastly inferior to those obtained by the permanent bridging of high-resistance ringers, the series telephone will not be discussed. Several different types of bridging telephones are considered to be desirable for rural telephone service, the precise choice depending on local conditions and the personal preferences of the purchaser. The type of instrument commonly used is equipped with a high-wound ringer and a standard four- or five-bar generator. The number of magnets in the latter depends to some extent on the number of telephones bridged across the line; for as the number of instruments is increased the current required to throw the drop at the exchange is correspondingly increased, as each additional telephone provides one more parallel path which the ringing current must traverse and, therefore, reduces by a fractional amount the current which passes through the apparatus at the end of the line.

Wiring of the calling circuit of these telephones may follow either of the two standard methods. In one type of set the apparatus is so arranged that the subscriber, upon calling central, will ring his own bell; while in the other, the local bell does not respond. Some manufacturers maintain that a subscriber prefers to hear his own bell ring when calling central; but general observation seems to indicate that this is not the case. The latter conclusion is based upon the fact that a subscriber will generally place his left hand on the gongs of the instrument before turning the crank of the generator. Then there is the additional disadvantage that the unnecessary ringing of the subscriber's bell furnishes another shunt circuit to the generator current, thereby reducing to a certain extent the energy available for operating the switchboard signal.

There is one serious objection to the straight bridging instrument, arising from the fact that a subscriber cannot signal the exchange without ringing the bell of every other subscriber on the line, thereby greatly reducing the current which is effective in operating the switchboard signal. Then again, many subscribers upon hearing their bells ring will go to the telephone and listen, making the telephone conservation anything but secret and materially cutting down the transmission. This objectionable feature can be avoided easily by using a telephone equipped with a pulsating current generator in place of the alternating generator commonly employed. The current from such a generator will not affect the ringers on the line but will operate the drop at the switchboard. This type of instrument is commonly known as a " central checking telephone," because a subscriber desiring to converse with another station on the same line must first signal central and make his wants known before obtaining the service desired.

Another way of overcoming this trouble is by the introduction of a grounding key at the subscriber's instrument and grounding one side of the drop at the switchboard. The exact manner in which this principle is applied can be explained best with the aid of a circuit, a conventional diagram of which is shown in Fig. 2.

The operation of the circuit is as follows: Should a person at station 2 wish to call central, he will first depress key *K*, which will disconnect the generator from the ring side of the line and connect the corresponding side of the generator to ground. Consequently the current generated upon turning the crank will follow a path that can be traced from the ground at the subscriber's instrument through the generator to the tip side of the line, and hence through the break contact in the jack and the coil of the line drop to ground. Thus the coil of the line drop will be energized, thereby causing its armature to be attracted, lifting the latch and permitting the drop shutter to fall. It will be observed that the other instruments do not shunt the current path traced in this circuit. Thus a subscriber may signal the exchange without in any way informing the other subscribers on the circuit that the line is in use. However, in case the person at station 2 desires to speak with a station on the same line, station 1 for example, he can signal this subscriber without disturbing central by turning the generator crank and allowing key *K* to remain in its normal position. This will obviously force the generator current out on one side of the line, the other side serving as a return path; and the current will necessarily find a path through the ringers in all the instruments on the line. Consequently, with a proper code of rings, stations on the same line may signal each other direct.

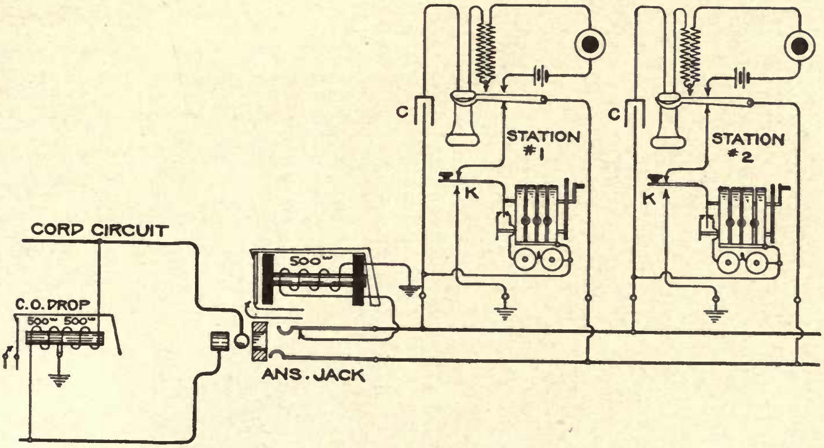


FIG. 2. — Grounding-button Telephone, Using One Side of Metallic Line.

The cord circuits of a magneto board used in a rural telephone system, having grounding keys, should be specially designed to permit the operation of the clearing-out drop by the signaling current which will flow over the tip side of the line to ground, as well as for generator current from a regular bridging or series telephone. In Fig. 2 the clearing-out drop is so arranged, the only special feature being the grounding of the central point of the drop winding. The current from any telephone provided with a grounding key will, if the key *K* is operated, flow over the tip side of the line and thence through one-half of the winding of the clearing-out drop to ground. Current from a regular bridging or series telephone will pass through the entire winding of the drop, as neither side of the generator is grounded. In making up such a cord circuit, care must be taken to ground the drop winding at exactly the middle point, since any great variation between the respective sides of the line as regards the resistance from the ground out to the telephone will have a tendency to unbalance the circuit, thus causing it to become noisy.

It might be well to give a word of caution with respect to the installation of the instruments just described, inasmuch as they must be so wired that the generator current will flow out over the tip side of the line when the ground key is depressed. If this requirement is not observed it will be impossible to signal the exchange. A circuit is shown in Fig. 3, in which the chance of trouble due to carelessness in this regard is eliminated; it is arranged also for signaling central without causing any bell on the line to ring. The operation of this circuit is as follows: When the subscriber at station 1 wishes to call the exchange, he will first depress the grounding key *K*. This operation grounds one side of the generator and at the same time connects the other side to both the tip and ring sides of the line. Therefore the current generated will flow over both sides of the line in parallel, and through the two windings of the line drop to ground. The coils of this drop are so connected that the magnetic energy created by the

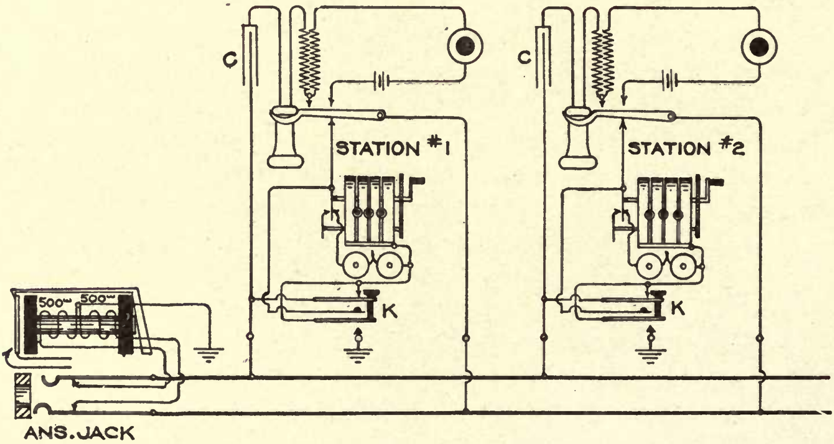


FIG. 3. — Grounding-button Telephone, Using Both Sides of Metallic Line.

current traversing one-half of the winding will be added to that of the other half, and thus release the shutter.

When one station is calling another on the same line, the key *K* is left in its normal position; and consequently neither side of the generator is grounded, so that the current will flow out over one side of the line and return on the other. Therefore this current will find a path through the ringer coils of each of the other instruments on the line, as well as the line drop. The latter will not operate, however, since the current passes around the core of the drop in one direction to the middle point of the coil, and thence through the other half of the winding in the opposite direction. Thus there is no tendency to draw up the armature, because the magnetic effect of one winding is neutralized by that of the other. It is obvious, therefore, that with this system, as well as with the one previously described, the stations on the line can signal one another without disturbing the operator.

This latter scheme has several advantages over the arrangement shown in Fig. 2. In the first place, no care need be taken to connect the same side of all the telephones to the tip side of the line; and secondly, since both sides of the line are worked in parallel in signaling the exchange, the resistance of the path that must be traversed by the generator current is only half as great as when a single wire is used. However, with the system illustrated in Fig. 3, it is not practicable to arrange the clearing-out drop in such a way that the subscriber can give the operator the disconnect signal without ringing the bells of the other subscribers on the line. This is due to the fact that it is impossible to operate a drop with current flowing from both sides of the line in parallel through the drop windings to ground, and also from one side of the line through the drop windings in series to the other side of the line. The system must be arranged for either one method or the other. Since the latter plan (Fig. 3) will suffice for straight bridging and series telephones, as well as the special ones, the cord circuit used with this scheme does not have the middle point of the clearing-out drop grounded. The drop is simply bridged across the tip and ring strands of the cord circuit. Therefore it is evident that with the system just described, any station in ringing off will cause all the bells on the line to respond; but this will be of no special disadvantage, since the calling-in signal is the one in connection with which secrecy is so essential.

The various circuits employing the grounding keys solve the question of silent signaling very nicely where metallic lines are in use; but it is quite evident that this scheme cannot be utilized on a ground return system. In exchanges of this class the desired results are accomplished by equipping the instruments with hand generators capable of generating either pulsating or alternating current, and keys are so wired as to enable the subscribers at will to produce either kind of current. The pulsating current is used in signaling the exchange and the alternating current for calling the various subscribers on the line by means of the usual code rings. With this arrangement, one subscriber upon signaling another will actuate the drop at the switchboard. The operator can very readily distinguish a code ring from an office call; and in case the call is for a station on the same line, she will simply restore the drop and not answer. To aid the operator in distinguishing the code signals, it is common practice to terminate a line of the kind just described in a combined ringer and drop. The one inherent disadvantage of the combined ringer and drop is that it takes up more of the available switchboard space than the ordinary drop. However, as an operator is not able to care for as many rural lines as regular subscribers' lines, it will be found that with the standard type of switchboard there is sufficient room for all of this kind of equipment that an operator can properly handle.

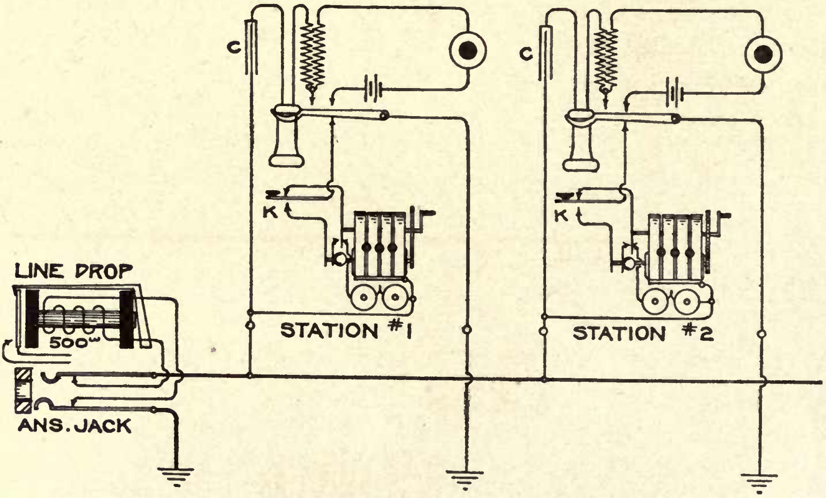


Fig. 4. — Pulsating and Alternating Current Telephone for Use on Grounded Line.

In Fig. 4 are shown the circuits of the telephone instruments and the switchboard end of the line for a system such as has been described. It will be noted by referring to this circuit that all the subscriber has to do to call central is to turn the generator crank. This operation puts pulsating current on the line and thus energizes the drop, thereby actuating its armature and releasing the shutter. Since the pulsating current flows in but one direction, it will not affect the bells at the subscribers' instruments, as this current tends to pull the bell armature in but one direction. The bell armature at a subscriber's station is normally biased by a light spring in order to prevent single taps of the bell which pulsating current might otherwise produce.

Under the scheme outlined in Fig. 4, a subscriber who desires to call a station on the same line will depress key *K* and ring, thereby ringing the various bells on the line as well as actuating the drop at the exchange. It is understood, of course, that this scheme is applicable to metallic as well as to grounded lines; but it is not quite as desirable as the grounding key system for the former, since subscribers on the same line cannot signal each other without attracting the attention of the operator, and so tending to reduce the number of rural lines an operator can handle.

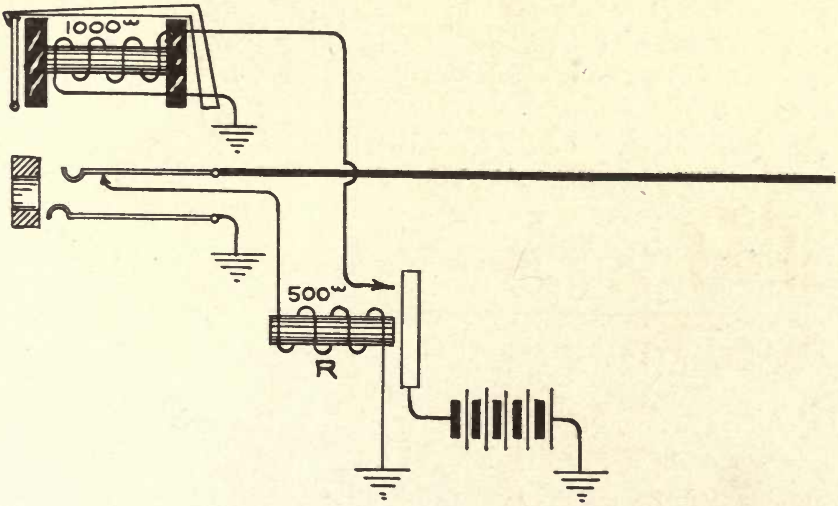


FIG. 5. — American Electric Telephone Company's Switchboard Circuit for Pulsating and Alternating Telephone.

This disadvantage of signaling the office each time a subscriber rings one of the other subscribers on the line has been avoided by the American Electric Telephone Company in an arrangement of apparatus as shown in Fig. 5. In this circuit the relay *R* is so designed that it will be actuated by pulsating current only. This is accomplished by making the armature of the relay so heavy that its inertia will be great enough to prevent it from drawing up when the relay coil is traversed by alternating current, but responsive at the same time to pulsating current.

This design is possible since an alternating current in one complete cycle passes from zero to a maximum in one direction, back to zero and to a maximum in the other direction, and finally back to zero again; whereas the pulsating current wave passes from zero to a maximum in one direction only, the other half of the wave being suppressed at the generator. Consequently the core of the line relay is exposed to a complete reversal of magnetism for each cycle of alternating current. The pulsating current, on the other hand, magnetizes the core of the drop in one direction only and produces a magnetization of greater effective intensity. Now, since the relay *R* in Fig. 5 must be energized before the line drop will be actuated by the local battery circuit, the subscribers in ringing one another with alternating current will not signal the exchange.

The Western Electric Company accomplishes the same results by making the armature of the drop exceedingly heavy and placing a copper shell over the core, thereby dispensing with the relay. The latter method is undoubtedly the better, since it avoids the local battery circuit and eliminates the use of the extra relay for each circuit.

By referring to the circuits thus far shown and described, it will be noted that a condenser *C* has been placed in the receiver circuit of all the subscribers' sets. The condenser as shown is not needed for the satisfactory operation of the telephone, but is simply inserted in the circuit to guard against trouble. Thus it is not uncommon for a subscriber on one of these rural lines to forget to hang up his receiver, or listen on the circuit from motives of mere curiosity. Under such conditions it would be impossible for the operator to ring any of the subscribers on the line if the condensers were omitted, as the low impedance of the receivers would shunt the greater part of the generator current and thus prevent the ringers from receiving enough current to actuate them. However, with the condenser in circuit, conditions are quite different. The condenser acts as a high impedance to the low-frequency ringing current, and thus shunts the ringer but slightly. Consequently, in case any subscriber carelessly neglects to hang up his receiver he will not tie up the entire line, as the operator is still in a position to signal any station desired. While this condenser offers a very high impedance to low-frequency currents, the impedance offered to the high-frequency voice currents is very low. The condensers used for this purpose are of low capacity, ranging from one-half to three-fifths of one microfarad. Experience with this plan leads practically all managers who have tried it to the opinion that its use is very beneficial. Even though the initial expense of the set is slightly increased, its adoption will more than pay for itself; it will save the lineman many a trip into the country, and so will naturally reduce the cost of maintenance.

In all of the systems thus far described there is one very serious disadvantage, namely, that the operator cannot signal the subscribers secretly, but must resort to code signals, thereby informing all the stations on the line that one of the subscribers is being called. It will be conceived very readily that the ideal system would be one in which the subscriber can signal central, and *vice versa*, without in any way notifying the other subscribers on the line. This kind of system is feasible when it is desired to place but a limited number of subscribers on the line. Practice and experience seem to indicate that four is the maximum number of telephones that can be placed on a grounded line, when the ideal conditions are desired, and that eight is the limit for a metallic circuit. A scheme which is frequently utilized in accomplishing these results is the selective ringing system, using alternating currents of four different frequencies, with one ringer tuned to respond to each frequency.

Fig. 6 shows a circuit in which the scheme just referred to is utilized. It will be noted that the ringer in each case is bridged directly across the line; but since they are designed so as to respond only to an alternating current of a particular frequency, the operator can readily select any subscriber by placing on the line ringing current of the particular frequency for which his ringer was designed. The frequencies ordinarily used in these systems are 33, 50, 66 and 16 cycles, for first, second, third and fourth stations, respectively. The design of the ringers is special to the extent that the tapper is rigidly fastened to a reed whose natural period of vibration corresponds to one of the frequencies mentioned above, the tapper itself being a weight which can be adjusted so as to tune the reed almost exactly to the period of vibration desired. The only difference between the several ringers is in the weight of the tapper, the low-frequency one having the heaviest and the high-frequency one the lightest weight; the other two range between these. It has been found practical, also, to wind the low-frequency ringer to a resistance higher than the other three.

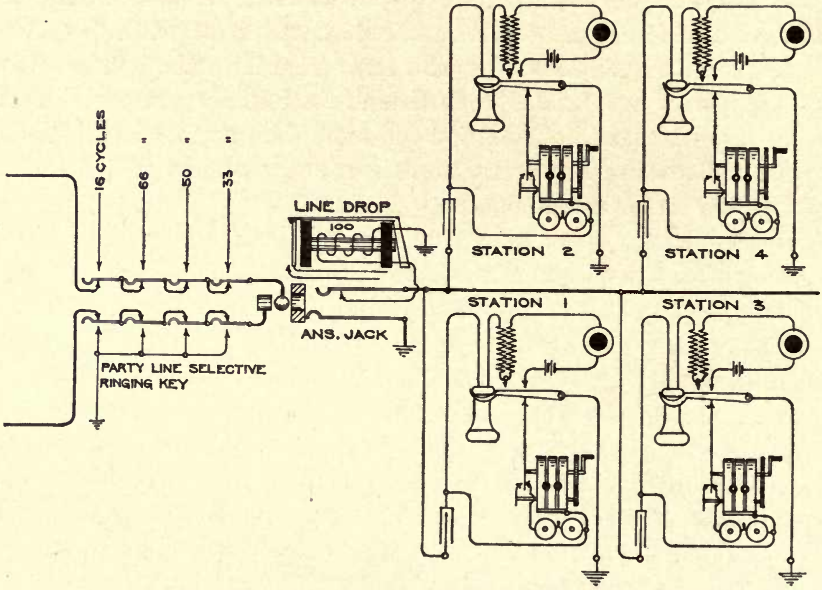


FIG. 6. — Four-party Selective System for Grounded Lines.

The trouble that has to be guarded against most in this kind of system is interference, which is the responding of more than one ringer to any one frequency. This is very often due to a poor adjustment of the ringer, or to the use of a ringing current which is not of the particular frequency for which the ringer was tuned, but some intermediate frequency capable of affecting, to some extent, two or more ringers. Then again, certain harmonics established in the generation of the ringing current and superimposed on the regular ringing wave might aid in bringing about the above-mentioned trouble. The difficulty of interference due to harmonics has been reduced almost to a minimum by the insertion of a one-microfarad condenser in the ringer circuit as shown in Fig. 6. It will be noted that when the receiver is off the hook the ringer is shunted by the receiver circuit. If the results above referred to in regard to avoiding trouble are desired, due to neglecting to hang up the receiver, a second condenser of one-half microfarad capacity must be inserted in the receiver circuit.

There is one other condition of the same order as interference, which must be guarded against in magneto systems of this type. A standard hand generator operated at the customary speed will generate a current approximating very closely to sixteen cycles. Consequently, if the circuit is not properly designed a subscriber upon signaling the exchange may actuate the sixteen-cycle ringer. In the circuit shown, this condition is avoided to some extent because the line drop is wound to but 100 ohms, and therefore the generator current will seek a path through this low-wound drop in preference to the path through the high-wound ringer and the condenser, the latter offering considerable impedance. The elimination of such trouble is further aided by reducing the output of the generators in the subscribers' sets, and is very readily accomplished by taking off some of the magnets. This reduction of the voltage of the generator is necessarily regulated by the length of the line. However, in case the line is of moderate length it is possible to operate with only one magnet on the generator. Many circuits working on this basis are in daily use, but no definite rule can be stated regarding the extent to which the output of the generator may be reduced, since this is governed, in a large measure, by the individual characteristics of the line. The most convenient method of ascertaining the best operating condition in such a circuit is by a process of experiment and elimination.

Fig. 7 shows the harmonic scheme applied to a metallic line on which eight instruments are installed. In this case, ringers of each frequency are connected from both the tip and the ring sides of the line to ground; and consequently we have a line on which eight telephones are operated, each of which is rung selectively. In case it is expedient to place more than eight telephones on the line, a semi-selective system can be resorted to and sixteen telephones may be installed. In this system four telephones of each frequency, sixteen in all, are bridged across the line, and the ringers of two instruments of each frequency are connected from either side of the line to ground. Accordingly two ringers will respond whenever any subscriber is called, and the stations have to be divided so as to respond to code signals of one and two rings.

In the foregoing nothing has been said regarding the type of cord equipment best suited for rural service. It has been common practice for many years past to use a cord circuit that is bridged by a high-wound drop. This arrangement operates very nicely where the two

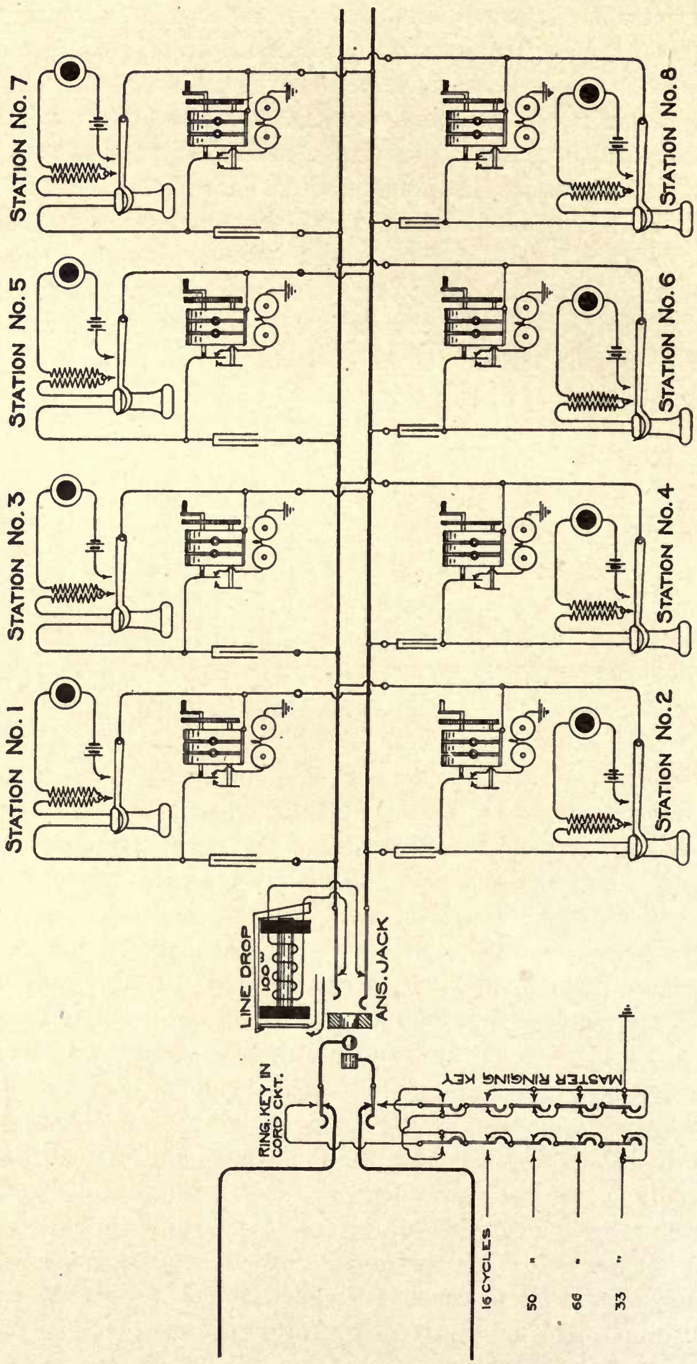


FIG. 7.— Eight-party Selective System for Metallic Lines.

lines connected are of the bridging type; but when a bridging line is connected to a series line, the parties on the bridging line will find it difficult to operate the disconnect signal, as the low-wound ringer on the series line will shunt out the high-wound clearing-out drop. When these conditions exist the two lines might be tied up for some time before the operator discovers the fact.

To overcome these troublesome conditions, a cord circuit such as shown in Fig. 8 has been employed and gives entire satisfaction.

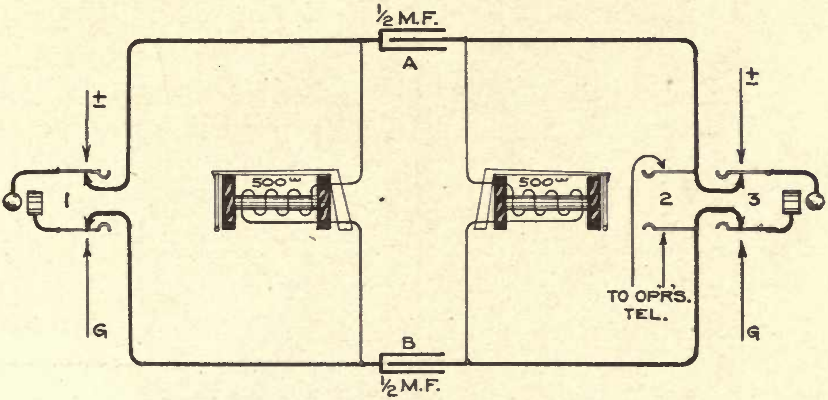


Fig. 8. — Double Supervision Cord Circuit.

This scheme, as indicated by the diagram, employs a clearing-out drop for each end of the cord. The condensers *A* and *B* are usually of one-half microfarad capacity, or slightly greater, and therefore present a very high impedance to the low-frequency ringing current and cause it to seek the easier path through the drop. On a board equipped with this type of cord circuit, there is no difficulty in receiving a disconnect signal, and its use is recommended where bridging and series lines are to be interconnected. The diagram in Fig. 9 shows the means of connecting a repeating coil to the circuit. The condensers, as before, are to force the ringing current through the clearing-out drop. The " talk-through " type of repeating coil can be used in these circuits, as it is not desired to have any of the ringing current pass through the coil. More will be said regarding repeating coils in one of the following chapters.

In concluding this chapter it is essential to emphasize the fact that for rural telephone instruments, simplicity in the construction of the parts and their assembly is of the utmost importance. The more complicated the wiring and the apparatus used, the greater are the chances for trouble; and consequently a heavy maintenance expense ensues, as well as many complaints of poor service. Very often complicated apparatus is installed with the idea of improving the service, while in fact it tends to bring about just the opposite result. In considering the purchase of telephones, the main thing is not the first cost. It is far better to think of the frequency with which the troubleman will be called upon to make an expensive trip, in order to make perhaps a minor adjustment which has put some telephone, or even the entire line, out of commission. The length of time a line will be out of service due to trouble, and the number of times the subscribers will tolerate interrupted service before ordering their telephones removed, are questions to be weighed with great care when contemplating the purchase of rural instruments. The merit of reliable efficient service is a great factor in successful operation and should be kept prominently in mind when purchasing rural equipment. The highest attainable degree of simplicity consistent with the class of service given is commended as the safest policy to follow.

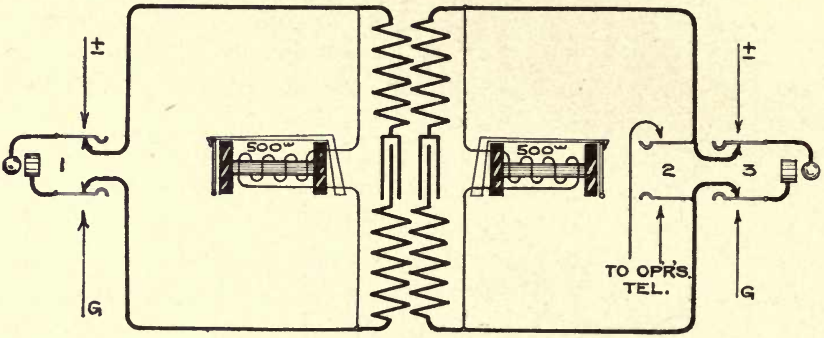


Fig. 9. — Double Supervision Cord Circuit, Using Repeating Coil.

CHAPTER III

TOLL CUT-IN STATIONS

ALTHOUGH the number of small towns which are not favored with local telephone service is very rapidly diminishing from year to year, many districts may still be found throughout the United States in which the sole means of telephonic communication consists of a single toll line which is strung through the locality. Since this is probably the only means of keeping in touch with the neighboring villages and the world at large, it will stand to reason that a service of the highest possible efficiency should be maintained. However, we find that many such toll stations are nothing more or less than a telephone set bridged across the line; and when we consider that, in all probability, there are many like stations on either side of any particular telephone, it is easily understood why transmission on these lines is often very poor, or uncommercial. The bridging of these numerous instruments across the line will not only cut down the transmission, but it also destroys the privacy of the conversation, for the addition of each telephone increases the probability that some one is listening to the conversation. To run a separate line to each one of these villages is naturally out of the question; but, on the other hand, a slight outlay of money will, if properly applied, very often improve conditions considerably.

It is generally conceded that the transmission on any line should not fall below a well-defined standard; and, therefore, any scheme or device which tends to maintain this efficiency is of great benefit. The fewer the telephones that are bridged on a line, the better will be the transmission, owing to the fact that each additional telephone provides another path for the voice current. While the coils of an ordinary 1000-ohm ringer offer a very poor path to the high-frequency voice currents, owing to their high impedance, still a very small portion of the current leaks across. When this shunting effect is multiplied fifteen or twenty times, or more, one begins to notice the effect at the receiving end of the circuit. While this effect is noticeable on speech currents, it is much more in evidence on the ringing current, as the ringer coils do not offer nearly as much impedance to the low-frequency ringing current as that presented to the voice current. This is why it is so difficult to ring on heavily loaded lines. This condition may be relieved to a considerable extent by using higher wound ringers, which reduce the amount of current passing through each ringer.

Quite often a considerable amount of trouble is met, due to placing telephone ringers of widely different resistances on the same line. The low-wound ringer provides such an easy path for the ringing current, that the high-wound ringer does not receive a sufficient amount to operate it satisfactorily, if at all. Care should be exercised to make all the ringers on a given line of practically the same resistance. If the line is very long, the resistance between the first and the last instrument may have the same effect as placing high- and low-wound ringers on the same line; *i.e.*, the ringer in the instrument nearest to the source of ringing current will receive the major portion of the current. This effect may be overcome by placing the ringer of highest resistance nearest the switchboard end of the line, and gradually diminishing resistances as the distance increases, thereby causing each ringer to receive the same current. While this may be beneficial so far as ringing the telephones on the lines is concerned, it has exactly the opposite effect when a station near the end of the line is trying to call central. But a smaller amount of current is required to operate a drop than to ring a bell satisfactorily, and consequently, the benefit on the one hand is not altogether offset by the detrimental effect on the other. We would not recommend the use of this scheme except on very long lines, where trouble has been experienced in reaching the stations at the end of the line.

When the line extends through trees, the wires should not touch any of the branches or even the foliage, as each leaf — especially in damp weather — offers a bypath through which the line current may leak to ground. On a long line on which the construction is not absolutely first class, it will be noted that the transmission is often poorer in damp than in dry weather. This is caused, to a certain extent, by a very small amount of current which leaks down each insulator. Furthermore, any foliage that touches the line wire, or any other defective construction, will likewise aid in this diffusion of telephonic current. If these conditions are allowed to multiply to an extreme, the combined effect is often great enough to render a line inoperative

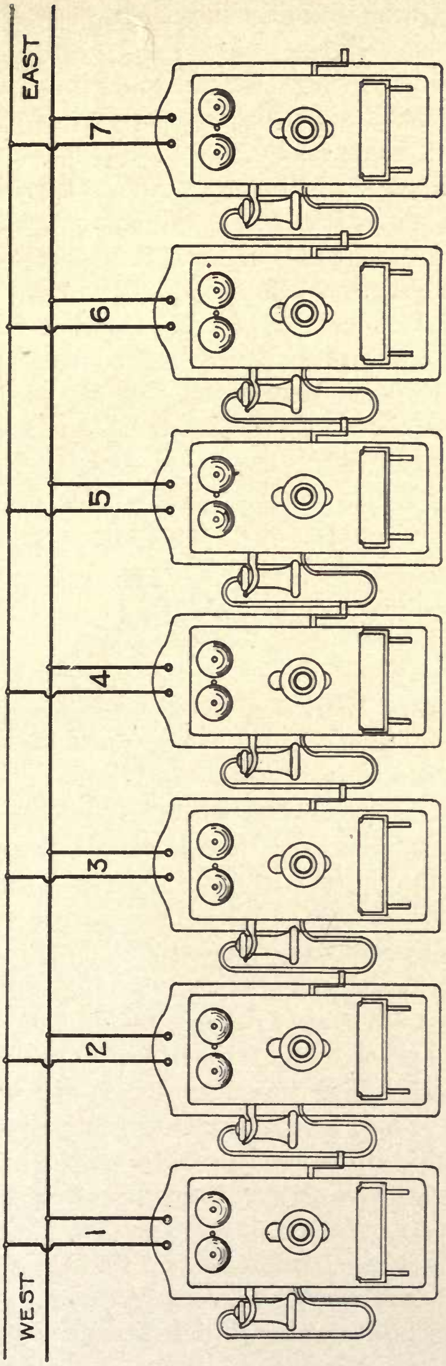


Fig. 10. — Bridging Party Line.

in damp weather, over which commercial transmission is possible in dry weather.

One method of improving this rural toll service, and avoiding to some extent the conditions just outlined, is to cut off that portion of the line which is not actually required in completing a connection. For example, in Fig. 10, suppose a person at station 4 desires to converse with a person at station 7. It will be apparent that that portion of the line which connects stations number 1, 2 and 3 could be disconnected from the main line to the betterment of the service. This would not only improve the transmission, but would also eliminate the possibility of interruption by any of the first three stations, since they would be temporarily cut off from this part of the circuits. The commercial efficiency of the line would be further improved, as any two of the first three stations could maintain an entirely distinct and separate conversation on their end of the line.

There are several methods of accomplishing the above-mentioned results. One of these which is most widely known is the method of employing a " cut-in " station, or " Waterloo equipment," as it is sometimes called. The name " Waterloo " is derived from a town of that name in the state of Iowa, where this type of equipment was first used. This equipment consists of a box about the size of an ordinary extension bell box; and is most commonly equipped with three jacks, a bell and a cord and plug. A diagram of the circuit for this scheme is depicted in Fig. 11; from which it will be observed that, normally, the line is connected through, with the bell *B* bridged across the line. The operation of the circuit is as follows. When the station receives the proper code of rings, the subscriber will insert the plug in jack 2, and upon ascertaining from which direction the call is coming, he will remove the plug from the middle jack and insert it in jack 3 if the call originates from the " west," or in jack 1 if the call comes from the " east." It will be noted that upon withdrawing the plug from jack 2, the bell *B* is again bridged across the circuit; and that it is cut off from the east or the west end of the line whenever the plug is inserted into jack 1 or jack 3, respectively. As a result of this condition, it will be observed that in case the attendant has plugged into jack 3, and is conversing with a " west " subscriber, the " east " subscriber can easily call this station, due to the fact that the bell *B* is bridged across the circuit, and the " west " circuit is entirely independent of the " east " circuit, due to the cut-off contacts in jack 3.

Another method of reaching the same result is shown in Fig. 12. In this scheme, as appears in the diagram, a two-way key is employed in place of the cord, plug and jacks used in the previously described method. The advantages cited for the second method are the elimination of plug and cord troubles and the superiority of a key contact to a jack and plug contact. The operation of this circuit consists in throwing the key in one direction to converse over the "west" line, and in the opposite direction to converse over the "east" line, the bell remaining bridged across the idle portion of the circuit. It will be noted that this circuit has no arrangement by means of which the attendant's telephone can be bridged across the through line; and this constitutes the principal disadvantage of the scheme, because in answering a call, he is as likely to bridge his set across the wrong end as the right end of the circuit. For calls originating at such a cut-in station, it is necessary to open the line to connect the attendant's telephone to the circuit; and this would interrupt any conversation which might be passing over the line. These disadvantages can be avoided by reversing the position of the bell and the attendant's telephone, as shown in Fig. 13. In this case, the bell in the telephone set is used in calling the station.

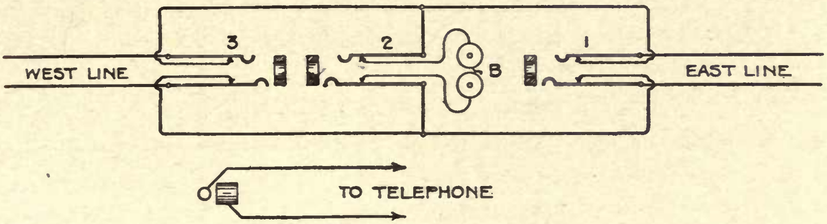


FIG. 11. — "Waterloo" Station Equipment.

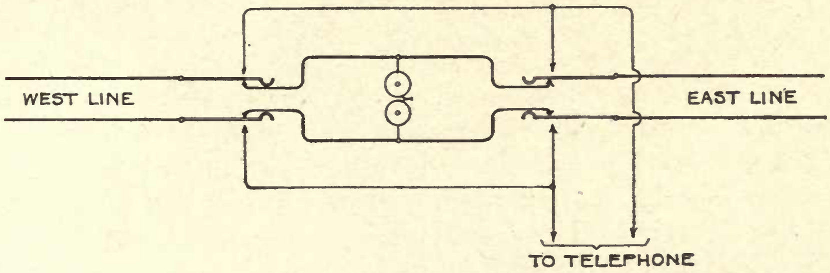


FIG. 12. — Toll Cut-in Station with Key Equipment.

The attendant at a station wired in accordance with this modification has merely to remove his receiver from the hook to answer a call, which is the least amount of work that can be demanded. In addition to this, the attendant will operate his cut-off key as soon as he ascertains from which direction the call originated, thereby disconnecting that portion of the line not in use. This circuit undoubtedly shows the ideal arrangement for this type of equipment.

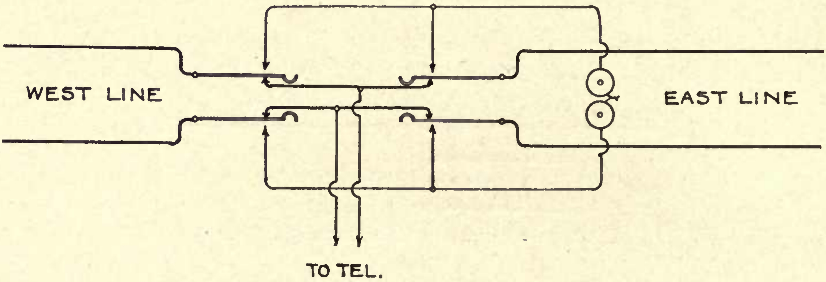


FIG. 13. — Approved Method of Wiring Key Equipment at Toll Cut-in Station.

The arrangements thus far described are all designed for metallic service; but since quite a number of the lines through rural districts are operated on a ground return system, there is shown, in Fig. 14, a circuit for use on such systems, which is a modification of the one shown in Fig. 13. The operation is identical with that given in the preceding paragraph.

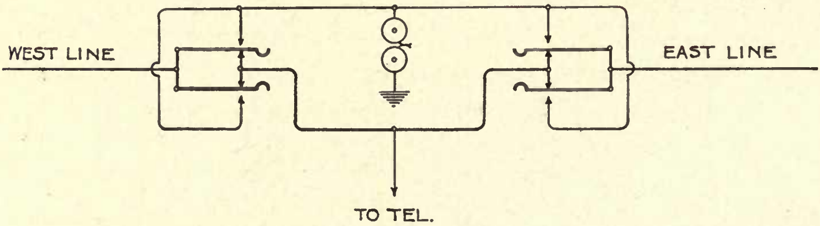


FIG. 14. — Toll Cut-in Station for Grounded Lines.

Another method of wiring a cut-in station on a ground return system is shown in Fig. 15. This scheme can be used only when through service is not required; but the attendant's station is so equipped that a conversation can be carried on in either direction, the part of the line not in use being cut off. In this case, the only additional apparatus required is a double-pole, double-throw switch and an extension bell. The switch is so wired, as indicated in the figure, that the subscriber's telephone is connected to one end of the line and the extension bell to the other, when the switch is in one position; while conditions are reversed when the switch is thrown in the opposite position. In the use of this scheme, it is well to equip the subscriber's set with a bell whose ring can be distinguished readily from the response of the bell used on the extension set, so that the attendant can always tell, by the character of the ring, from which direction a call arrives.

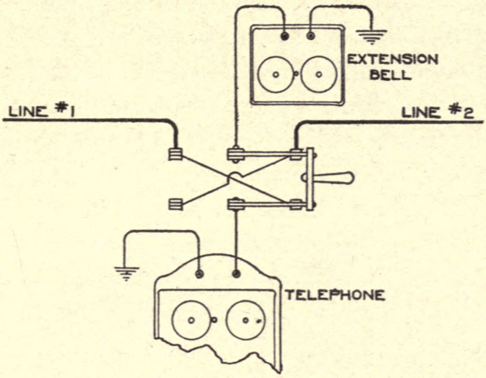


Fig. 15. — Telephone Station Switch for Use with Two Grounded Lines.

In this connection we wish to show the general method used in connecting a grounded line extension, or branch line, to a metallic toll line, which necessitates the use of a repeating coil. The circuit used for this scheme is presented in Fig. 16. The use of a repeating coil becomes necessary because it is impossible to connect a grounded line direct to a metallic line and still preserve the advantages inherent

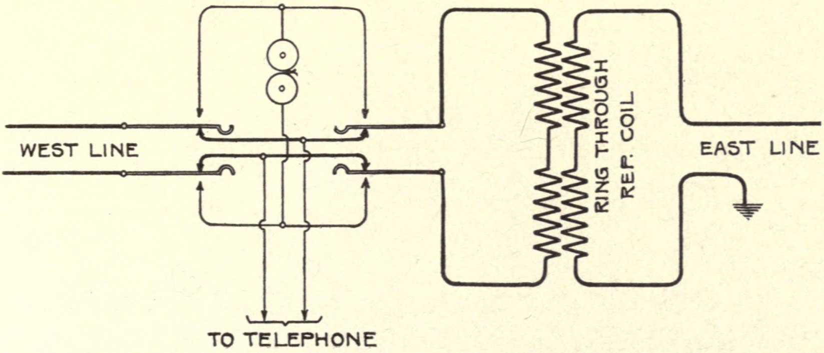


Fig. 16. — Toll Station Switch for Connecting Grounded and Metallic Lines.

in a metallic line. Thus, if the grounded line is connected direct to one side of the metallic line, it is evident that the other side of the metallic line will have to be grounded to complete the circuit through the grounded instrument. Hence the metallic circuit would be practically transformed into a grounded circuit for its entire length, and would be susceptible to all earth currents and other disturbing features common to grounded lines. The repeating coil, however, keeps the metallic and the grounded lines physically separate, with no connection, except inductively, through the coil windings. This maintains the balance of the metallic line and greatly reduces the inductive interferences that might otherwise exist. The coil shown in Fig. 16 should be of the ring-through type, to permit subscribers on the grounded line to ring through to the metallic line and *vice versa.* The key arrangement in this circuit is the same as that shown in Fig. 13.

A few words of explanation in regard to the construction of the two general types of repeating coils are appropriate here. The operation of a repeating coil rests upon the same principles as those of a transformer, in theory. To obtain an efficient transformer for heavy electrical currents, the designer must know the frequency and the voltage of the primary current and also the voltage and maximum current that will be taken from the secondary side. In power work, these quantities are all definite; the designer has a problem with comparatively few variables and is able to design a highly efficient apparatus. But, on the other hand, the number of variables in repeating coil design is so great as to make it most difficult to attain high efficiency.

The frequencies of voice currents range from a few hundred to several thousand cycles per second and, as such, complicate the design of an efficient transformer. A repeating coil should be designed to transform most efficiently those frequencies that are most vital in the transmission of speech; but no coil will be uniformly efficient for all the frequencies. However, practice has proven that a commercial repeating coil designed with a comparatively small amount of iron will repeat voice currents with a talking efficiency of ninety per cent, or slightly more. Such a coil is intended for talking currents only, as no consideration has been given to the low-frequency ringing currents.

A coil designed for repeating both kinds of current must naturally cover a much wider range, as the ordinary ringing frequency is about sixteen cycles, while the frequency of waves corresponding to vocal overtones may reach several thousand cycles. The coil must be designed to transmit the ringing current efficiently enough to operate the bells, and at the same time the voice currents must be repeated without material loss of energy. A coil designed for this double purpose must have a large amount of iron in its core to be able to repeat the ringing current; and the iron must be very soft and finely laminated in order to repeat the voice currents efficiently. Such a coil, at best, is more or less of a compromise. If a coil for this purpose is constructed with a talking efficiency of about seventy-five per cent under the most severe conditions, its design may be considered good.

If the junction of the grounded line with the metallic line is not at a point where a telephone is desired, the connection can be made through a repeating coil, as shown in the diagram in Fig. 17. At points where repeating coils are used, special care should be exercised to obtain good lightning protection, or a great amount of trouble will arise due to the burning out of the coils.

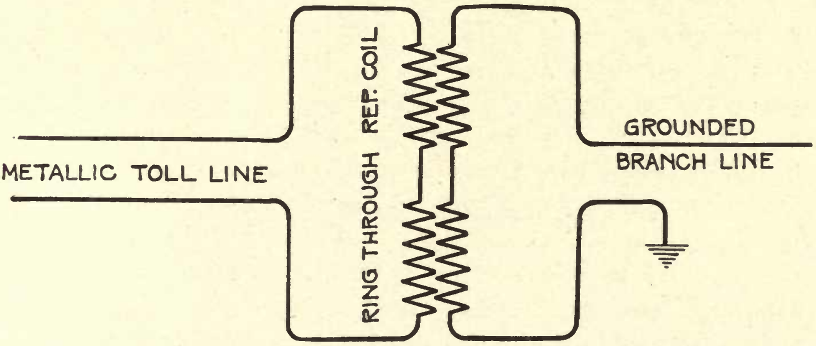


FIG. 17. — Repeating-coil Connection Between Metallic and Grounded Lines.

There are many standard forms of protectors which are satisfactory for this kind of work; and as the protection required is identical with that which should be used at the toll station itself, the following description will suffice for both. These arresters should contain, for each line wire, a fuse, which will blow if an abnormal amount of current flows over the line, and carbon blocks provided with a small air gap, by way of which static or lightning charges can pass to ground. The last-mentioned function of the arrester is one of the most important, as the burn-outs on aërial lines can be traced frequently to lightning. These burn-outs can generally be avoided by providing a suitable path of very low resistance for the lightning. The most vital feature in all lightning protection is the provision of a satisfactory ground connection, for without this the best of equipment is of no avail. When the building in which a telephone is located is piped for water, ready means for good and permanent grounds are available. But as this is of rather infrequent occurrence in rural districts, other means of securing a satisfactory ground must be devised. The ordinary ground rod, which is six feet long by one-half inch in diameter, is very satisfactory for this purpose in case the soil into which it is to be driven is naturally moist. However, in loose sandy soil, a depth of six feet is very frequently insufficient to insure permanent moist earth about the rod. For this reason, in localities that are exceptionally dry, ground rods are frequently placed in the cellars under the houses. This is a very good way of obtaining a satisfactory ground connection, as it practically lengthens the ground rod by a length equivalent to the depth of the cellar. Upon securing a good ground, the next step is to wire the same properly to the arrester. The wire used for this purpose should be run in a direct line, avoiding turns as much as possible. The wire should never be contained in an iron conduit, as lightning is oscillatory in nature and of a very high frequency. In order to insure a permanently good contact, the ground wire should always be securely soldered to the ground rod.

Trouble due to poor grounds, aside from the standpoint of protection, is of frequent occurrence where the earth is used as a return for both the talking and the ringing currents. In this case, considerable trouble is frequently experienced in ringing a station, if the telephone is not properly grounded. Thus a ground might be of such resistance as not to greatly diminish the talking current, but at the same time high enough to prevent the passage of sufficient ringing current. Such cases of trouble are extremely annoying, for the trouble-man may naturally consider the ground in good condition, since the line will transmit the talking currents, and so attribute the trouble to a defective ringer. Another trouble to which the ground is subject is "drying out"; this may be very exasperating to the subscriber, since the service will vary from day to day according to whether the soil is dry or wet. In other words, the service will be good directly after a rainfall, from which time it will gradually become poorer as the ground dries out.

Having described the method of operation of the various kinds of equipment for this class of work, there are several features to be noted in the arrangement of the equipment itself. The extra equipment necessary for this service is sometimes wired in the telephone set itself. This arrangement forms a very compact equipment, but since it makes the entire equipment special and the wiring somewhat complicated, it is not very desirable. The most satisfactory equipment for these stations is a standard telephone provided with a 1600-ohm bell, a four- or five-bar generator and a separate box containing the necessary "cut-in station" equipment. Such an equipment using the key arrangement is shown in Fig. 18 and that for the jack and plug arrangement in Fig. 19.

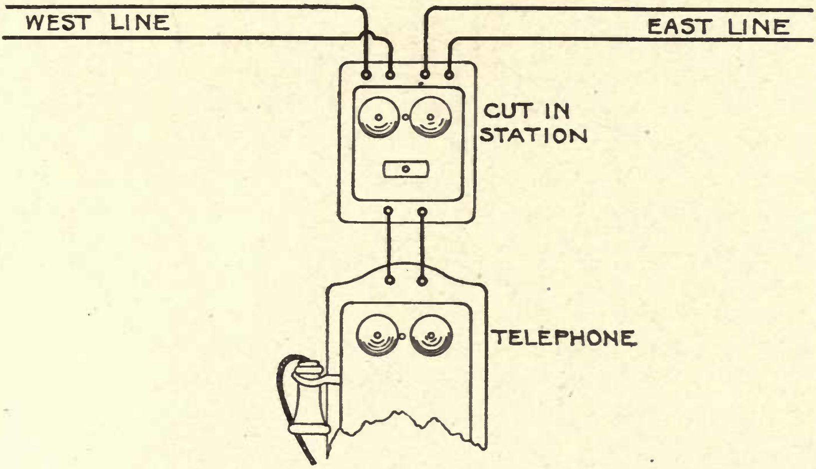


FIG. 18. — Key-type Equipment at a Toll Cut-in Station.

When it is desired to cut in on a toll line which passes through a town where local service is given, it is advisable to run the line through the local switchboard in accordance with the circuit shown in Fig. 11. The bell, in this case, is replaced by an ordinary switchboard drop of 1600 ohms; or, possibly, by a combined ringer and drop, the latter of which aids the operator in distinguishing the code signals.

When the scheme just outlined is adopted, the operator at the switchboard will answer an incoming call with the answering cord of one of her regular cord circuits; and upon ascertaining the direction from which the call arrives, she will switch the plug over to the proper jack and insert the calling plug of the pair used in the jack associated with the subscriber's line called for, thus completing the connection.

Where only one or two toll lines are to be cared for at a small local board, it is sometimes more convenient not to have the toll equipment in the board at all, but mounted in a box as previously described, and fastened to the end of the switchboard cabinet within easy reach of the operator. In this way the general arrangement of the apparatus in the board is not disturbed by any special equipment; and the wiring for the toll lines can be of such size and insulation as best suits the local conditions. It is customary to bring the local lines into the switchboard through a cable; and if the toll lines were carried through the same cable, they might either pick up some local trouble, or, in turn, introduce some disturbance in the local lines. Therefore it will be seen that there are advantages in keeping the toll equipment entirely independent of all other equipment.

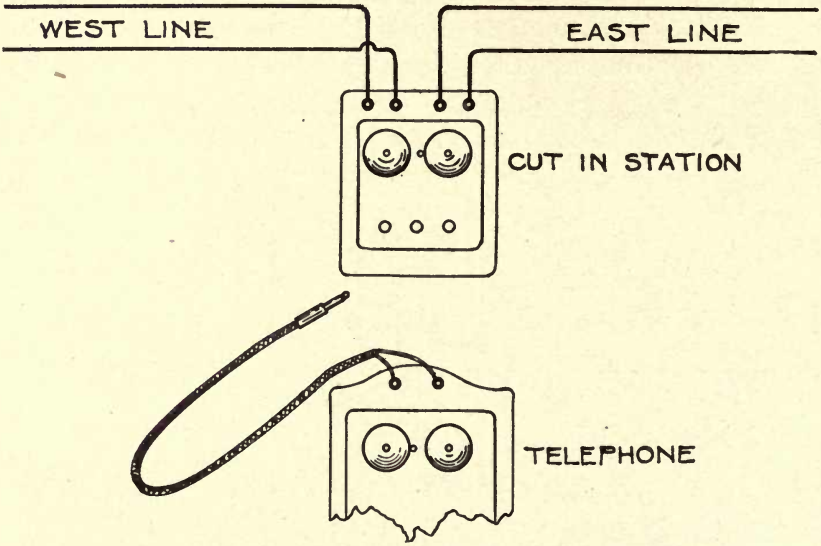


Fig. 19. — Jack-type Equipment at a Toll Cut-in Station.

In most cases it is necessary, in connecting a toll line with a local line, to use a repeating coil. This is often true where the connections are made in small rural exchanges; for here the majority of the local lines are of the grounded type. Where common battery systems are employed, the repeating coil must always be used, so that the only place where it is not required is in connection with metallic magneto lines. For connecting with a through toll line, it is customary to have at least one cord circuit in the switchboard equipped with such a coil.

When a toll line terminates at the local board, it is sometimes more convenient to have the repeating coil inserted permanently in the line; this is the case if there are but one or two lines, as the operator can use any cord in the board to complete a toll connection. In Fig. 20 there is shown a circuit of a toll line which is somewhat special; but it has met with a great deal of favor in some of the western states. The equipment is all mounted in a small box and attached to the end of the local switchboard. The terminals of the toll line, the public telephone and the generator are brought to binding posts on the outside of the box to facilitate wiring. The line is normally connected to the public telephone in the exchange, and when the operator hears the bell ring, she will answer by inserting any of the answering plugs in the jack associated with this line; this operation will connect her through the repeating coil to the toll line. Then, upon learning that a local subscriber is desired, she will complete the call in the usual manner. In case a party having no telephone is desired, he will be called by a messenger to the public telephone, in which case the operator will withdraw the plug from the toll-line jack. When it is desired to call over the toll line, the operator will simply throw the ringing key and turn the crank of the hand generator. With this arrangement, a conversation from the public telephone can be held over the line direct, thereby avoiding the path through the repeating coil and switchboard cords, which improves the transmission. The repeating coil, in this instance, is of the talk-through type only; the condensers in the circuit are used to divert the generator current through the ringer of the public telephone at the toll-line end and through the switchboard drop at the local end of the circuit.

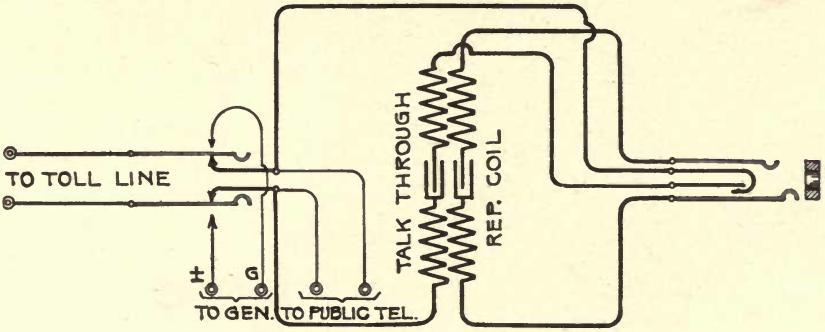


FIG. 20. — Wiring of a Toll Terminal for a Small Switchboard.

CHAPTER IV

TOLL POSITIONS AT A LOCAL SWITCHBOARD

In approaching the problem of toll switchboard equipment it is but natural to start with the small exchange, in which one position of the local board is given up to the handling of toll calls. Therefore a study of the conditions that warrant an installation of this kind of equipment will be considered first. In a small exchange having from five to ten toll lines, which are not very busy, the installation of a separate toll board is an unnecessary expenditure. These conditions are nicely met by equipping the first position of the local board as a toll position. In case it is found that the toll lines are not in service enough to keep the toll operator busy, the rural lines in the exchange can also be turned over to her.

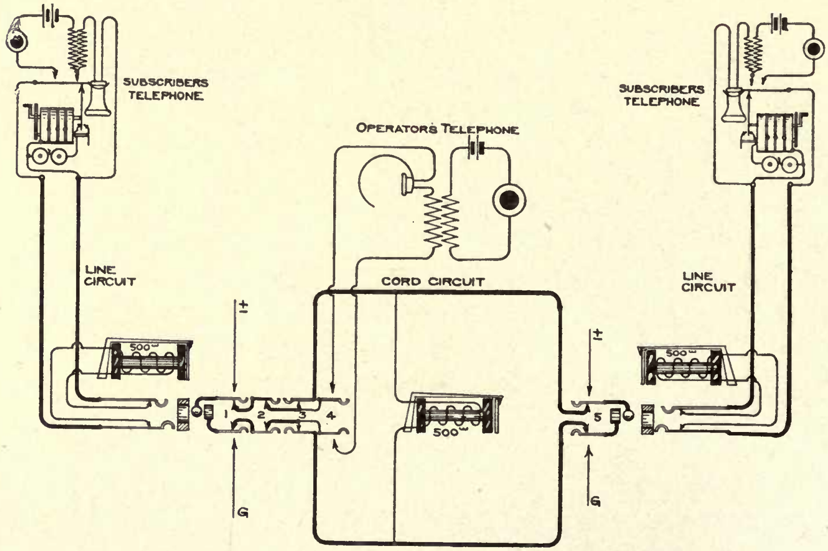


FIG. 21. — Toll-to-Toll Connection at a Small Magneto Switchboard.

In the study of toll circuits, the simple toll-to-toll circuit should be considered first, inasmuch as this type of connection is necessary in all toll work, no matter how complicated the other equipment may be. In Fig. 21 is shown such a toll-to-toll connection which is suitable where there is no toll-line multiple. The cord circuit used for this class of service consists, as shown, of the two strands of the cord across which is bridged a standard high-wound clearing-out drop.

How this position can best be equipped depends in a large measure upon the type of local board, as to whether the same is multiple or non-multiple, magneto or common battery. The various types of equipment necessary can best be explained by a complete and distinctly separate description of each.

The Magneto Non-multiple Board. — This type of board very seldom reaches an equipment of more than six hundred lines; and since the revenue from a board of this size is not large enough to warrant the engaging of an expert, the toll equipment should be so simply designed that a man of little experience will have no difficulty in keeping it in working condition. This requirement is well fulfilled by the circuit arrangement shown in Fig. 22, the operation of which can most readily be explained by tracing a call through to completion.

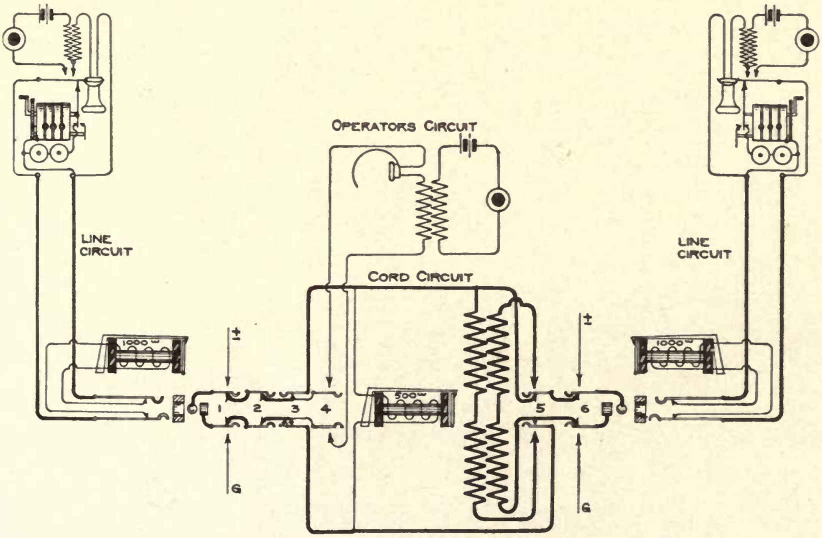


FIG. 22. — Toll-to-Toll Connection with Repeating Coil.

When a toll subscriber desires to call central, he will operate his generator, thereby releasing the shutter of the high-wound drop that is bridged across his line by means of the series contact in the line jack. The operator will then insert the answering plug of a pair of cords in the jack and thus disconnect the drop from the line. She will then operate her listening key 4, and ascertain the number of the subscriber desired. If the jack of the subscriber wanted terminates in the toll position or the one adjoining, the toll operator will simply insert her calling plug and ring. Should the two lines thus connected be noisy, the operator may, by operating the repeating coil key 5, connect the two lines inductively and thus reduce to a minimum any disturbances that exist, due to unbalance. This unbalanced condition is usually caused by connecting a toll line with a local grounded line, but the use of the repeating coil is not necessary where two metallic lines are connected. If the line of the called subscriber terminates in a distant position, the need of a transfer circuit becomes apparent.

It will be noticed that in the transfer circuit shown in Fig. 23, the toll-line end terminates in a jack, and that it ends in a plug at the local position. The reason for this will be apparent from the following. When the toll operator finds that she cannot reach the jack of the subscriber desired, she will plug into a transfer terminating in the position at which that jack is located. This operation will light the lamps associated with each end of the transfer. She will then press an order key, the circuit of which terminates at the desired position, and instruct the local operator as to what number is desired; this operator, upon receiving these instructions, will take up her transfer plug and insert it in the jack of the desired line. The raising of the plug will operate the plug switch, and this will extinguish the transfer lamps. The toll operator will then ring the station called for and the connection will be completed. When the subscribers have finished they will "ring off," thereby operating the clearing-out drop, which is permanently bridged across the cord circuit. The toll operator will then operate her listening key, to determine whether the conversation has been completed, or whether the subscribers wish further service. In case she finds that the subscribers have finished she will take down the connection. This will light the lamps associated with the transfer circuit and give the local operator a disconnect signal; she will then remove the connection and thus restore the apparatus to its normal condition.

If a toll call originates at the local position, the answering operator will simply take down the local plug and insert the plug of one of the transfer circuits in the line jack. This will operate the plug switch, thereby lighting the lamp associated with the transfer at the toll position, as well as the one at the local position. The toll operator,

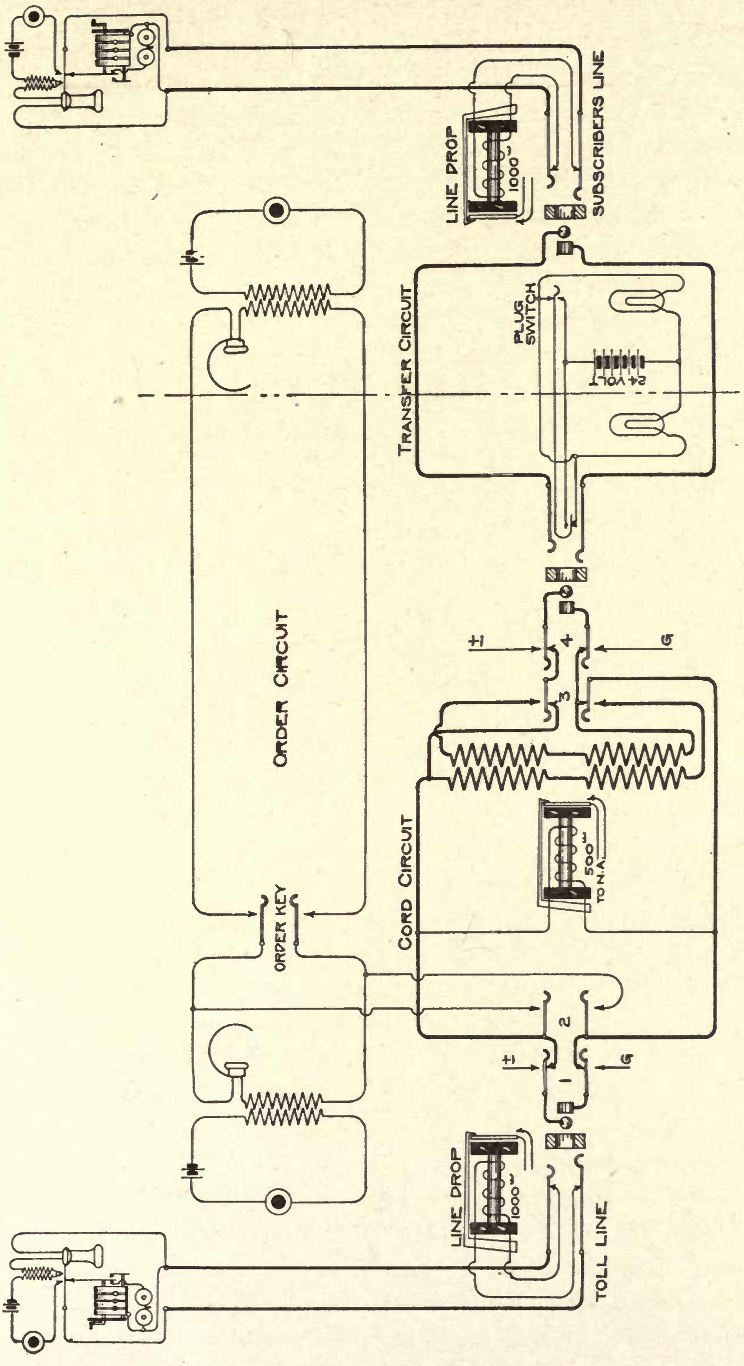


FIG. 23. — Toll-to-Toll Connection, Using a Transfer Circuit.

upon observing this lighted lamp, will plug into the jack associated with this transfer circuit, thus extinguishing both lamps, and will then handle the call in the regular manner just described.

A few words of comment upon the advisability of a plug-ended transfer may be of interest. As will be observed from the above, the toll operator has absolute control of the connection; whereas if a jack-ended transfer were used, it would require the use of another cord circuit in setting up the connection at the local position. This would not only cut down transmission, but might also result in a confusion of signals. Furthermore, the local operator would have an opportunity to cut in, by means of her listening key; and this is an important consideration in a small exchange where the operators are not always busy.

At first glance it might seem that the use of a repeating coil in each cord circuit is superfluous. However, when one stops to consider that this equipment obviates the changing of cords due to special conditions, which are prevalent in small exchanges on account of inferior construction, and that operating efficiency is thereby increased with but small expenditure, the practice seems to be well justified.

It is very often necessary that the operator should be able to talk to each party separately. In this case the circuit should be equipped with a double cut-off key 2 and 3 as shown in Fig. 21. Thus when an operator has a subscriber waiting on the line for a toll connection, she should be able to cut off that portion of the line while she is making arrangements for the other end of the connection. By this means she can avoid all unnecessary interruptions by the waiting subscriber, and, consequently, can complete her connections with much greater rapidity. Since speed of operation is an important factor, small additional expense for such facilities is a good investment. The cord circuit shown in Fig. 22 represents advanced or improved practice, but has not yet been extensively adopted in rural systems. Fig. 23 indicates the conditions which will be found prevalent throughout the country in the small plants.

Magneto Multiple. — The next consideration, in order, is the magneto multiple board. A multiple of all the local lines appears directly in front of the toll operator in this type of board, and hence the method of handling toll calls is simplified to the extent that no trunking equipment is necessary. The cord circuit previously explained in Fig. 23 can be adapted very readily to this class of service, the only change necessary being the addition of a third conductor. This third conductor is the means by which battery is put on the sleeve of the jack for the busy test, and is wired through a retardation of ten ohms to a battery of about ten dry cells. This arrangement of the equipment is indicated in Fig. 24. When an operator plugs into the multiple, she puts the potential of the negative side of the previously mentioned battery on the sleeve of the jack; and hence, if a toll operator tests a busy line in the usual manner, she completes a circuit through the sleeve conductor of her cord and the tertiary winding of the induction coil to ground, and will, consequently, obtain the regular busy signal. In case no test is obtained, the connection will be put up in a manner like that previously explained for the non-multiple switchboard, when no trunking is necessary.

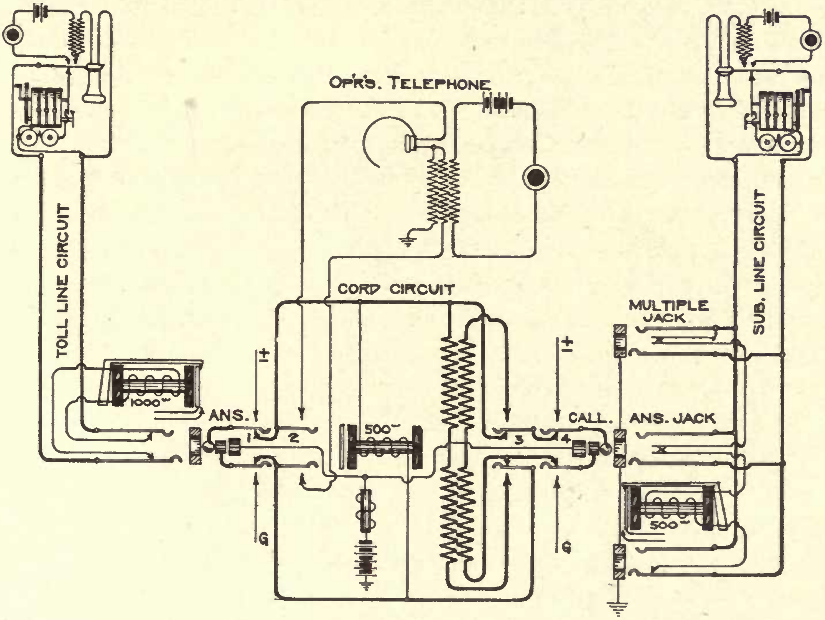


FIG. 24. — Toll-to-Local Connection in a Magnetic Multiple Switchboard.

THE NON-MULTIPLE COMMON BATTERY BOARD. — In connecting a toll line to a common battery local line, it is imperative that the connection be made through a repeating coil, so as to keep the battery which feeds the local line from sending current out on the toll line. For this reason the cord circuit must be arranged so that it is universal, that is, adapted both for toll-to-toll and toll-to-local connections, or otherwise two kinds of cords will have to be installed. It is advisable whenever possible to make the cord circuits universal; for, since operators are not infallible, they are likely in a busy moment (if two sets of cords are installed) to use the wrong pair of cords, thus causing confusion and giving poor service. Furthermore, if an operator does not have to work with two kinds of cords she can handle a larger number of calls per hour.

A very ingenious method of accomplishing the above result is depicted in Fig. 25. The toll end of this circuit is an exact duplicate of that shown in Fig. 21; but the local end of the cord is dissimilar in the respect that it has a three-conductor in place of a two-conductor cord, and the repeating coil key is omitted since its functions are performed automatically by means of the relay in the sleeve circuit.

The cost per cord circuit for such equipment is a little more than for the other type; but due to the fact that the operation is simplified, less circuits will be required and the equipment for the position as a whole is not much more expensive. The design of this circuit is such that in its normal condition it is arranged for toll-to-toll connections and therefore the sleeve conductors of the toll-line jacks are left open. The use of a repeating coil is not necessary in a toll-to-toll connection, if these lines are metallic. In case any of the lines entering the exchange are ground return circuits, a toll-to-toll cord equipped with a repeating coil, such as was shown in Fig. 22, should be installed.

Referring to Fig. 25, if a plug is inserted in the jack of a local line whose sleeve is wired to ground, it is apparent that this will complete a circuit through the sleeve of the cord and the sleeve relay to battery. This energizes the relay, thereby placing the repeating coil in circuit and at the same time feeds battery current to the local subscriber. For this sort of connection the toll operator's work is reduced to a minimum.

If the local positions at the board number three or more, however, it will be necessary to transfer all calls, excepting those for numbers which terminate in the jacks at the toll position or the one adjacent. A transfer well suited for this purpose is shown in Fig. 25 and the method of operation is as follows: Should the toll operator desire to connect a toll line with a subscriber whose line terminates in a distant position, she will plug into one of the transfer circuits, the plug end of which is located at the position where the desired line terminates. This act will energize the relay in the transfer circuit and thus light

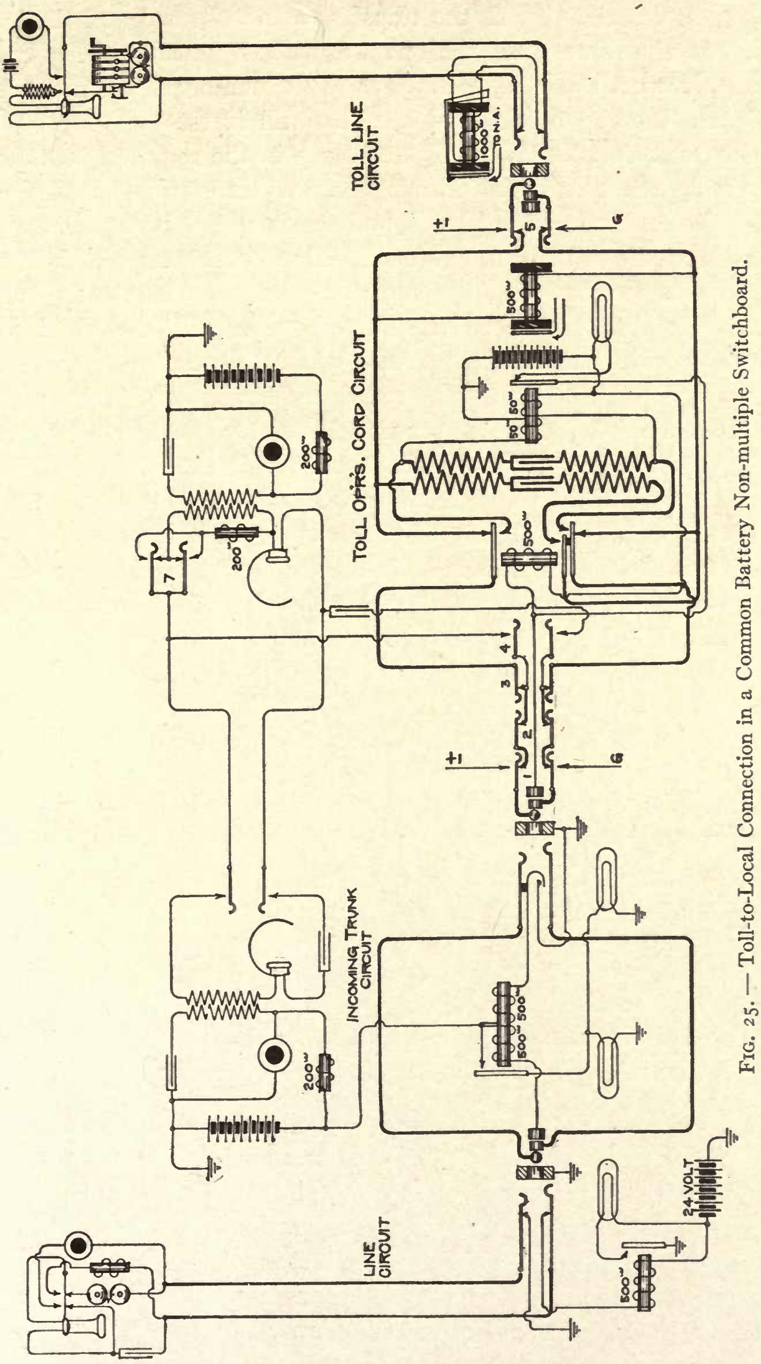


FIG. 25. — Toll-to-Local Connection in a Common Battery Non-multiple Switchboard.

the lamps associated with the transfer at the toll end and the local end. At the same time, the operator will, by means of her order circuit, instruct the local operator as to the number of the subscriber desired. Thereupon the local operator will insert the plug of the transfer associated with the lighted lamp in the required jack, thus energizing the differential winding on the transfer relay; this will cause the armature to fall back, and the lamps at both ends of the transfer circuit will be extinguished. The toll operator will then ring the local subscriber and the connection will be completed. When the conversation is finished, the toll subscriber will "ring down" the clearing-out drop in the cord circuit, while the local subscriber, upon " hanging up," will light the supervisory lamp. The toll operator will then remove the cords, thus lighting the transfer lamps and giving the local operator a disconnect signal; the latter will take down the cord of the transfer. All apparatus will be restored then to its normal condition. It will be observed that in this system, as well as in those previously described, the toll operator has the entire supervision of the connection. This condition is an important one for fast service. If a toll call originates at a local position, the operator will take down her local cord and replace it with one of her transfer cords, thus lighting the lamp at the toll position associated with this transfer. The toll operator will then take up the connection and complete it in the usual manner.

COMMON BATTERY MULTIPLE SWITCHBOARD. — When a position at a common battery multiple board is equipped as a toll position, the conditions are somewhat different from those for a non-multiple board, since it becomes necessary to test the multiple jacks to ascertain whether or not a line is busy. A circuit arranged to meet these requirements is shown in Fig. 26; it illustrates the fact that as an exchange grows and the local equipment improves, the local end of the toll cord circuit becomes more complicated. The toll end of the cord is similar to that in Fig. 21, whereas the local end is radically different; a two-conductor cord and a repeating coil key are again employed. The circuit in its normal condition is arranged for toll-to-local connections with the repeating coil in circuit, but the latter can be cut out of service by operating key 5; this operation also disconnects the battery from the tip and the ring conductors of the cord circuit and thus adapts the circuit for toll-to-toll connections.

The operation of the circuit is as follows. When a toll subscriber

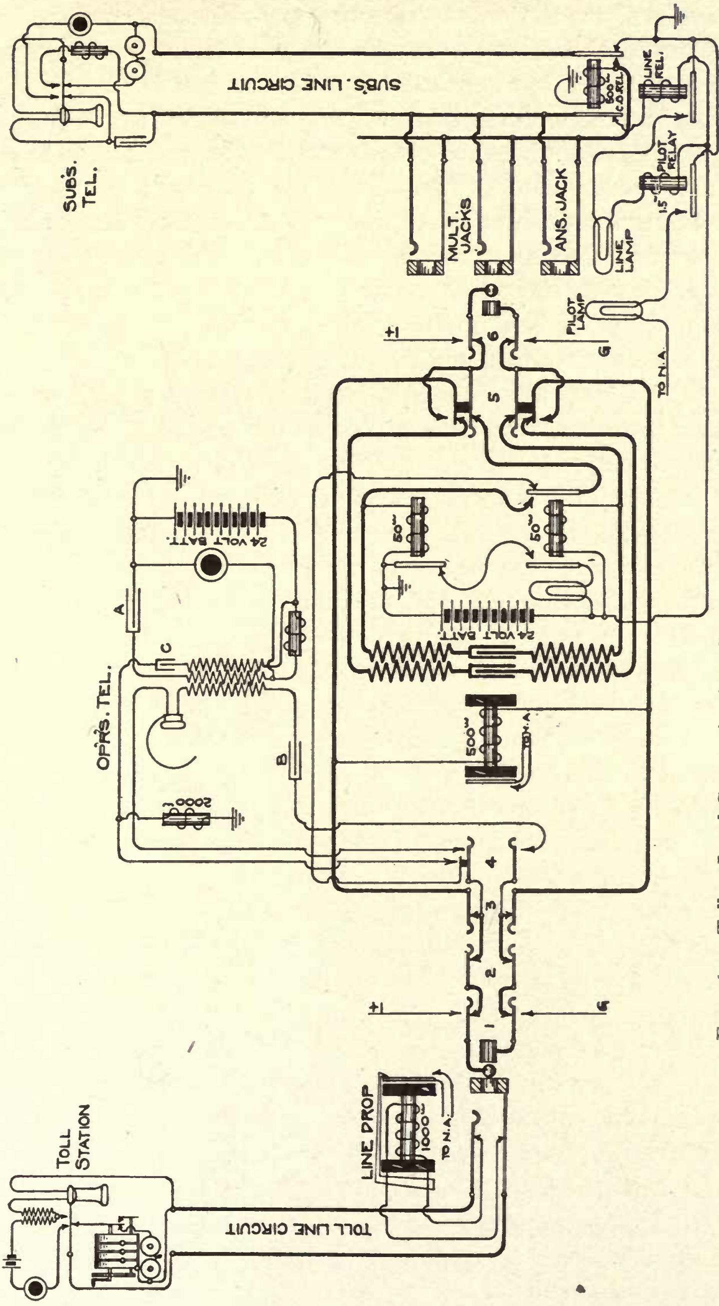


Fig. 26. — Toll-to-Local Connection in a Common Battery Multiple Switchboard.

desires a local connection, the toll operator will test the multiple jack of the line desired, in the usual manner. If the line is not busy, the sleeve of the jack is at ground potential and hence, if the operator touches the same with the tip of her plug, no flow of current can take place, because the tip of the plug is at the same potential; the latter condition is caused by virtue of the ground attached to the winding of the retardation coil in the operator's set, which connects with the tip of the cord through the back contact of the ring relay. If the line is in use, however, the potential of the sleeve of the jack will have been raised, by the ring of the plug inserted, to that of the negative side of the battery; and, consequently, if the toll operator makes a busy test, she will obtain a flow of current through the winding of the retardation coil and will receive the usual busy signal. This signal is the result of a readjustment of the potentials at the terminals of condenser *C*, which causes a momentary flow of current through the tertiary winding of the induction coil; this, in turn, acts inductively upon the secondary winding and causes a momentary flow of current in the receiver circuit. If she finds that the line is not busy, she will insert the plug and ring the subscriber. The insertion of the plug will light the supervisory signal through the " make " contact of the ring relay. The signal will be extinguished when the subscriber answers, by the action of the tip relay, the back contact of which opens the lamp circuit.

When the conversation is finished, the toll subscriber will " ring down " the clearing-out drop; the local subscriber will hang up his receiver, thereby interrupting the current in the tip relay, which in turn will cause the armature to fall back and light the supervisory lamp. The toll operator will then take down the connections and restore the apparatus to its normal state. In case a toll call originates at a local position, the operator, by means of her order circuit, will give the toll operator the number of the subscriber calling. Then the toll operator will answer in the multiple, and the local operator will take down her connection. The call will be handled thereafter in the regular manner. If a toll-to-toll connection is desired, the toll operator will merely operate the repeating coil key 5, plug up the connection and ring. If the exchange contains any ground return lines, toll or rural, it is advisable to install one or more cord circuits like that shown in Fig. 22.

In case the local multiple is a three-wire circuit the transformation

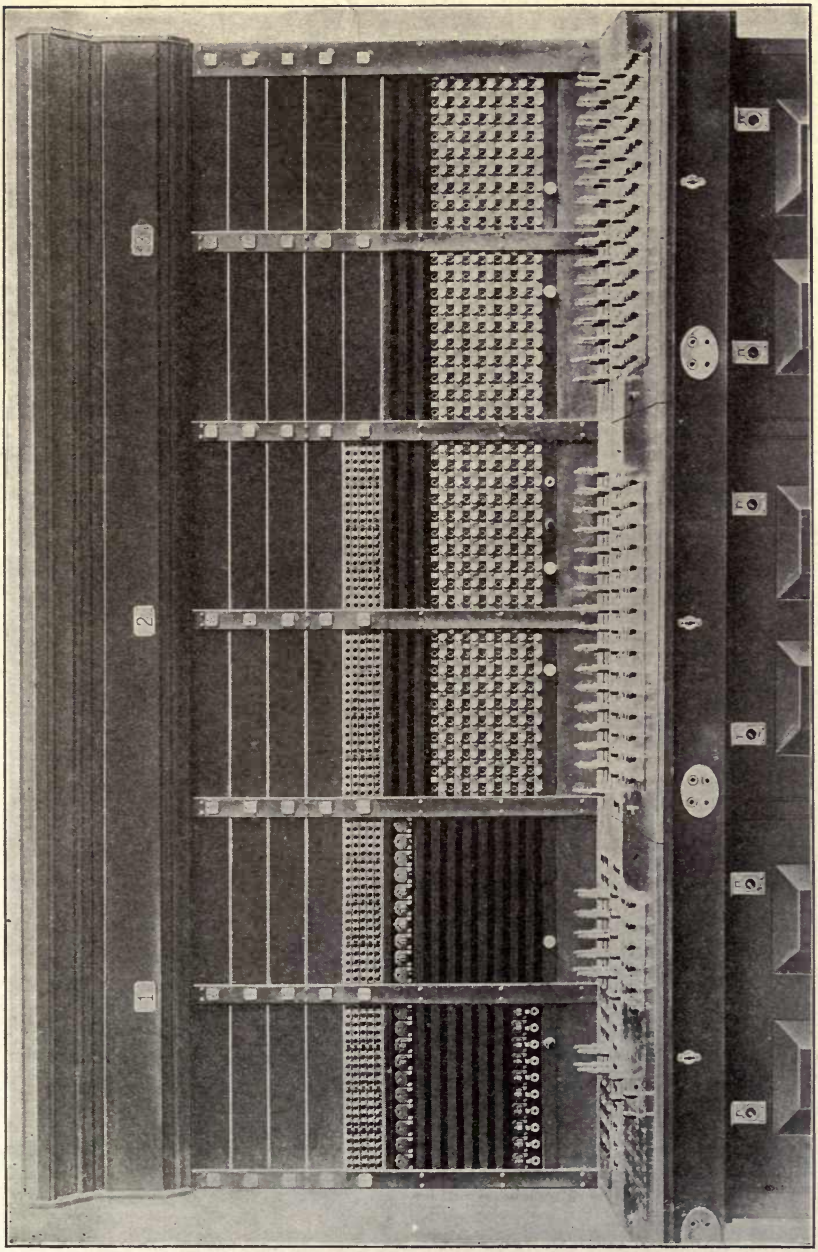


FIG. 27. —Section of Common Battery Multiple Switchboard Showing Toll Position.

of the cord from a toll-to-toll to a toll-to-local circuit, and *vice versa*, may be accomplished automatically. This can be done by an arrangement of apparatus similar to that shown in Fig. 25.

Thus far, nothing has been said about the operator's circuit. The circuit shown in Fig. 25 contains a secondary cut-out key 7. It is quite important that each operator's circuit be equipped with one of these keys, since the operator is able by means of it to listen to the connection without interfering. By operating this key, the secondary of the induction coil is opened and a retardation coil is inserted in series with the receiver. By opening the secondary circuit all the noises which may be picked up by the transmitter are prevented from reaching the line. Furthermore, the insertion of the retardation coil of high impedance materially cuts down the shunting effect of the operator's telephone set.

CHAPTER V

TOLL SWITCHING SYSTEMS

The toll line, in most instances, is a trunk line connecting two or more cities; and as such is used by any two widely separated subscribers who wish to communicate with each other. In some instances, however, as shown in the preceding chapters, a toll line may terminate in a telephone instrument. Such conditions are confined, naturally, to small or isolated villages where no local service is given; and the telephone instrument, in such instances, is usually installed in some place which is always accessible to the public, usually the general store or the post office.

The interconnection of toll, trunk and terminal lines to form continuous circuits between subscribers who are not in the same local exchange district is the mission of the toll switchboard. Such a board fulfills the same purpose in toll practice that the local board does in the local exchange, namely, the provision of means for interconnecting the various lines comprising the system.

The toll board is somewhat more complicated, however, since there are more conditions to satisfy than in local service. In a city exchange switchboard, the majority of connections are made between subscribers located in that particular city only; while in a toll exchange connections may be set up between two toll stations, or between a toll station and a distant subscriber, or a local subscriber and a toll station, or again, between two local subscribers in different towns or cities. In addition to setting up the connections, an accurate record must be kept of the names of the persons or subscribers using the line and the length of time the conversation is carried on, so that a proper charge can be made for the service rendered.

Different kinds of equipment at the toll board are required for handling the several classes of connections mentioned in the foregoing paragraph. Consequently we must expect somewhat complicated conditions both as to the construction and the operation of the particular type of board which may be under consideration. The complications are somewhat multiplied by the various types of local boards with which connections must be made. The local boards can be divided into the three following classes: the local battery or magneto switchboard, in which an individual talking battery is provided with each telephone; the common battery or central energy switchboard, in which the battery used for talking, as well as for signaling, is located at the central office; and the automatic switchboard, with which no manual operators are required. Each of the first two general classes may again be divided into two subclasses, namely, the multiple and the non-multiple equipments. Thus it is evident that there are five widely different types of local equipments which must be taken into consideration in the design of toll switchboards. These five types are restated in tabular form below.

1. Local battery or magneto switchboards:
    (*a*) Non-multiple.
    (*b*) Multiple.
2. Common battery or central energy switchboards:
    (*a*) Non-multiple.
    (*b*) Multiple.
3. Automatic Switchboards.

Although there are many different designs of multiple and non-multiple common battery boards, it will be found that their effect upon the design of the toll board circuits, with which they are to operate, is not so great as might be supposed. The authors' experience in adapting a given toll equipment to operate with a local board of different manufacture indicates that there are few obstacles, if any, of a serious character.

Toll board equipments can readily be classified along different lines from those just given, the basis being the kind of service rather than the type of local board. The board may be designed, first, for connecting toll lines with toll lines, only, this type of board being known as the "Through Toll Board"; second, the equipment may be laid out for the connection of toll lines with local lines, this type being known as the "Toll Terminal Board"; the third is the type of board which is most commonly encountered, being a combination of the two types just mentioned. Each of these types may be divided again into multiple and non-multiple equipments. This classification may be tabulated as follows:

1. Through toll board:
    (*a*) Non-multiple.
    (*b*) Multiple.
2. Toll terminal board:
    (*a*) Non-multiple.
    (*b*) Multiple.
3. Combination through and terminal board:
    (*a*) Non-multiple.
    (*b*) Multiple.

Each subdivision of the last two groups may be divided according to the classification given in the first table; for example, the equipment of a toll terminal multiple board depends upon the type of local board with which it must operate.

A through toll board meets the requirements where switches between toll lines are handled exclusively. A toll terminal board serves such requirements as those at the center of a large city, but a combination through and terminal board meets the average conditions. The diagram shown in Fig. 28 illustrates the use of the three general types of toll equipments. It is possible, at the through toll office *A*, to connect a line which enters the office from any given direction to a line which leaves it in any of the other three directions. The real purpose of the through office, as can be seen readily from the diagram, is to give the system flexibility with a minimum amount of wire mileage. If this office were eliminated it becomes self-evident that station *B* would require direct lines to stations *F*, *J*, *M*, etc. This would be satisfactory if there were sufficient business between each of these points to keep such lines constantly in use. But direct lines are not justified until the business exceeds a certain number of messages per day; when the business is less than this amount it must be switched over tandem circuits by the most expedient route.

The use of all of these types of office equipments is possible, as a rule, only in large toll systems. The toll plant of the American Telephone and Telegraph Company is a case in point; this system comprises a very comprehensive network covering the country as a whole, east of the Rocky mountains.

A good illustration of the use of through and terminal equipments may be cited in the present installation at Chicago, Ill. The long-distance toll board, for combined through and terminal service, was located formerly at Morrell Park (southwestern outskirts of city), but in 1908 a new office was installed at Franklin St., in the downtown business district, for terminal service, and the old office was retained for through switching. The Morrell Park office is about seven miles from the business district and consequently the change diminished the average length of switching and recording trunks very materially; it also relieved other difficulties of an operating nature which were burdensome. All toll lines enter the through board at Morrell Park and pass thence to the terminal board at Franklin St. Under the operating plan the terminal operators answer all incoming toll calls and signal the through operators when necessary; since the terminal business greatly predominates, this plan is economical. An exception occurs in the case of terminal business with Milwaukee, Wis., about 85 miles distant, which is handled over direct underground loaded circuits.

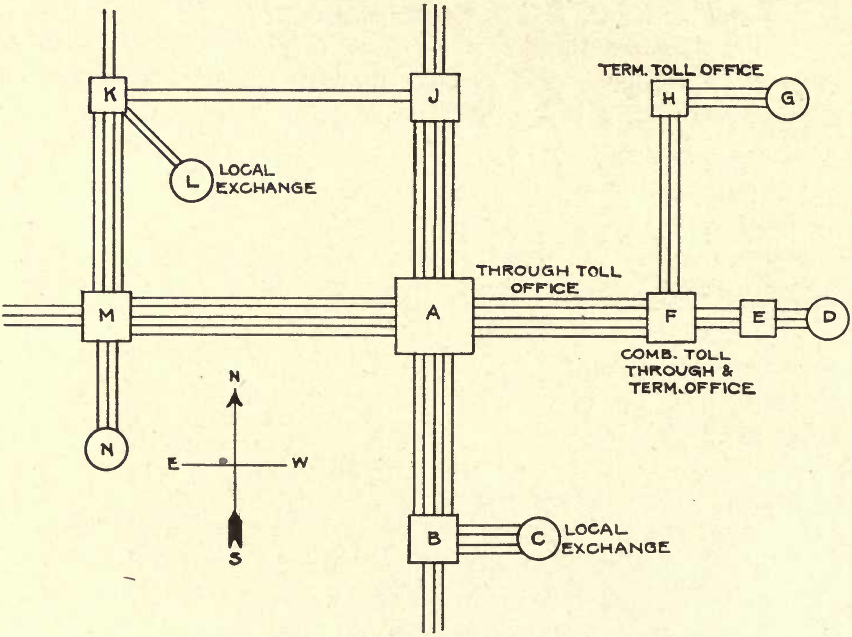


FIG. 28. — Typical Lay-out of a Toll System.

CHAPTER VI

SMALL TOLL SWITCHBOARDS

THE methods of handling toll traffic at one of the positions of a local board were outlined in a preceding chapter. In many respects this is not as satisfactory as having the toll equipment located at an entirely separate board, even though the toll business is not very heavy. The isolation of the toll operator from the local operators, especially when there is insufficient traffic to keep them all occupied, will result, as a rule, in better discipline and better service.

Looking at this matter from the standpoint of the adaptability of the equipment to the service it is intended for, it is evident that the toll operator can work most effectively at a board specially designed for such service rather than at a board where the toll equipment must be so placed as to conform in many respects to an equipment designed for local service. In the first place, the keyboard for a local equipment is frequently too high and too narrow to afford proper space for a toll operator's work, and it becomes necessary to alter the equipment in some respects. Space for spreading out several toll tickets, without obscuring signals or interfering with keys, is very essential. It is often necessary to mount the calculagraph on a floor standard, at the operator's side, instead of in the keyboard.

For these reasons a separate toll board has distinct advantages. This applies primarily, in the case of small offices, to the period of the day when the traffic is considerable. There is ordinarily little or no business from nine P.M. to seven A.M., and during this time it is desirable, if possible, to transfer the toll calls to the local board so that only one operator will be needed.

This can be accomplished by duplicating the toll-line equipment at each board and employing a transfer system as shown in Fig. 29. This method employs multiple jacks and drops at each board; during the day period the drop at the local board is cut off by means of a dummy plug in the jack, and at night the plug is transferred to the toll board. This method suffices very well if the number of toll lines is limited, but becomes cumbersome if the number is large.

Several plans are available in the latter case. One of the preferable methods is shown in Fig. 30, in which the toll line proper terminates in the lever springs of the key, whose inner contacts are connected in series with the line to the toll board, while the line to the local board is connected in a similar manner to the outer springs. Thus the key is the means by which the toll line can be switched at will from the toll to the local board and *vice versa*. These switching keys may be associated with the line drops or the answering jacks at the toll board.

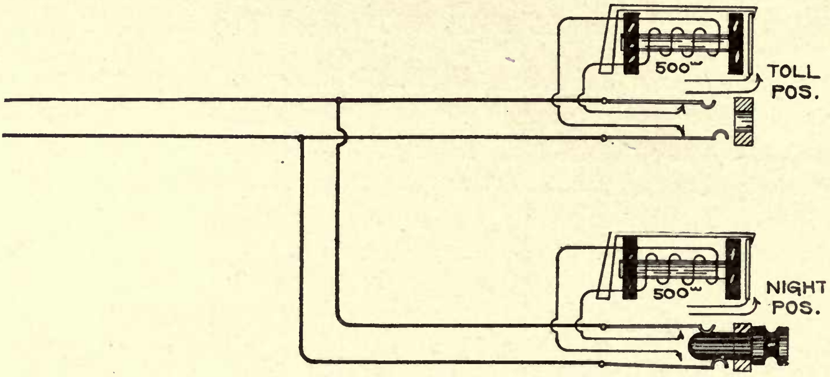


Fig. 29. — Method of Transferring Toll Lines for Night Service by Means of Dummy Plugs.

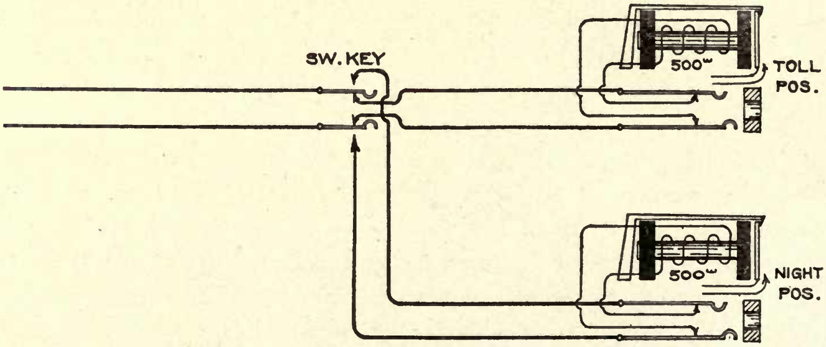


Fig. 30. — Method of Transferring Toll Lines for Night Service by Means of Keys.

A very convenient way is to use keys of the push-button type mounted on strips with the same spacing as the line jacks and either directly above or below the latter. These strips are made by the different manufacturers, varying in width from one-half to one and one-half inches.

Some engineers object to the scheme outlined in Fig. 30 for the reason that it adds an additional contact in each of the line conductors. While this is true and should be avoided as far as possible, there is very little chance for trouble to originate in a well-made key. This objection is avoided, however, in the circuit shown in Fig. 31, in which the talking wires are in no way connected with the switching device. An objection to the latter design is the fact that the drop which is not in use is connected to one side of the line, the other side being opened by the key. But this difficulty is sometimes more theoretical than real; it can be overcome, however, by the additional expense of a key with enough contacts to cut the idle drop entirely clear of the line.

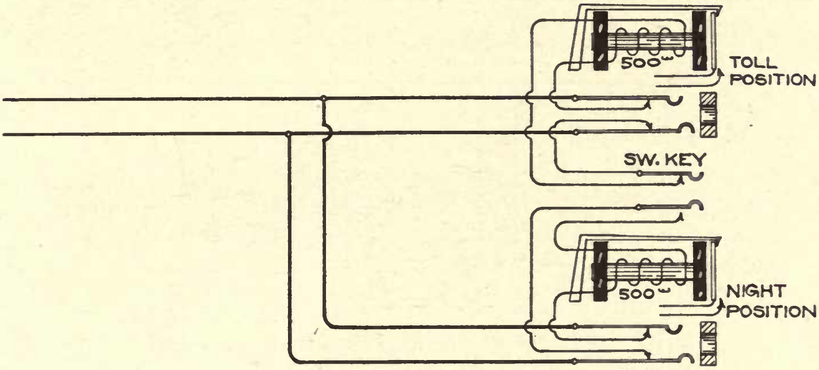


FIG. 31. — Method of Transferring Toll Drops for Night Service by Means of Keys.

The wiring in Fig. 30 is the easiest to install as there are but the two line wires extending between the two boards; whereas the circuit shown in Fig. 31 requires, in addition to this, two wires to the switching key. But taking everything into consideration, there is little to choose between the two methods.

Among the principal features to be observed in the design of a toll board, exclusive of the equipment, are wide key shelves, with plenty of space for the operator to prepare tickets and do any clerical work which may be assigned to her; book stalls for filing the telephone directories that may be required in obtaining the telephone number of a subscriber; pigeon holes for the filing of toll tickets, etc.

In Fig. 32 is shown a desirable arrangement of apparatus for a one-position toll board. It will be noted that this board embodies those features mentioned in regard to book stalls, pigeon holes and wide key shelves. The reasons for distributing the equipment, as shown in the figure, should be explained, since the relative position of this apparatus is important. It will be noted that all the drops are located above the jacks, in which position the operator will always have a clear and unobstructed view of them. To show how the relative location of the drops and jacks will affect operation, let it be assumed, for example, that some of the jacks have been placed above the drops.

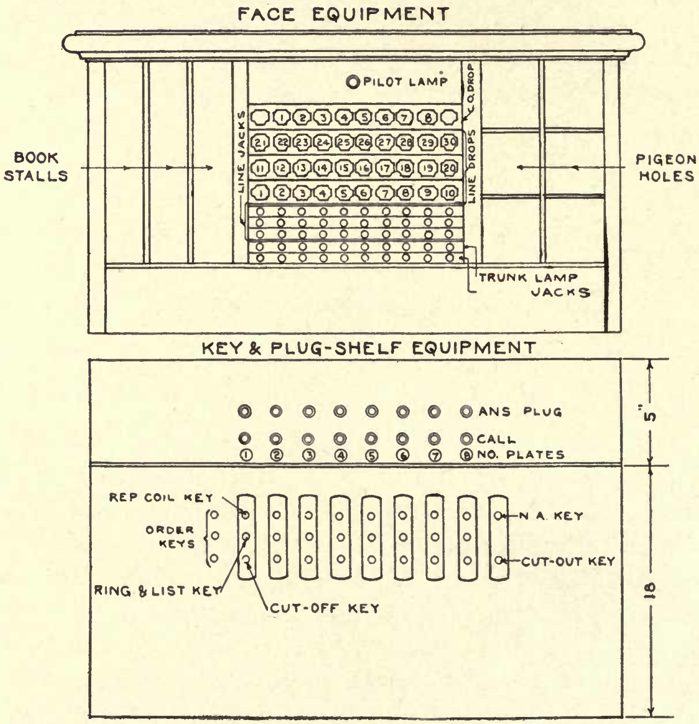


FIG. 32. — Jack and Key Equipment of a Single-position Toll Board.

Then, whenever a number of connections have been put up, it will be apparent that the cords obscure a full view of some of the drops, and therefore the operator may fail to see a signal. It is also imperative that the line drops and jacks be numbered in a neat and clear manner, so that no time will be lost in locating corresponding drops and jacks. This is also true of the cord equipments; that is, each pair of cords and the accompanying clearing-out drop should be numbered alike. The cords are best numbered by embedding a number plate in the leather plug-shelf directly in front of each pair of cords, while the drops should be numbered in the usual manner.

In arranging the key equipment to suit the convenience of the operator, it should be kept in mind that the keys which will be used most should be placed nearest the operator and *vice versa*. As shown in the last figure, the repeating coil key is the one nearest the face of the board, because it is operated but once, if at all, during a connection. The double cut-off key has its place next to the operator and the ringing and listening key is placed between the other two. This arrangement, or one in which the relative positions of the double cut-off and the ringing and listening keys are reversed, are the ones most generally used.

Although the equipment shown in the diagram is intended for a toll board which is to work in connection with a magneto local board, the same general arrangement of apparatus would be used for a board that is to operate in connection with a common battery local board, with the exception that a supervisory lamp should be added for each cord circuit, this lamp being placed in front of each pair of cords.

In Fig. 33 is shown the arrangement of the equipment for a two-position toll board, designed to operate in connection with a common battery local board. The general arrangement of apparatus is the same as for the one-position board, with the exception that the trunk jacks are placed in the middle panel. This is advisable because in that position they are more easily accessible to each operator. A calculagraph is placed in the key shelf between the two operators, so that toll connections may be accurately timed.

Managers are sometimes of the opinion that the purchase of a calculagraph is an unnecessary expense for a small board; but experience has shown that this instrument will more than pay for itself, because of the accuracy with which calls can be timed with little labor, and the reduction of unpaid overtime. It is now universally acknowledged by men who have had experience with large toll boards, that the calculagraph is indispensable for this work. If it is a profitable investment for such boards, it should be equally valuable for small boards unless the volume of business is extremely limited. An ordinary clock is in no sense a substitute for the calculagraph and gives unsatisfactory results.

The equipment of small toll boards will next be discussed in relation to the four types of local board with which it may operate, magneto and common battery, non-multiple and multiple, respectively.

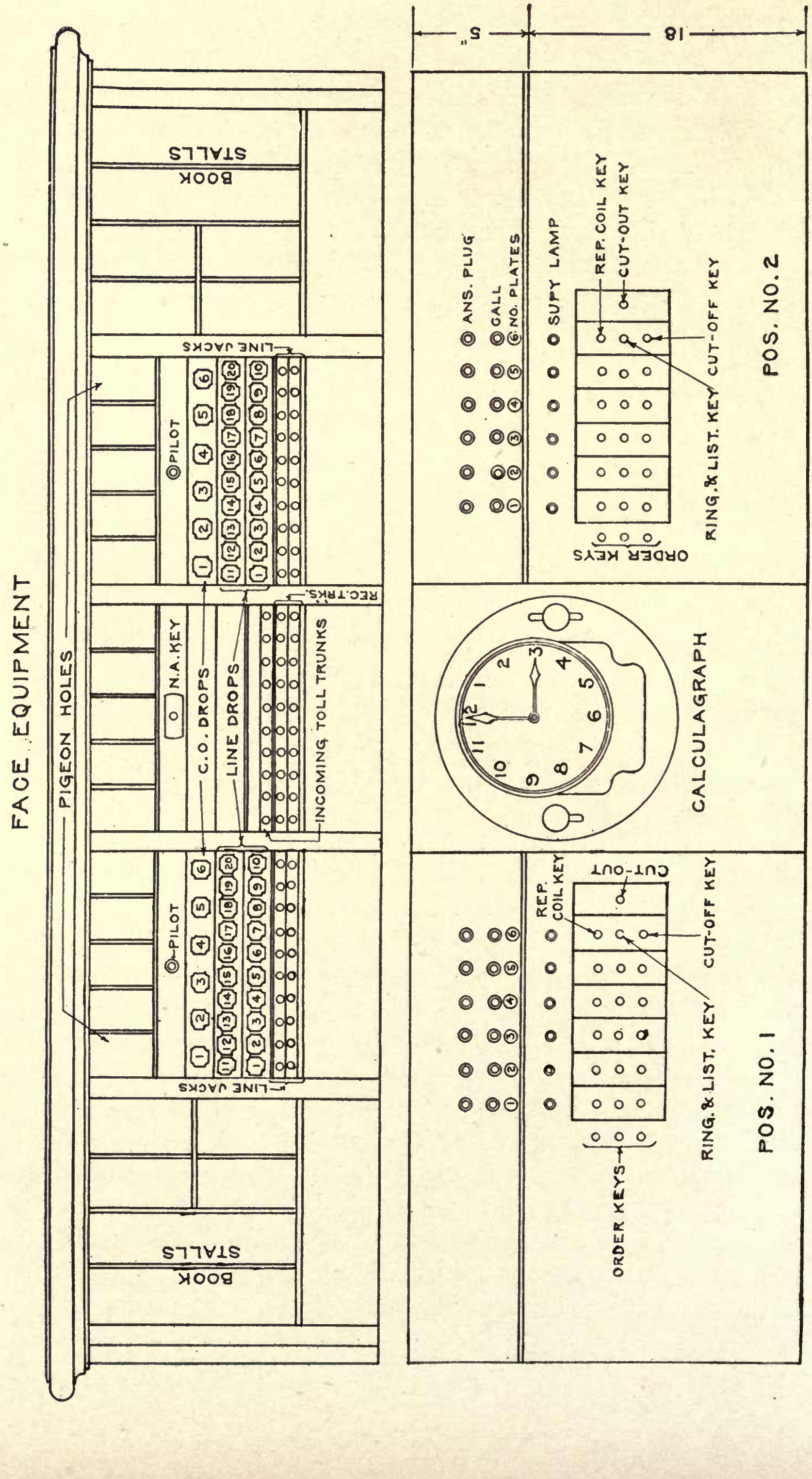


Fig. 33. — Jack and Key Equipment of a Two-position Toll Board.

Magneto Non-multiple Switchboard. — The circuits used at a toll board which is to operate in connection with a local magneto non-multiple switchboard are identical with those used at the toll position at the local board; and, consequently, will require no further discussion in this chapter.

Magneto Multiple Switchboard. — The operation of a toll board in connection with a local magneto multiple board is similar to that of the magneto non-multiple board, the only difference being in the trunk circuit. The plug at the local end of this circuit must be provided with a sleeve conductor which will raise the potential of the sleeve of the jack, in which it may be inserted from ground to that of the negative side of battery, for the usual busy test. The trunk circuit used for this purpose will be identical with the one shown in Fig. 25, with the exception that the jack at the toll board will be of the two-conductor type. In order to obtain a clear conception of the operation of this system, it seems advisable to trace a call through its complete course.

Upon the arrival of an incoming toll call, the operator after ascertaining the number of the subscriber desired, will insert the calling plug of the pair of cords in use in one of the trunk jacks, thus energizing the relay and lighting the lamps at the toll and the local ends of the trunk. At the same time, by means of her order circuit, she will instruct the local operator at whose position the trunk terminates, as to the subscriber's number desired; whereupon the local operator will insert the plug (associated with the lighted lamp) in the multiple jack of the line called for. This will extinguish the lamps at each end of the trunk as previously described. If the toll operator, upon listening, finds the line is not busy, she will ring the subscriber; in case the line is busy, however, she will leave her cut-off key open until the local subscriber is disengaged. It has sometimes been the practice for the toll operator to interrupt a local message, so as to complete the toll connection with the least delay. When the conversation is finished both subscribers "ring off," thereby actuating the clearing-out drop. The toll operator will then take down the connections, thus opening the circuit of one of the differential relay windings, which will light the lamps associated with the trunk circuit in use. This gives the local operator a disconnect signal and she will then remove the connection and thus restore the apparatus to its normal condition.

Should the call originate at the local board, the operator, upon ascertaining that a toll connection is desired, will withdraw the plug of the answering cord and insert the plug of one of the toll trunks. This will light the lamp associated with the trunk in front of the toll operator, who in turn will answer and complete the connection in the usual manner.

Common Battery Non-multiple Switchboard. — The operation of a toll board in connection with a common battery non-multiple board is identical with that previously described for a toll position located at the local board itself. The circuits used are of the same general design as those shown in Fig. 25.

Common Battery Multiple Switchboard. — A non-multiple toll board that is to work in conjunction with a common battery multiple board is somewhat more complicated, as one would naturally expect, than any of the types thus far considered and a more complete description of its operation is therefore included.

Although the toll-line equipment remains the same, the necessary methods of trunking to and from the local board are more complex and the major part of the description will be devoted to such operation. There are two general methods of handling connections between the toll and the local boards. The first comprises a two-way trunk, which may be used, as the name implies, for putting up a connection from the toll to the local board or *vice versa*; the second employs separate recording and switching trunks. The first system mentioned is well adapted to an exchange where there are ten positions or less equipped at the local board. The reasons for this will become apparent after completing the description. The circuit used for such a system is shown in Fig. 34, and reference will be made to this in tracing out the following connection.

When an incoming toll call is received, the toll operator will place herself in connection with the local board by means of her order circuit, and instruct the operator as to the number called for. The local operator will then assign the trunk to be used and insert the plug of the latter in the multiple jack of the subscriber's line wanted. If the local line is idle, a circuit may be traced from ground by way of relay *E*, to the sleeve of the jack, thence over the ring strand of the trunk through the series contact in the trunk jack and through relay *A* to battery. These relays will consequently be energized and will light the lamp associated with the local end of the trunk, in case the toll operator has not previously plugged into the jack. The act of plug-

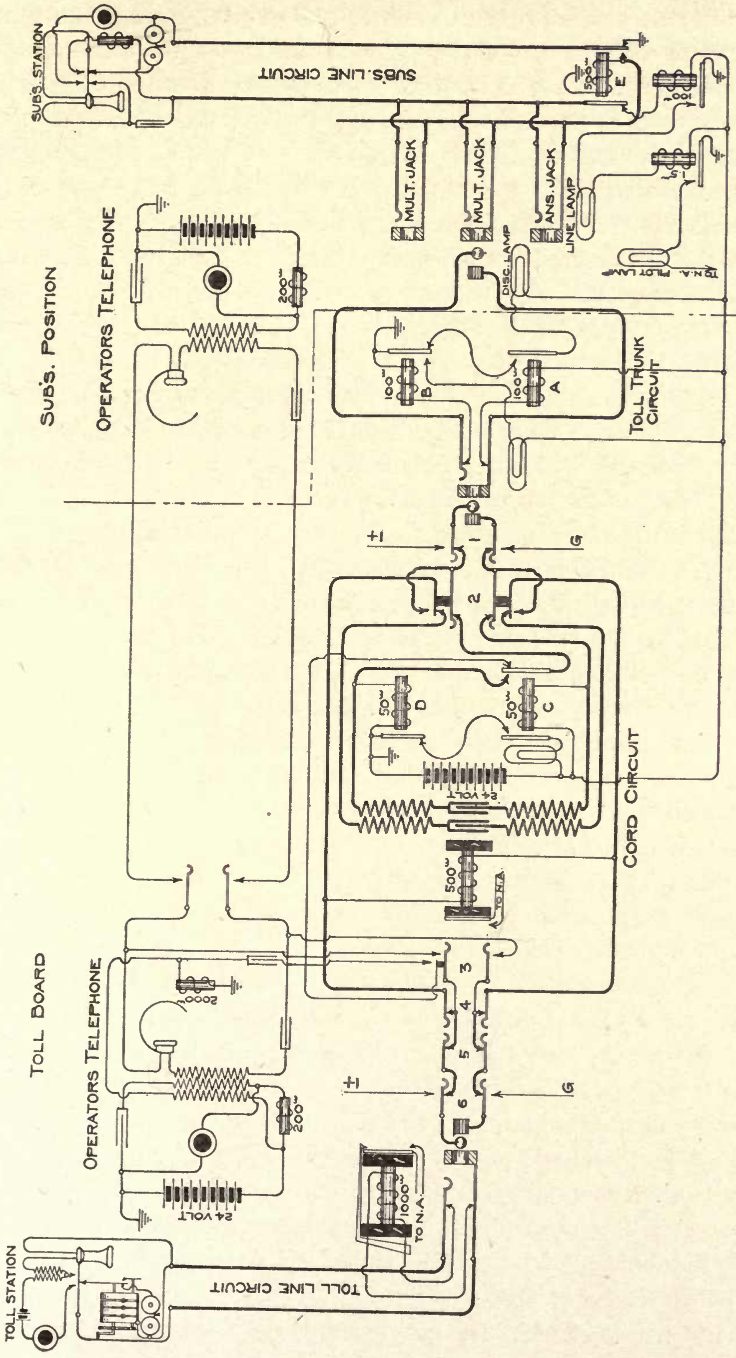


FIG. 34. — Two-way Toll Trunk Between a Non-multiple Toll Board and a Common Battery Multiple Local Board.

ging into this jack will open the series contacts in the latter and thus de-energize relay *A* and extinguish the lamp. At the same time a circuit will be established from the ground at *E*, over the ring strand of the trunk and the toll cord, through the contacts of keys 1 and 2 and relay *C* to battery. This relay, therefore, will be energized and will light the supervisory lamp associated with the cord. When the local subscriber removes his receiver, he will bridge his telephone set across the line, thereby causing the battery current to flow through the coil of relay *D*. The energizing of relay *D* will open the local lamp circuit and extinguish the supervisory signal, thus informing the toll operator that the subscriber has answered.

In case the local line is busy, the supervisory lamp associated with the toll operator's cord will not light, since the line is bridged by the local subscriber's telephone. In this case, the operator may either actuate the cut-off key, which will prevent the toll subscriber from listening to the local conversation, and wait for the line to be released; or, if the toll line is a busy one, she may interrupt the local conversation and tell the subscriber that a long-distance call is waiting, with a request that it be given precedence.

When the toll conversation has been completed the "ring off" from the toll line will actuate the clearing-out drop and the local subscriber will hang up, thus de-energizing relay *D* and lighting the supervisory lamp. The toll operator, upon seeing the disconnect signals, will take down the cords, which in turn will close the series contacts in the trunk jack and thus energize relay *A*. The latter will light the lamp associated with the trunk at the local board, giving the local operator a disconnect signal; she will then remove the connection and so restore the equipment to its normal state.

In case the toll call originates at the local exchange, the operator will remove the answering plug and insert in its place the plug of a two-way toll trunk. This will light the lamp associated with the trunk at the toll board, due to the operation of relays *A* and *B*. The toll operator will then answer with the local plug of a pair of cords, which extinguishes the lamp, and thereafter the call will be handled in the usual manner. If the desired toll line is busy, or if it requires some time to complete the connection, she will tell the subscriber to hang up his receiver and wait until called. The connection, if completed, will be handled as already described.

In the use of the trunking system above described, it must be apparent that each local operator should have at least one two-way trunk at her command. A very desirable distribution of this type of trunk equipment is effected by placing a group of two or three trunks between each pair of local operators, in which position either operator may utilize them. It will be readily realized from this that when a local board has more than ten equipped positions, the number of trunks becomes so large that the cost of installation becomes excessive; and a less expensive substitute is desirable. This difficulty may be obviated by placing all the trunks at one position. In this case a local operator, upon receiving a toll call, will instruct the operator at the trunk position by means of her order circuit, as to the number of the subscriber who desires toll service. The trunk operator will then insert one of the trunk plugs in the multiple jack of the subscriber's line, and the local operator at whose position the call originated will withdraw the answering plug. The call will then be dealt with in the manner just described.

This arrangement of the trunking equipment, using two-way trunks, will do very well when the amount of toll traffic is small, but when this business assumes larger proportions, it becomes necessary to adopt different methods. Since a toll call must go through the hands of two operators before reaching the toll board, in the method just described, it follows that this will give rise to some loss of time, which can be avoided, to a certain extent, by a system that employs separate recording and incoming toll or switching trunks.

Before taking up the detail operation of this system, it is necessary to have a clear understanding of the various operations required in establishing a complete connection. In order to appreciate this it becomes essential to bear in mind that a toll exchange is a means of interconnecting widely separated local exchanges by long-distance toll lines. These toll lines, as already stated elsewhere, are in reality trunks connecting various towns and cities. This will be more readily appreciated by referring to the diagram in Fig. 35 which is divided into four parts by means of broken lines to show the different offices. The sections at *A* and *D* are local offices and those at *B* and *C* are toll offices.

The sequence of operations in a call is briefly as follows: When a subscriber at exchange *A* desires to communicate with a subscriber at the distant exchange *D*, for example, the local operator inserts the calling plug in an idle recording trunk jack and gives the connection

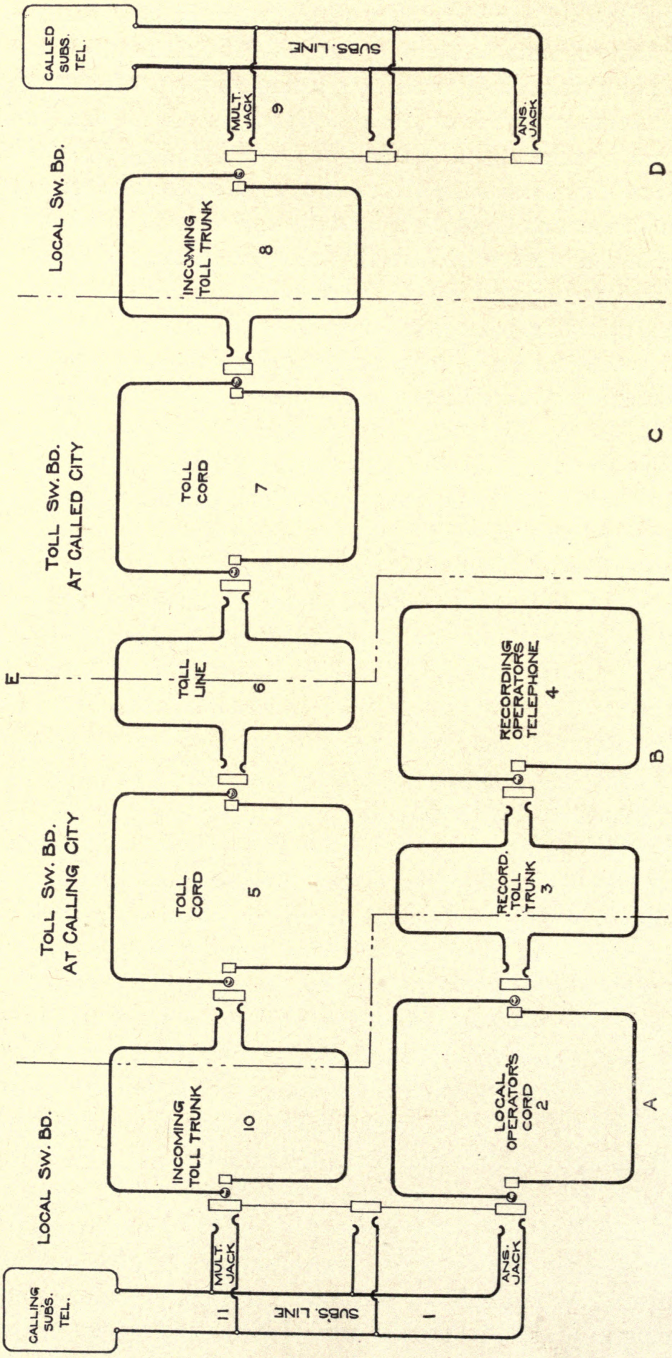


FIG. 35. — Diagram of a Complete Toll Connection.

no further attention until she receives the disconnect signal. The recording operator at office *B* then answers and after obtaining the information necessary to fill out a toll ticket, informs the subscriber that he will be called as soon as the connection is ready. The toll ticket is then passed to the toll-line operator at the *B* office who has charge of the desired toll line. The latter operator will then call the toll-line operator at the *C* office in the usual manner and ask for the particular local line desired. The last-mentioned operator will then communicate to the trunk operator at office *D*, by means of an order circuit, the number of the local subscriber desired; whereupon, the trunk operator will assign the trunk and complete the local connection. The toll operator at *C*, as soon as she gets the called subscriber, will signal the operator at *B*, and the latter will then call the subscriber at *A* who originated the call; the connection is then ready for conversation to commence.

It is evident from the foregoing that a toll connection can only be established with the aid of several operators. The call passes over the various circuits in the order indicated by the numerals of the diagram. This method of handling toll connections is practically standard throughout the country wherever the volume of business does not exceed a certain limit.

In the detailed circuit diagrams which follow, showing complete connections, only one local office *A* and one toll office *B* will be shown; everything to the right of the dividing line *E*, referring to Fig. 35, will be reduced to a magneto telephone set. This is done to make the diagrams as simple as possible.

Fig. 36 shows one of the forms of incoming toll (switching) trunks which has been used considerably. The local end of the trunk is usually handled by the operator at the first local position, as the number of such trunks required, in connection with a non-multiple toll board is seldom sufficient to keep one operator busy. The operation of the circuit is outlined in the following description, it being understood, of course, that this circuit merely takes the place of the two-way trunk circuit shown in Fig. 34. Reference will be made to the latter in connection with Fig. 36, in this description. The toll operator, in handling an incoming call, will answer the toll-line signal in the usual manner. Upon receiving a request for connection with a local subscriber, she will communicate over the order circuit with the operator at the local board who handles the toll trunks, giving the latter the number of the subscriber desired. The local operator will thereupon assign an idle trunk and connect it with the subscriber's line. The toll operator will connect with her end of the trunk by means of the local plug of the cord circuit which was used to answer the toll line. This will clear the trunk circuit of all signaling apparatus. If the local line is not in use, the toll operator will ring the subscriber in the usual way. When the conversation has been completed, the toll operator will receive the disconnect signals in a manner similar to that already described for this cord circuit. Upon receiving these signals she will remove the cords, thereby closing the series contact in the trunk jack. This will light the lamp at the local end of the trunk over the circuit traced from ground by way of relay *E* to the sleeve of the jack, thence over the ring strand of the trunk, through the jack contact and relay *F* to battery. Relay *F* will be energized and in turn will light the disconnect lamp. The local operator, upon receiving this disconnect signal, will remove the trunk cord, which will open the circuit and restore all equipment to its normal condition.

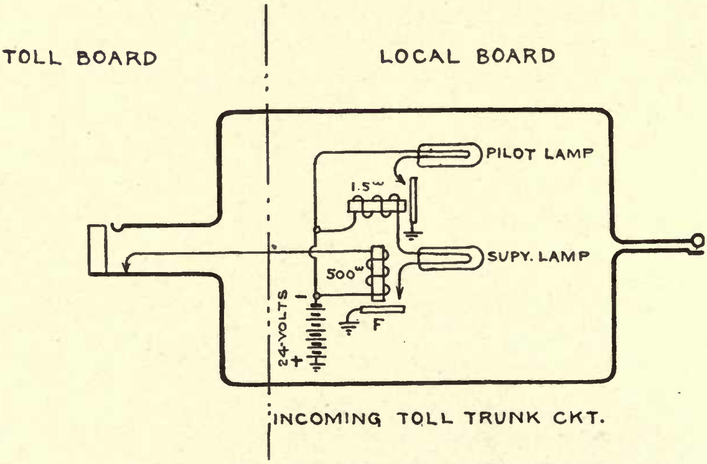


FIG. 36. — Type of Incoming Toll Trunk Used with a Non-multiple Toll Board.

Should a local subscriber call for a toll connection, the operator will insert the calling plug of the cord circuit in one of the recording trunk multiple jacks, after she has made the usual busy test. The recording trunk circuit is shown in Fig. 37. A circuit will be completed from battery through the ring relay in the cord circuit, over the ring conductor of the cord and the trunk through relay *B*, the back contact 1 of relay *A*, thence through the contact in the jack and back to battery (ground) over the tip strand of the trunk and the cord and the tip relay. Relay *A* is not operated because of the short-circuit through the jack contacts. At the same time, relay *B* lights the calling lamp before the toll recording operator. The operation of both relays in the cord circuit prevents the operation of the supervisory signal. When the recording operator answers, the short-circuit in relay *A* is removed by the opening of the jack contacts; thereupon relay *A* responds and extinguishes the calling signal. After taking the details of the call from the subscriber, the operator will tell him to hang up his receiver and wait until called. Then she will disconnect from the trunk. This will establish a connection to ground from the tip strand of the trunk, which may be traced from the jack contact, through the contact 2 of relay *A* and thence to ground. This ground connection serves a double purpose; first, it locks relay *A*, which was already energized, and thus prevents the relighting of the calling lamp; and secondly, it shunts the tip relay in the local cord circuit, which in turn releases, and lights the supervisory lamp. Thereupon the local operator clears the connection and thus restores all equipment to its normal condition.

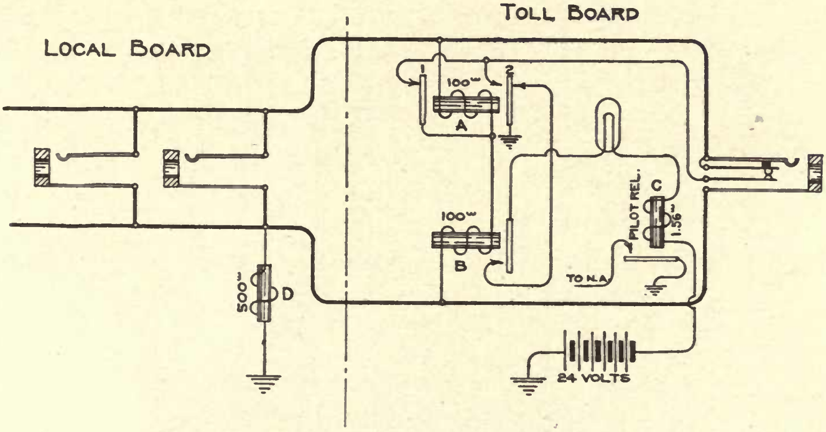


FIG. 37. — Type of Recording Toll Trunk Used with a Non-multiple Toll Board

The ticket which bears the details of the call (toll ticket) is then passed to the toll-line operator, who will complete the connection in accordance with the procedure before outlined, making use of the toll trunk shown in Fig. 36.

The two-way toll trunk as shown in Fig. 34 and the incoming toll trunk shown in Fig. 36 have no provision for testing the multiple jacks to ascertain whether the local line is busy. This feature can easily be added, as shown in Fig. 38, by placing a key in the tip conductor. This key in its normal condition closes the talking circuit, but upon being operated opens the conductor and connects the plug end of the cord to ground through the induction coil in the operator's set. When this key is operated and the tip of the plug is applied to the sleeve of the multiple jack of the busy line, the flow of current will give the operator the usual busy signal. It is hardly necessary to add that the operator, when provided with this equipment, should make the busy test before assigning the trunk.

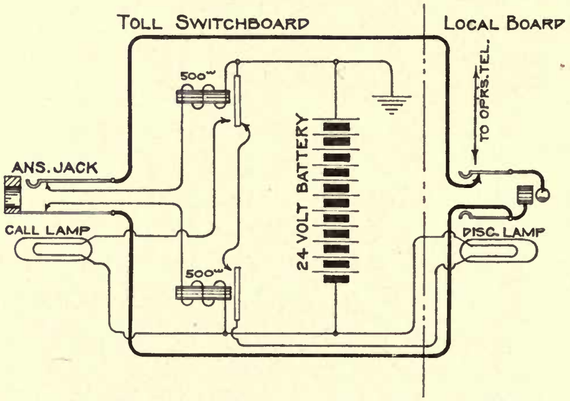


FIG. 38. — Two-way Toll Trunk with Busy-test Key.

It is hard to determine whether the system employing the key for a busy test is an advantage or not, since each method has its merits. The chief advantage of the first method is the facility with which a trunk assignment can be obtained, regardless of whether the local line is busy. It also saves labor at the local board and, in case the local line subscriber is busy, provides a busy test which insures precedence for the toll call over any subsequent calls. One of the principal advantages of the second method is the freedom from interruption of local messages by the toll operators. A further advantage arises from the reduction of the number of trunks as compared with the number required in the first method, due to a smaller average holding time.

CHAPTER VII

MULTIPLE-DROP TOLL SWITCHBOARDS

WHEN the number of subscribers in a non-multiple local switchboard becomes so large that three or four operators are unable to properly handle the traffic, it is common practice to adopt the multiple type of board. This applies also to toll boards, and since the discussion of the non-multiple toll board has been completed, the study of the multiple type is now in order. In a multiple toll board, as the name implies, all the toll lines entering the office are placed in front of each operator; that is, the lines are multipled in each section in a manner identical with that used in the local multiple switchboard. Thus the necessity of transferring calls is obviated, since every toll operator is able to call any toll office or toll subscriber direct from the multiple. Consequently any local-to-toll connections can be handled by any toll operator, since all the toll lines in the office can readily be reached in the multiple; whereas in a non-multiple board, the call would have to be given to the operator at whose position the desired line terminated. The local-to-toll business, therefore, can be more evenly distributed among the operators in a multiple board; whereas in a non-multiple board this is not possible. From the foregoing statements it is evident that by means of a multiple toll board it is possible to operate much faster and therefore more efficiently. These items become factors worthy of consideration when the toll business has assumed large proportions. However, a multiple toll equipment makes the use of a recording operator imperative. This operator, as previously explained, does all the clerical work for local-to-toll connections; that is, she makes out all toll tickets for outgoing calls. It will be evident that this division of labor results in greater accuracy and speed and higher efficiency in the operators' work.

The multiple toll boards may be divided into three distinctly separate groups. These are, first, those using drop signals exclusively; second, those employing only lamp signals; and third, those combining both drop and lamp signals. Local conditions to a great extent determine the kind of equipment best suited to any particular office. In a drop board the panel equipment for a certain number of lines requires more space than the apparatus necessary for the same number in a lamp board. However, the lamp board is more expensive than the drop board. The principal reason for this is that all the equipment in a drop board, both for lines and cords, can readily be placed in the switchboard framework, thus avoiding the installation of a relay rack in the terminal room and the necessary cable from this rack to the board. But it is often an advantage to have the line equipment on a separate rack, where, if neatly numbered, it is readily found by the repair man in clearing trouble. In a lamp board it is customary to distribute the equipment in this manner. It is understood, of course, that in a lamp equipment a line relay is used with each toll line, in place of the drop in the non-multiple boards previously described. This relay has two windings, one of which is connected directly across the line and is actuated by incoming ringing current, while the second is merely a locking winding, which holds the armature in place after it has been drawn up by the alternating impulses. This line relay and the associated cut-off relay are mounted on the rack in a manner similar to that employed for the same relays in a local common battery equipment. One of the objections which may be raised to the lamp board is that on account of the use of a line relay the action is not as positive as it is in the drop system, because there are chances for trouble in the local circuit from the relay to the board, such as a burnt-out lamp or a poor relay contact. Therefore an incoming signal might fail to reach the board, which would be less likely to happen with the other type of equipment. It must be obvious that the circuits in a lamp board are more complex than those used in a drop board, and for this reason the drop board is preferable where skilled attendance is not available. One of the very desirable features of a lamp board is the facility for mounting the line signal immediately above the jack, which is not advisable in a drop board for reasons explained in Chapter VI.

All toll lines should be cabled from the high-current arresters to the main distributing frame and thence to the intermediate frame; from the latter they should be carried directly to the answering jacks. The use of a connecting rack at the rear of the board, as a substitute for the intermediate frame, is not good practice. The objection to the use of a rack is the lack of flexibility. In laying out the cable runs in a toll board installation all sharp corners should be avoided, since it is the general experience that these are weak spots of an installation; when a high potential current finds its way into the board, such sharp turns are frequently the seat of burn-outs. A sharp corner may appear more sightly, but this is an instance where appearance should be sacrificed to insure reliability and freedom from trouble.

Before going into a detailed description of either type of board, the methods of obtaining the busy test on multiple toll boards will be considered briefly. There are two standard methods of obtaining this test: first, the well-known audible test, and second, a visual test, employing a signal associated with each multiple jack. The audible test is applicable to either system, while the visual test is not desirable in a drop board, but may be used with excellent results in a lamp board. The use of visual busy signals is not entirely successful in drop boards because a short interval of time elapses during which a line may be busy while the signal does not indicate that condition. This is due to the fact that the busy signal is energized by the operation of the cut-off relay and therefore there is no indication that the line is busy from the time the drop falls until the toll-line operator answers. While this interval may be but a few seconds at the most, it is long enough to permit another operator to take up the line in the multiple. In a lamp board the conditions are different, because the local circuit through the busy signal is closed by a contact on the line relay; and when the cut-off relay is energized (releasing the line relay) it again closes a battery circuit through the signals, so that they indicate a "busy line" from the time an incoming ring is received until the operator takes down the connection. These conditions will be described in detail after each system has been discussed, and the operations may then be comprehended more readily.

Since a drop board is the simplest form of multiple toll equipment, a detailed analysis of this type will be considered first and will occupy the remainder of this chapter. The best means of obtaining a clear conception of an equipment of this kind is to study each class of connection separately; that is, toll-to-toll, toll-to-local and local-to-toll, under various conditions, as indicated by the headings which hereafter appear.

Joint Toll and Local Offices: Two-wire Local Board

(*a*) **Toll-to-Toll Connection.** — A connection of this character is independent, of course, of the local office and will be disposed of first. The complete circuit appears in Fig. 39. By referring to this drawing it will be observed that the toll-line drop is bridged across the line through the break contacts of relay *A*. The function of this relay is identical with that of the cut-off relay in a subscriber's line circuit; that is, it disconnects the drop from the toll line. This improves the efficiency of both signaling and transmission. The cord circuit is a through metallic connection, the tip conductor of which is normally open to provide suitable means for obtaining the busy test.

The operation of the circuit is as follows: An incoming toll-line signal will actuate the drop in the usual manner. The operator upon seeing the signal will plug into the answering jack and thus complete a circuit from battery through the winding of relay *A*, which will open the line contacts to the drop. The act of plugging in will also raise the potential of the sleeve strand of the jack and hence should an operator test any multiple jack of this line, she will obtain the busy signal. The operator will then bridge her telephone set across the line by operating key 4, and ascertain the details of the call; if the line called for is idle she will plug in and ring. Due to the insertion of the plug, the potential of the sleeve strand of the line jack will be raised as before, and at the same time a circuit will be established from the ground on relay *A*, over the sleeve conductor, through relay *B* to battery, which will operate relays *A* and *B*. The operation of relay *A* disconnects the drop from the line, while that of relay *B* opens the test circuit and at the same time closes the tip strand of the cord, which completes the circuit between the two toll lines. When the conversation is completed the ring-off signal will actuate the clearing-out drop, which is permanently bridged across the cord circuit; and the operator upon receiving this signal will take down the connections. In case the desired line is busy, however, the sleeve strand of the jack associated with this line will have had its potential raised by virtue of the plug previously inserted; and the operator, upon testing the multiple, will receive the usual busy signal. This circuit may be traced from the negative side of battery to the sleeve of the jack and by way of the tip strand of the cord, through the break contact of relay *B* and the tertiary winding of the induction coil, to ground. The operator,

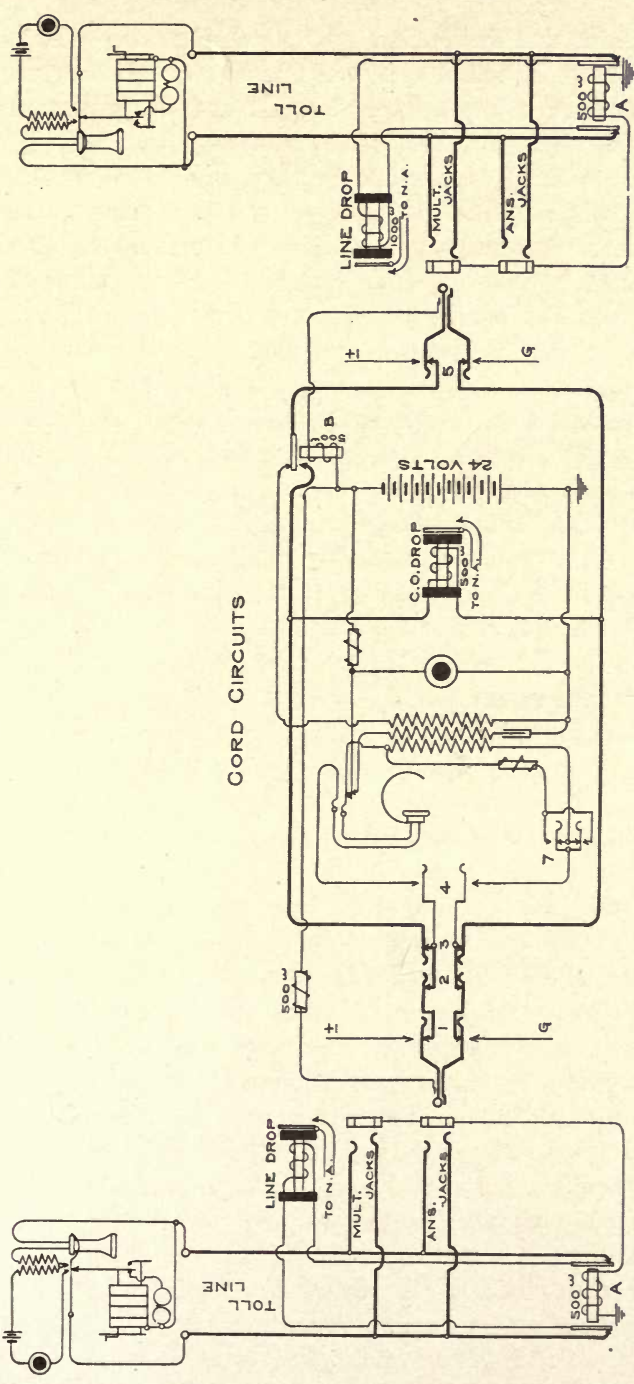


FIG. 39. — Toll-to-Toll Connection at a Multiple-drop Toll Board.

upon learning that the line is busy, will so inform the calling operator or subscriber. It will be observed that this circuit is provided with a double cut-off key 2 and 3, so that the operator can converse over either line, individually, if she so desires.

(*b*) **Toll-to-Local Connection.** — In a toll-to-toll connection the operator is in a position to complete the entire connection without further assistance, but when she desires a local subscriber she must call the trunk operator, who is situated at the local board, for a trunk assignment. The trunk circuit to the local board, together with a complete diagram of a toll-to-local connection, is shown in Fig. 40. As would be naturally inferred, and as the circuit shows, the toll end of the connection remains the same, while the cord circuit is no longer a through metallic connection, but is divided into two distinct parts; one end is adapted to the toll line and the other to the local trunk, these two parts being connected inductively by means of the repeating coil. The trunk circuit is plug-ended at the local board, and all trunks terminate at the trunk operator's position; while at the toll board the trunk is jack-ended and these jacks are multipled in each toll section so as to be readily accessible to each operator.

The operation of the circuit is as follows: The toll operator will, by means of her order circuit, place herself in communication with the trunk operator and inform her as to the number of the local subscriber desired. The trunk operator upon receiving this information will operate key 6 (non-locking) associated with one of the idle trunks and proceed to test the jack of the line called for. If the line is idle she will plug into the jack, at the same time giving the toll operator the trunk assignment. When the trunk operator inserts the plug a circuit can be traced from the ground at relay *D*, over the ring conductor of the cord, through the series contacts in the trunk jack and via relay *E* to battery. Due to the completion of this circuit, relays *D* and *E* will be energized; the operation of *D* disconnects the signaling apparatus from the line, while *E* closes the local lamp circuit and thus lights the trunk supervisory lamp at the local board. However, this lamp will remain lighted but a short interval, since the toll operator, upon receiving the trunk assignment, will plug into the trunk jack; this will open the jack contacts and break the circuit just established, thus releasing relay *E*. Relay *D* will remain energized, since a circuit can be traced from the ground at *D*, over the sleeve strand of the line, thence over the ring conductors of the trunk and cord circuits and

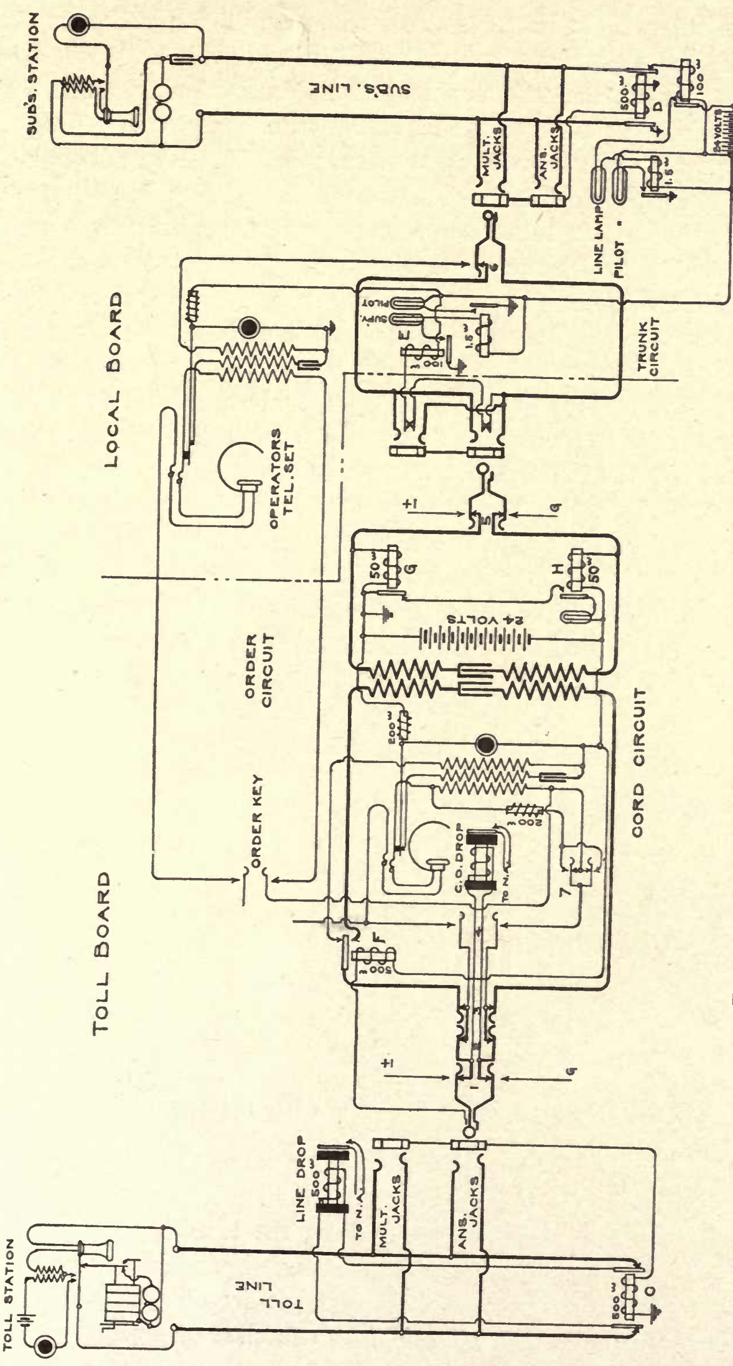


FIG. 40. — Toll-to-Local Connection at a Multiple-drop Toll Board.

through relay *H* to battery. This will energize relay *H* and thus light the toll supervisory lamp. The lighting of this lamp will show the toll operator that the local end of the connection has been completed, while the extinguishment of the trunk lamp will inform the trunk operator that the toll end has been taken up. The toll operator is now ready to ring the subscriber, which she does in the regular manner. When the subscriber answers he bridges his telephone set across the line, which causes current to flow over the toll cord circuit through relays *H* and *G*. This will operate relay *G* and extinguish the toll supervisory lamp, thereby informing the operator that the subscriber has answered. When the conversation is completed the clearing-out signal from the toll line will actuate the clearing-out drop. The local subscriber will hang up his receiver and thus release relay *G*. This will light the toll supervisory lamp and thus give the toll operator the disconnect signal. The latter will then take down the connection. The removal of the plug from the trunk jack will open the circuit through relay *H* and thus extinguish the supervisory lamp; it will also close the series contacts in the trunk jack. Thus the circuit through relay *E*, as explained above, will be reëstablished, and, consequently, this will light the trunk supervisory lamp, giving the trunk operator

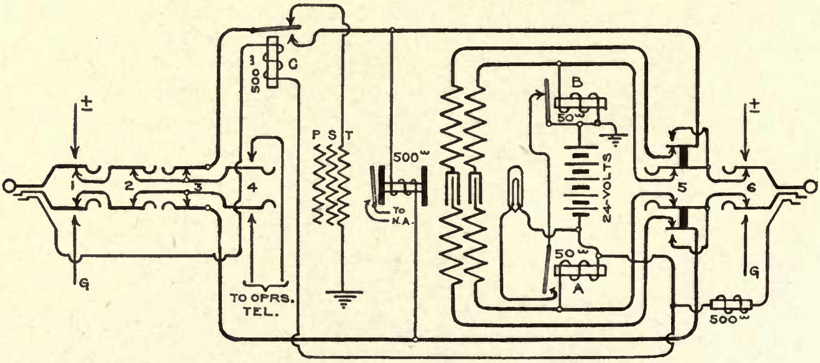


FIG. 41. — Combination Cord Circuit for a Multiple-drop Toll Board.

a disconnect signal. She will then take down the cord and thus restore the apparatus to its normal condition. In case the toll operator orders up a local line which is busy, the trunk operator will so inform her, and this information will be passed back over the toll line.

Thus far in the description of the multiple-drop toll board the cord circuits shown have been adaptable to one class of service only. A circuit embodying the essential features of the last two cord circuits described, and far superior to either, is the combination toll-to-toll and toll-to-local circuit shown in Fig. 41. This circuit in its normal condition is arranged for toll-to-local connections, as shown in the sketch, the two lines being connected inductively by means of the repeating coil; battery current is fed to the local subscriber's station through the coils of relays *A* and *B*. The only operation necessary to convert the circuit into a through metallic cord, for toll-to-toll service, is the operation of key 5, which cuts out the repeating coil and the local supervisory apparatus. The advantages of a circuit of this type have been fully discussed in Chapter VI; and, as the operation of the circuit is identical with the two last described, further discussion is unnecessary.

(*c*) **Local-to-Toll Connections.** — The local-to-toll connections naturally bring to mind the recording toll operator and her functions. The recording circuits, together with those necessary to complete a local-to-toll connection, are illustrated in Fig. 42. It will be observed that the recording trunk terminates in jacks at both ends, the local-board end being multipled in each section of the board so as to be accessible to all operators. At the toll board the trunks all terminate in jacks before the recording operators.

The method of handling a local-to-toll connection is as follows: A local operator, having been asked for toll, will test the recording trunk jacks until she finds one which is idle. She will then connect the subscriber with the trunk. The act of plugging into a recording trunk jack will raise the potential of the sleeve of the jack and thus put a busy test on the multiple. At the same time a circuit will be established from battery, through the coil *F* of the calling supervisory relay, over the ring strand of the cord and thence by way of the sleeve strand of the trunk, through relay *H* to ground. Relay *H* will thus be energized and will close a circuit from the ground on the make contact of relay *H* to the break contact of relay *G*, through the lamps associated with the trunk used and thence to battery. Consequently these lamps will be lighted and will attract the attention of a recording operator. The calling supervisory lamp in the local cord circuit will also be lighted, due to the energizing of coil *F* of the calling supervisory relay. The recording operator, upon plugging into the trunk jack, completes a circuit from battery through coil *L* and thence over the sleeve strand of the cord and trunk, through relay *K* and thus to

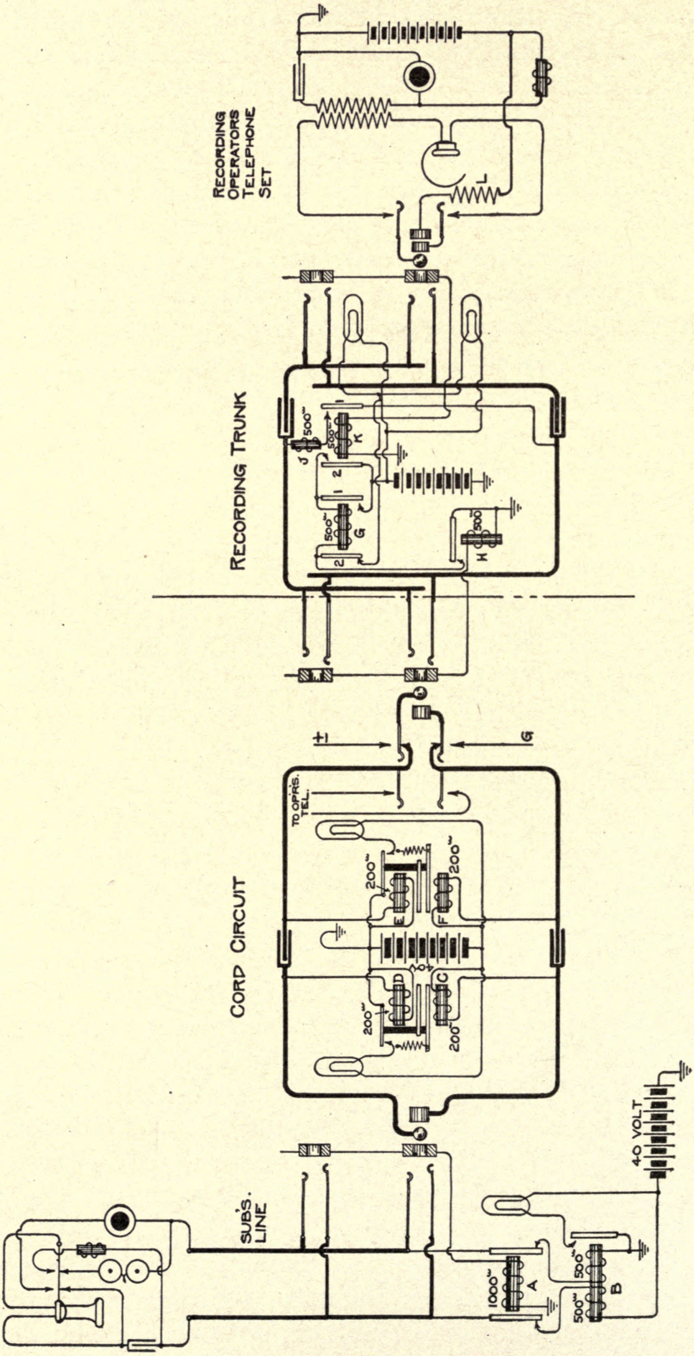


FIG. 42. — Recording Connections for a Multiple-drop Toll Board at St. Louis, Using a Three-wire Trunk.

ground. This will cause the operation of relay *K* and in turn will complete the two following circuits. First, the attraction of armature 1 of the relay will bridge the retardation coil *J* across the recording trunk, which in turn will cause current to pass through coil *E* of the calling supervisory relay in the local cord circuit. Since the magnetic pull of coil *E* opposes that of coil *F*, the retractile spring will have sufficient strength to draw up the armature and extinguish the local supervisory lamp; this will inform the local operator that the recording operator has answered the call. Second, the attraction of the other armature of relay *K* will close a circuit from battery through the make contact, thence through relay *G* and to ground through the make contact of relay *H*. Consequently the armatures of relay *G* will be drawn up, and will be locked by the make contact on armature 1, by means of the circuit that may be traced from battery through the make contact, the armature, the coil of relay *G*, and thence to ground through the make contact of relay *H*. Relay *G* will not be unlocked until relay *H* is de-energized. The attraction of armature 2 will break the lamp circuit, thereby extinguishing the recording trunk lamps. The recording operator will then take the details of the call from the subscriber and make out a toll ticket. She will then tell the subscriber to hang up his receiver and advise him that he will be called when the connection is ready. She will then disconnect from the trunk, thus releasing relay *K*. This will open the circuit of the bridged retardation coil *J*, which in turn will de-energize coil *E* of the supervisory relay and thus light the lamp in the local cord. The recording lamp will not relight, owing to the fact that relay *G* is still energized by means of the locking scheme previously described. When the local subscriber hangs up his receiver, the answering supervisory lamp in the local cord will also light and the local operator, upon seeing these signals, will remove the connections. The withdrawal of the plug from the recording jack will release relay *H*, which in turn will unlock relay *G* and thus restore the apparatus to its normal condition. The recording operator will then pass the toll ticket to the proper toll-line operator, who will obtain the subscriber desired and complete the connection as though it were a toll-to-local call.

Separate Toll and Local Office: Two-wire Local Board

(*a*) **Toll-to-Local Connection.** — The trunking circuits just described in Figs. 40 and 42 should be used only when the toll and local boards are in the same building. This follows from the design of the circuits, which require three wires in each trunk between the boards. Such a condition is met when there is but one local office in a city or town. If there are two or more local offices a two-wire trunking system is necessary for reasons of economy. Under the latter circumstances it is sometimes best to locate the toll office near the city outskirts, at or adjacent to a junction of the toll lines, in order to minimize the wire mileage in through connections. This is not universal practice, however, even though it is often the best method from a theoretical standpoint. Another method places the toll office in the same building with the largest local office. This is the practice followed by the Kinloch Telephone Company of St. Louis, and a description of their method of handling traffic between the toll board and the local branch offices will be given next.

A theoretical diagram of the circuit used for the toll-to-local connections in this system is shown in Fig. 43. It will be observed that the toll cord circuit is equipped with lamp supervision; the toll-line signals are drops, however, and therefore this board comes under the classification of "Combined Drop and Lamp Boards," referred to previously. The cord circuit is universal and somewhat special in design; a single lamp gives the disconnect signal for toll-to-toll connections, but a double disconnect signal is obtained on toll-to-local connections. This will be very evident from an inspection, so no further description of the operation of the cord circuit will be given, except as it affects the operation of an incoming toll trunk.

The toll board end of the trunk circuit terminates in a spring jack as shown; these jacks are multipled in each section of the toll board. At the local board the trunk is plug-ended, these plugs being situated at the toll trunk positions in the various branch offices. The method of handling a toll-to-local call, including the operation of the above circuit, is as follows: The toll operator will communicate, by means of an order circuit, with the trunk operator at the particular local office in which the desired subscriber's line terminates, asking for a trunk assignment. The trunk operator will then test the multiple jack of the line called for; if the line is idle, she will plug in and ring,

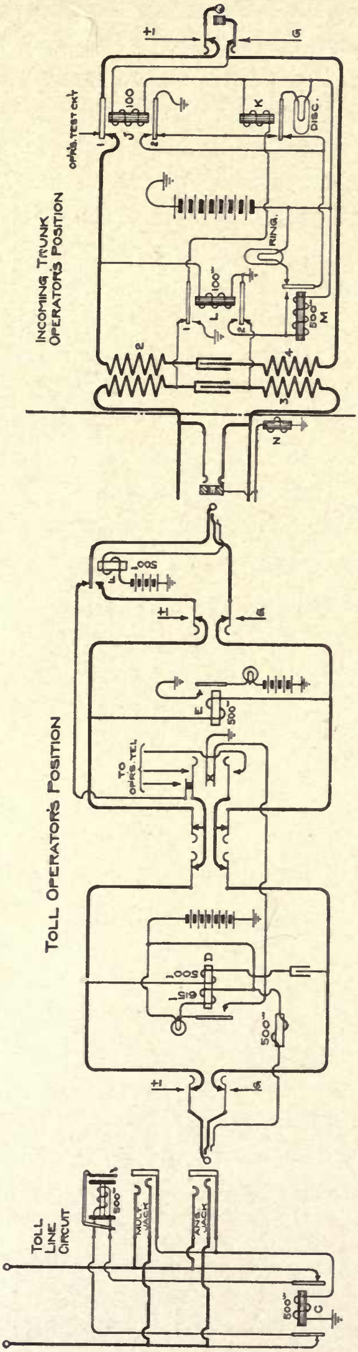


FIG. 43. — Toll-to-Local Connection, Using Two-wire Trunk at St. Louis.

at the same time giving the toll operator the trunk assignment. Herein lies the chief disadvantage of this system, since the work of ringing the local subscriber is transferred to the trunk operator. It will be remembered that in the circuit shown in Fig. 40 the ringing was attended to by the toll operator, and thereby gave her complete control of the connection; whereas in this system the toll operator must depend upon the trunk operator for this part of the work. When the trunk operator inserts the plug just referred to, a circuit may be traced from the ground on the line cut-off relay (not shown) to the sleeve of the multiple jack and thence over the ring strand of the trunk plug and cord, through relay *J* to battery. Therefore, relay *J* will be energized; armature 1 will open the lead to the operator's telephone set and at the same time close the tip strand of the talking circuit. The attraction of armature 2 will close a circuit through the disconnect and the ringing lamps, which will consequently be lighted. The circuit through the disconnect lamp can be traced from the ground on armature 2 of relay *J* to the break contact and armature of relay *K* and thence through the lamp to battery; the circuit containing the ringing lamp may be followed from the ground on the armature of relay *J* to the armature and break contact of relay *M* and thence through the lamp to battery. In the meantime, however, the toll operator will have inserted a plug in the multiple trunk jack assigned, thereby causing a flow of current from the ground on the retardation coil *N* to the sleeve strand of the trunk jacks and the cord circuit through relay *F* to battery. This will cause the operation of relay *F*, which will remove the test connection from the tip of the cord and close the tip strand of the cord circuit. The insertion of the plug of the toll cord will also close a circuit which can be traced from the ground on armature 2 of relay *L*, by way of the break contact to winding 3 of the repeating coil, thence to the ring strands of the trunk and the toll cord circuits, through the bridged relay *E*, returning over the tip strands of the cord and the trunk circuits, through winding 1 of the repeating coil, to the break contact and armature 1 of relay *L* and thence through relay *K* to battery. The completion of this circuit will cause the operation of relays *E* and *K*. The operation of relay *E* will light the supervisory lamp in the toll cord circuit, thereby informing the operator that the subscriber has not answered. The operation of relay *K* will extinguish the disconnect lamp at the local end of the trunk, by opening its circuit. The trunk operator then knows that the connection at the toll board has been taken up. When the local subscriber answers, a circuit will be completed from the ground on the coil of relay *L* to the tip strand of the trunk and thence by way of the subscriber's line circuit, to the ring of the trunk and through relay *J* to battery. This will operate relay *L*, and the attraction of its armatures will open the circuit through relay *E* in the toll cord circuit, by means of the break contacts. This will extinguish the lamp in the cord circuit. Furthermore, the attraction of armature 1 of relay *L* will maintain the circuit through relay *K*, by means of the ground on the make contact. The attraction of armature 2 of relay *L* will close a circuit from ground to the make contact and the coil of relay *M* to battery. Thus relay *M* will open the circuit containing the ringing lamp and close a circuit that can be traced from the ground on armature 2 of relay *J*, through the armature, make contact and winding of relay *M*, to battery. The latter will lock relay *M* until the subsequent release of relay *J*. The ringing lamp in the trunk circuit and the supervisory lamp in the toll cord circuit have now been extinguished, thus informing both operators that the local subscriber has answered. The toll connection can now be completed if the calling subscriber is waiting on the line. The toll operator will then supervise the connection until conversation starts satisfactorily.

When the subscribers have finished talking, the distant toll operator will ring off, thereby energizing relay *D* which will lock itself and thus light the answering supervisory lamp in the toll cord circuit. The action of relay *D* will be explained more fully under the description of the multiple-lamp toll board in a subsequent chapter. The local subscriber, by hanging up his receiver, will open his line circuit and consequently relay *L* will be de-energized. This will again close the circuit through relay *E* and thus light the calling supervisory lamp in the toll cord circuit. The release of relay *L* will have no effect upon the trunk operator's signals, as relay *M* will remain energized until relay *J* is released; therefore, the ringing lamp circuit remains open. When the toll operator receives the disconnect signals, she will operate her listening key to make certain that the subscribers are through talking; she will then operate the calculagraph and take down the connections. This will open the circuit containing relay *K* and its subsequent release will close the circuit containing the disconnect lamp. The lighting of the lamp will give the trunk operator a disconnect signal and she will thereupon take down the connection.

This will release relay *J* which, in turn, will release relay *M* and thus restore the apparatus to its normal condition.

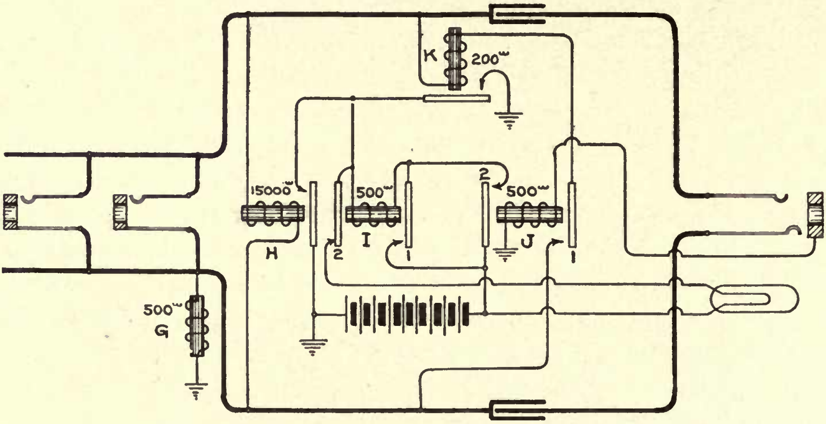


Fig. 44. — Two-wire Recording Trunk Circuit, Kinlock Telephone Company, St. Louis.

(*b*) **Local-to-Toll Connection.** — There now remains but one class of service that has not been explained in connection with this type of equipment, namely, the local-to-toll connection. In Fig. 44 is shown the recording trunk circuit used for this purpose. This trunk will operate with the circuits shown in the toll-to-local connection in Fig. 42, replacing the trunk circuit shown in that figure. The recording trunk shown in Fig. 44 is the one used in the St. Louis toll board in conjunction with the branch offices. These branch offices are equipped with the Kellogg Switchboard and Supply Company's four-relay cord circuit; but as the operation of this circuit is identical, theoretically, with the Stromberg-Carlson cord circuit shown in Fig. 42, it is possible to refer to the latter in the following description of the operation of the trunk shown in Fig. 44.

In the use of this circuit the local operator, upon being informed by the calling subscriber that a toll connection is desired, will test the recording multiple until an idle trunk is found and then complete the connection. This will complete a circuit from battery through coil *F* of the supervisory relay in the local cord circuit to the ground attached to coil *G* on the ring strand of the recording jack, thus operating the relay and lighting the supervisory lamp; this will also raise the potential on the sleeve of the jack, thus placing a busy test on the trunk multiple. At the same time a circuit will be established which may be traced as follows: from battery through coil *F* of the supervisory relay in the cord circuit, over the ring strand of the cord and the trunk, through relay *H* and thence by way of the tip strand of the trunk and the cord through coil *E* of the supervisory relay in the cord circuit, to ground. Due to the very high resistance of relay *H*, the local supervisory relay will not operate, while the large number of turns on relay *H* will cause it to respond and close a circuit that may be traced as follows: from ground on the armature of relay *H*, by way of the make contact, to the armature and the break contact of relay *I*, and thence through the recording lamp to battery. This lamp will light and signal the operator to answer. The act of plugging into the jack will complete a circuit from the battery through coil *L*, by way of the sleeve strands of the recording cord and trunk circuits, through relay *J* to ground. This will operate relay *J* and the subsequent attractions of armature 1 will place the 200-ohm relay *K* in parallel with the 15,000-ohm relay *H*, thereby decreasing the current in the latter sufficiently to permit it to release. Furthermore, the closing of the circuit through relay *K* will allow enough current to flow through coil *E* of the supervisory relay in the local cord circuit to cause its operation, thereby extinguishing the local supervisory lamp and informing the local operator that the call has been answered. Since the circuit through relay *K* has been closed, it will be actuated and will complete the following circuit: from the ground on the make contact of relay *K*, by way of the armature, through the coil of relay *I*, to the make contact and armature 2 of relay *J*, to battery. Relay *I* will thus be energized and the subsequent attraction of armature 2 will extinguish the recording lamp, while the attraction of armature 1 will lock the relay by means of a circuit which can be traced from the battery on the make contact, by way of armature 1 and the coil of the relay, to the armature and make contact of relay *K*, to ground. Relay *I* will therefore remain closed until relay *K* is de-energized. The recording operator is now ready to converse with the subscriber. Having obtained the necessary information she will request him to hang up his receiver. The act of hanging up the receiver will light the answering supervisory lamp in the local cord circuit, while the removal of the recording plug will open the circuit containing relay *J*; this in turn will remove the shunt around relay *H* and cause it to respond. The coil *E* of the supervisory relay in the local cord will be in circuit again with the high-wound relay and the current will be insufficient to hold up its armature, which will light the calling supervisory lamp in the local cord. The recording lamp will not relight, because relay *I* is still energized. The latter condition results as follows. When the recording operator removes the plug, as explained above, the armature of relay *K* falls back and relay *H* is immediately energized, thus shifting the ground connection from the make contact of relay *K* to the make contact of relay *H*; and since relay *K* is designed to be slow acting, this shift is made before the make contact of relay *K* is broken, and hence relay *I* remains locked. This locking circuit can be traced from the ground on the armature of relay *H*, by way of the make contact, through the coil of relay *I*, the armature and the make contact of the latter, to battery. Now, as stated above, the supervisory lamps in the local cord circuit have been lighted and consequently the local operator will remove the connections. This will open the circuit through relay *H*, which in turn will release relay *I* and thus restore the apparatus to its normal condition.

The discussion of the multiple-drop toll board has been confined thus far to the equipment, which is necessary for operation in conjunction with a two-wire local equipment, strictly speaking. The other type of toll equipment is the one which operates in connection with the three-wire local board. An example of the second type is the equipment which has been used by the American Telephone and Telegraph Company, illustrated in Fig. 45. The design of these circuits is such that they should be used only where the toll and local boards are in the same building, because three wires are used in the inter-board trunks. Inasmuch as a toll-to-toll connection with the equipment about to be described is practically identical with that outlined in connection with Fig. 39, no further comment on that type of connection will be necessary. The description will be confined, therefore, to the trunking equipment.

Joint Toll and Local Offices: Three-wire Local Board

(*a*) **Local-to-Toll Connection.**—The operation of the circuit shown in Fig. 45 is as follows. When a local operator ascertains that a toll connection is desired, she communicates with the incoming trunk operator by means of an order circuit, giving the latter the number of the local subscriber desiring the toll connection. The trunk operator will thereupon insert the plug of one of the toll trunks in the multiple jack associated with the subscriber's line. She disregards the busy test on this jack, which she receives because of the plug that was

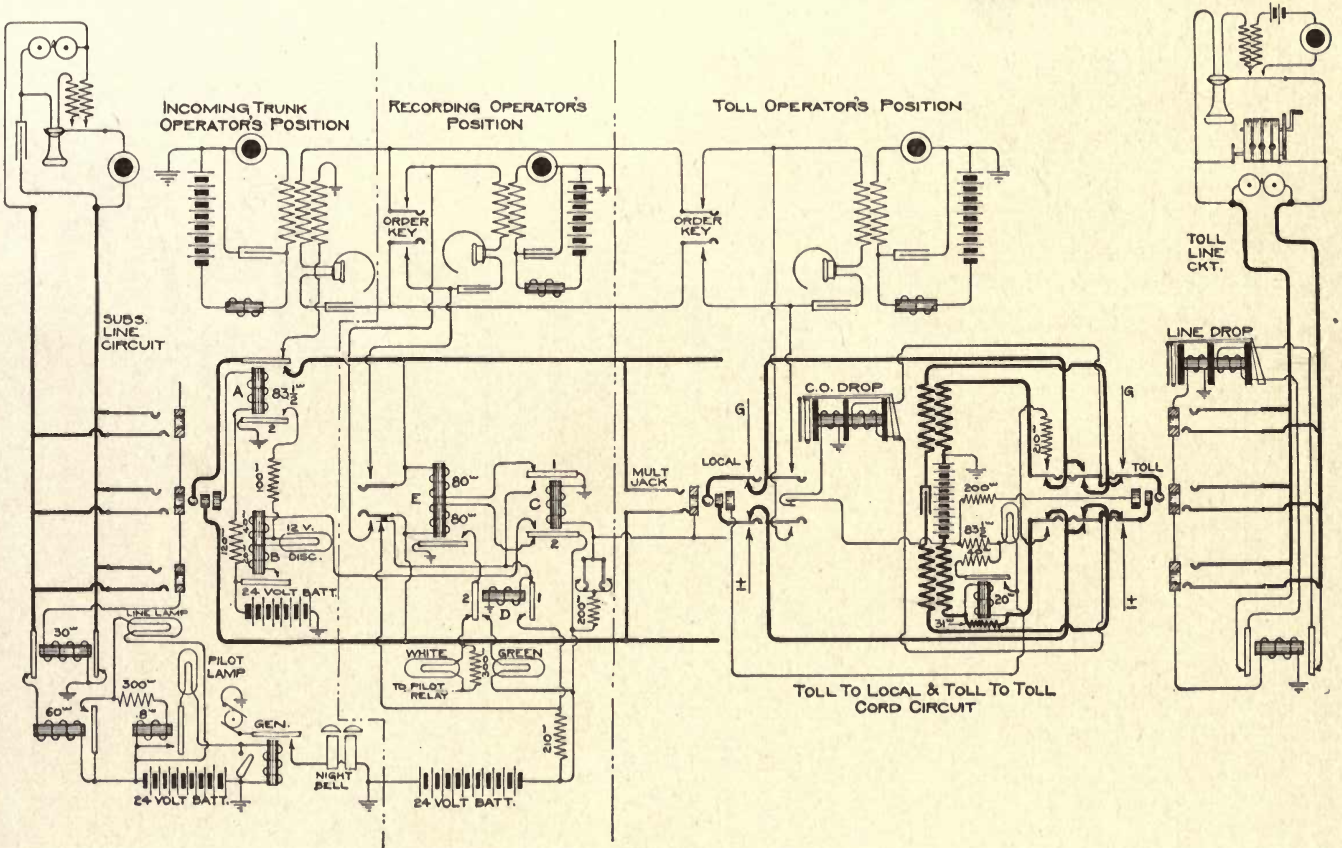


FIG. 45. — Toll Connection, Using a Three-wire Combined Switching and Recording Trunk, of the American Telephone and Telegraph Company's Type.

previously inserted in the answering jack by the local operator. The local operator will then withdraw the answering plug. The insertion of the trunk plug in the multiple jack of the local line will actuate relay *A*, the operation of which will remove the busy test connection from the tip of the plug and close the tip talking strand. This will also connect the ground, attached to armature 2, to one side of the disconnect lamp. This lamp will not be lighted, however, since the circuit to battery is open at the make contact of relay *B*. The insertion of the trunk plug and the subsequent operation of relay *A* will close a circuit through the double-wound relay *E*. This circuit may be traced from ground by way of armature 1 and the make contact of relay *C*, through one of the 80-ohm windings of relay *E*, to the tip strand of the trunk and thence to the line; then, since the subscriber's receiver is off the hook, the circuit is completed by way of the ring strand of the line and trunk, through the other 80-ohm winding of relay *E*, to the break contact and armature 2 of relay *C*, to battery. Relay *E* is thus energized and will light the white lamp at the recording operator's position. This lamp circuit can be followed from the ground on the armature of relay *E*, over the make contact, to armature 2 of relay *D* and then via the break contact through the lamp and pilot relay to battery. It will be noted that the white lamp is shunted by means of a 300-ohm resistance coil. The resistance of this coil is so great that the major part of the current will flow through the lamp; but should the lamp burn out, this resistance will provide a path by means of which the pilot relay will be energized. The pilot lamp in that case will light, thus notifying the recording operator that a call is waiting and she will proceed to operate her listening keys until she finds the particular trunk. Upon seeing the white lamp displayed, the recording operator will operate the listening key associated with this trunk, and obtain from the subscriber the details of his call. The operation of the listening key, in addition to bridging the recording operator's telephone set across the trunk, will close the make contact on this key. The closing of this contact completes a circuit which may be traced from ground through the winding of relay *D*, to the make contact in the key and then by way of the 210-ohm resistance coil to battery. This will energize relay *D* and the attraction of its armatures will perform several functions. First, the attraction of armature 1 will lock the relay by means of a circuit from ground through the winding to armature 1 and thence by way of the make contact and the 210-ohm resistance coil to battery; second, the attraction of armature 2 will substitute a green lamp for the white lamp previously mentioned. The object of furnishing these two lamps is to prevent a second answer by the recording operator while the toll ticket is on its way to the line operator. It is necessary that the recording operator be provided with some signal which will inform her that the line operator has taken up the trunk. This could be accomplished by re-lighting the white lamp but it might lead to the complication just mentioned.

When the recording operator has completed the toll ticket, she will pass it to the regular line operator who is to complete the connection. When the latter receives the ticket, she will insert the plug of the local end of one of her regular cord circuits in the designated trunk jack, which will actuate relay *C* due to the fact that battery is connected to the sleeve of the toll plug and ground is connected to the sleeve of the trunk jack by way of the coil winding of relay *C*. The operation of relay *C* will de-energize relay *E*, since the circuit by means of which the latter was energized, is opened at armatures 1 and 2 of relay *C*. This will extinguish the green lamp at the recording operator's position because the lamp circuit is opened at the armature of relay *E*. The recording operator knows, therefore, that the toll operator has taken up the connection. The attraction of armature 1 of relay *C* also unlocks relay *D*, as the winding of *D* is now shunted by a path from armature 1 of this relay to the make contact of armature 1 on relay *C* and then to ground. The unlocking of relay *D* restores all the apparatus to normal, except relay *C* at the recording position, which remains energized as long as the plug of the toll cord remains in the trunk jack; relay *C* thereby prevents the further operation of any of the recording equipment. The operation of relay *C* closes another circuit which can be traced from battery to armature 2 of the relay and then by way of the make contact, through the 40-ohm winding of relay *B*, through the 100-ohm resistance coil and the make contact of relay *A*, through the armature and thus to ground. Thus relay *B* will be energized and locked, due to the circuit that can be traced from battery to the armature of relay *B* and thence by way of the make contact, the 20-ohm winding, the disconnect lamp, the 100-ohm resistance coil and the make contact and armature 2 of relay *A*, to ground. This locking circuit will remain effective and hold up the armature of relay *B* until the connection is finally broken by the withdrawal of the trunk plug from the multiple jack. The disconnect lamp contained in the last circuit will not be lighted because it is shunted by the 40-ohm winding of relay *B*. The toll operator, having plugged into the trunk jack with the local plug of a pair of cords, will next insert the toll plug in the jack of the toll line and proceed to pass the call. When the called subscriber is ready, the conversation can be started and the toll operator will stamp the ticket in the calculagraph to time the connection. When the conversation is completed the local subscriber will hang up his receiver and thus light the supervisory lamp in the toll cord circuit in the regular manner. The toll operator will thereupon operate the listening key in the cord circuit to determine whether the conversation is finished. The operation of the listening key will restore the clearing-out drop in case it has been actuated, since a circuit is established through the restoring winding of this drop by means of the make contacts on the listening key. If the toll operator, upon listening-in, learns that no further service is desired, she will take down the connections. The removal of the local plug from the trunk jack will open the circuit containing relay *C*. This relay will thus be released. The restoring of armature 2 will open the shunt circuit around the disconnect lamp; the latter, therefore, will light and give the local trunk operator a disconnect signal. She will then take down the trunk connection and restore the apparatus to normal.

(*b*) **Toll-to-Local Connection.** — A distant toll operator calling the office in the usual manner will be answered by the line operator, who uses the toll end of one of the cord circuits. The line drop will be automatically restored at the same time, by the actuation of the restoring coil. The line operator, upon ascertaining that a local connection is desired, will make out a ticket and order up a trunk at the local trunking position, by means of her order circuit. The trunk operator will thereupon test the jack of the local line desired and, if it is idle, will insert the toll trunk plug, at the same time giving the line operator the trunk assignment. The latter will then insert the plug of the local end of the cord circuit in the jack of the trunk assigned, which will energize relay *C*. The insertion of the trunk plug at the trunking position will energize relay *A*; and since relay *C* is already energized, the circuit through the 40-ohm winding of relay *B* will be closed, and this relay will lock itself as explained in the local-to-toll connection. The disconnect lamp at the switching position will not

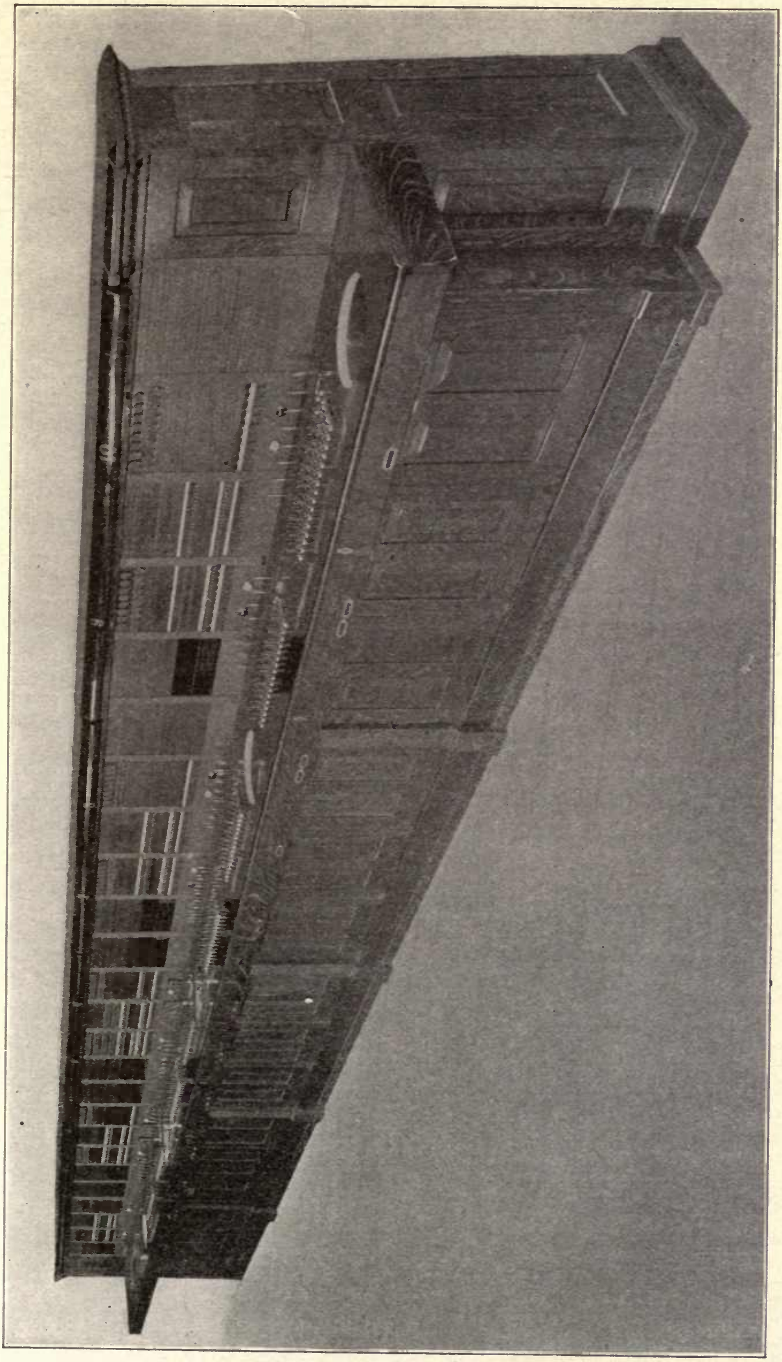


Fig. 46. — Stromberg Carlson Multiple-drop Toll Switchboard, Installed at Toledo, Ohio.

light, however, due to the fact that the shunt circuit around this lamp is closed at the make contact on armature 2 of relay C. The operation of relay C is the only one which takes place in the apparatus at the recording position, since this relay is operated before the subscriber answers, and hence the circuit through the two windings of relay E is permanently opened. Thus the recording operator will not be disturbed by any false signals. Now, as the local subscriber's receiver is on the hook, the supervisory lamp in the toll cord circuit will light and remain in this condition until the subscriber answers. The toll operator is then in a position to ring the subscriber. When he answers, the supervisory lamp in the toll cord will be extinguished and then the line operator will see that conversation starts. Upon the completion of the conversation, the disconnect signals will be obtained in the manner previously described.

There now remains to be shown the design of the circuits used by the American Telephone and Telegraph Company when the local and the toll offices are in separate buildings. The design of the trunk circuit there used is a radical departure from anything thus far shown, since the repeating coil, which heretofore has been situated in the cord circuit, is transferred to the trunk circuit. This serves to establish an objectionable feature in the respect that the trunk operator must ring the local subscriber, as it is impractical to ring through the repeating coil. Thus the toll operator loses complete control of the connection.

Separate Toll and Local Offices: Three-wire Local Board

(*a*) **Local-to-Toll Connection.** — The circuits employed with this type of equipment are shown in Fig. 47. The subscriber, after signaling the local operator in the usual manner, will be trunked to the recording operator in the manner previously described, when the offices are in the same building. The incoming trunk operator will insert the plug of an idle trunk in the subscriber's multiple, disregarding the busy test; the local operator will then disconnect from the answering jack. The insertion of the plug by the trunk operator will close a circuit from ground through the winding of the cut-off relay, thence over the sleeve of the jack and the sleeve strand of the cord, through the winding of relay A and the ringing lamp to battery. Thus relay A will be energized and the attraction of armature 1 will disconnect the testing circuit from the tip of the plug and at the same

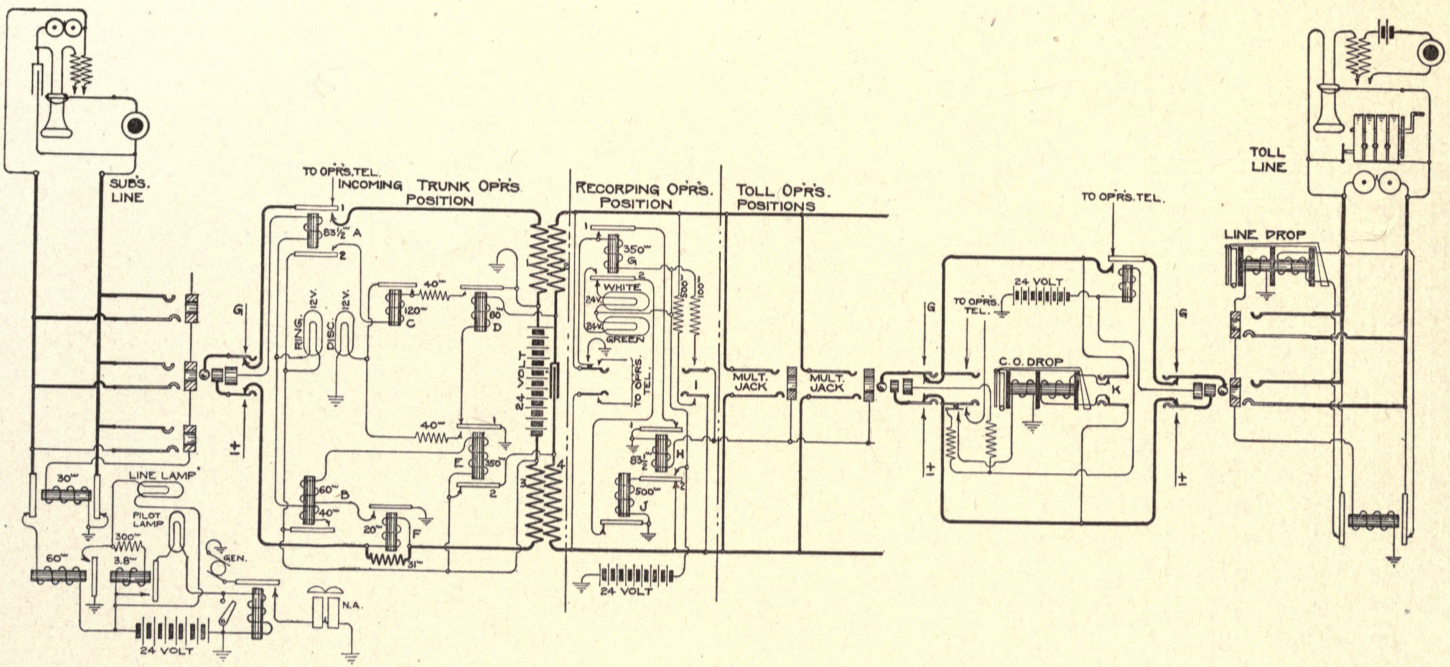


FIG. 47. — Toll Connection, Using a Two-wire Combined Switching and Recording Trunk, of the American Telephone and Telegraph Company's Type.

time close the tip talking strand. The ringing lamp, in the closed circuit just outlined, will not light on account of the actuation of relay *F*, which in turn energizes relay *B* and shunts the lamp by means of the 40-ohm locking winding. Relay *F* is energized because the subscriber's receiver is off the hook; and hence the battery will find a path from ground by way of winding 1 of the repeating coil, to the tip of the trunk and line through the subscriber's set, returning by way of the ring strand of the line and trunk, through relay *F* to winding 3 of the repeating coil and battery. The operation of relay *F* will close a circuit from the ground on the armature, to the make contact and through the windings of relays *B* and *E* to battery. Relay *B* is thus energized through the 60-ohm winding and will lock through the 40-ohm winding. The actuation of relay *E* and the subsequent attraction of armature 1 has no immediate effect upon the apparatus. The attraction of armature 2, however, opens a circuit which normally is closed through relay *J*. This circuit is traceable from ground, through the winding of the relay, to armature 2 of relay *H*; and thence by way of the break contact of the latter, through the ring strand of the trunk and winding 4 of the repeating coil, to armature 2, and the break contact of relay *E*, to battery. Relay *J* is thus de-energized and will close a circuit from the ground on its armature to armature 2 and the break contact of relay *G*, through the white recording lamp and then to battery. The lamp is therefore lighted and the recording operator, upon seeing this signal displayed, will actuate the listening key associated with the trunk. This will bridge her telephone set across the circuit so that she can converse with the subscriber. Due to the extra set of make-contact springs on the recording operator's listening key, a circuit is closed from the ground at these springs through relay *G* to battery. Thus relay *G* will be energized and attract its armatures. The attraction of armature 1 locks this relay, owing to the establishment of a circuit that can be traced from the ground on armature 1 of relay *H*, by way of the break contact of armature 1 of relay *G*, and the make contact and coil of this relay to battery. This relay is actuated, therefore, as long as relay *H* remains energized. The attraction of armature 2 of relay *G* opens the circuit containing the white recording lamp previously mentioned, and closes a similar circuit containing a green lamp. The restoration of the listening key, however, does not extinguish the green lamp because of the locking circuit just referred to. The purpose of these two signals is to give positive supervision as indicated in the description of the system immediately preceding.

The operation has now been traced to the toll-line operator. This operator, upon receiving the toll ticket, will insert the answering plug of one of the toll cords in the multiple jack of the trunk designated. This will close a circuit from the battery connection on the sleeve of the toll cord, to the sleeve of the trunk jack and through the coil of relay *H* to ground. The attraction of armature 1 of relay *H* opens the locking circuit through the coil of relay *G*; the latter will be released, thus opening the circuit containing the green recording lamp. The extinguishment of this lamp informs the recording operator that the line operator has taken up the connection. The attraction of armature 2 of relay *H* will close a circuit from the ground at the coil of relay *J*, to armature 2 of relay *H* and then to battery. Relay *J* is thus energized and prevents the relighting of the white recording lamp. The apparatus at the recording position, with the exception of relay *H*, is now in its normal condition, and will remain so until the toll plug is withdrawn from the trunk jack, which will release relay *H*. The line operator will now proceed to complete the connection as previously described. When the conversation is completed, the clearing-out drop in the toll cord circuit will be actuated either by a clearing-out signal from the toll line or by the subscriber's act of hanging up his receiver. The operation of the former circuit is self-evident; but the latter is somewhat difficult and therefore will be explained.

When the local subscriber hangs up his receiver, the line circuit is opened at his instrument, which causes the release of relay *F* and in turn the release of relay *E*. The return to normal of the armatures of relay *E* closes a circuit from the ground on armature 1 and the break contact of this relay, to the winding of relay *D* and the winding 2 of the repeating coil, over the tip side of the trunk and cord circuits, thence through the winding of the clearing-out drop and over the ring side of the cord and trunk, through the winding 4 of the repeating coil, and armature 2 and the break contact of relay *E* to battery. The completion of this circuit will actuate the drop and also energize relay *D*; the latter, in turn, will close a circuit from the ground on its armature to the make contact, thence through the 40-ohm resistance coil, the winding of relay *C*, the make contact and armature 2 of relay *A* and then to battery. Relay *C* will then close a circuit from ground, through the disconnect lamp, to the armature and make contact of relay *C*, the coil of the latter, and the make contact and armature 2 of relay *A*, to battery. Relay *C* is locked, therefore, through the make contact and armature 2 of relay *A* and will remain so until the trunk operator takes down the connection. The disconnect lamp contained in this locking circuit will not light, however, due to the shunt circuit established by the 40-ohm resistance coil and the armature of relay *D*, to ground. However, when the toll operator obtains the clearing-out signal, she will take down the connections and this will open the circuit containing the coil of relay *D*, previously traced. The release of relay *D* will open the shunt around the disconnect lamp. The lighting of this lamp will give the trunk operator the disconnect signal and she will take down the trunk connection, which will release relay *A* and consequently relay *C*. All apparatus will then be restored to its normal condition.

(*b*) **Toll-to-Local Connection.**— The toll-line operator, upon receipt of an inward call, will communicate with the trunk operator by means of the order circuit, and inform her as to the number of the local subscriber desired. The trunk operator will assign a trunk and test the multiple jack of the local line. In case the line is busy, she will insert the trunk plug in a busy-back jack to give the toll operator a busy signal. If the line is idle, she will insert the trunk plug, of course, in the multiple jack. This will light the ringing lamp associated with the trunk circuit, due to the fact that relay *F* is not energized. The trunk operator will then ring the local subscriber. When he answers, relay *F* will be energized and the ringing lamp will be extinguished, as explained in the local-to-toll connection. In the meantime, the toll operator will have inserted the calling plug of the pair of cords used to answer the incoming toll call in the multiple jack of the trunk assigned. This will have operated relay *H*, and thus prevented the operation of the remaining apparatus at the recording operator's position. The subscriber is then in communication with the line operator, and the connection is handled in the same manner as described for the local-to-toll connection.

It will be observed that the toll cord circuit is equipped with a key *K*, by means of which the operator may disconnect the clearing-out drop from the circuit. This key is used on line connections only, when it becomes necessary to improve transmission to the utmost; in this case, the removal of the bridged drop will slightly improve the talking efficiency of the circuit.

Auxiliary Toll Board Circuits. — A discussion of some of the local circuits or trunks, used in connection with a multiple-drop toll board, is necessary to make clear the methods of handling any calls which involve irregular operations. These circuits can be adapted, with few changes, to any of the systems previously described in this chapter.

One of the important circuits in a board of this kind is the interposition trunk, used by the operators for intercommunication and transfers. At first sight it might seem that a circuit of this kind would be detrimental rather than beneficial, owing to the possibility that operators might use it improperly for personal conversation. However, in a well-disciplined office cases of this kind should be rare. These circuits may be used also for information trunks; in this case one end of the circuit terminates at the information operator's position. One of the types of interposition trunk is shown in Fig. 48. It will be noted that the circuit is jack-ended; these jacks are multipled in each section of the board, so as to be accessible to all line operators. It is customary to place a designation strip directly above the jacks, by

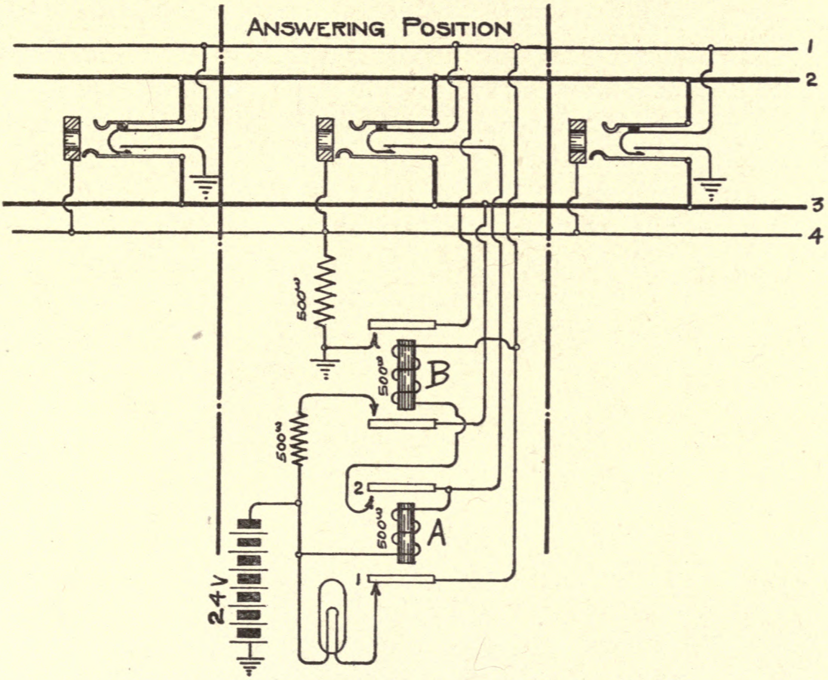


FIG. 48. — Interposition Trunk Circuit.

means of which they may be suitably numbered. The answering jacks shown at the " answering position " in Fig. 48 (with associated apparatus) are distributed among the various sections or positions, so as to provide universal intercommunication. The lamp shown is usually placed in the pilot rail so as to make it as conspicuous as possible.

The operation of the circuit is as follows: When one operator desires to communicate with another, she will insert the local plug of one of her cords in the jack of the trunk which terminates before the desired operator. This operation will connect battery to the sleeve of the jack, for a busy test, and will also close the make contact in the jack. The closing of this contact will complete a circuit which can be traced from the ground on the jack contact, along wire 1 to armature 1 of relay *A*, and thence through the interposition lamp to battery. This signal will order the desired operator to answer; the latter will do so with the local plug of one of her cord circuits. This will close the jack contact in the answering jack and thus establish a circuit from battery through the coil of relay *A* (and the contact just mentioned), thence over wire 1, through the make contact in the calling operator's jack and then to ground. The operation of relay *A*, by means of armature 1, will open the circuit containing the interposition trunk lamp and extinguish the latter. The attraction of armature 2 will close a circuit from the make contact and armature 2 on relay *A*, through the coil of relay *B* to wire 1. It will be observed that relay *B* is short-circuited by part of the circuit previously traced, that is, by the wire from armature 2 of relay *A*, to wire 1 of the trunk. Therefore relay *B* will not operate.

The operators are now directly connected by means of wires 2 and 3. When the called operator disconnects, the short-circuit on relay *B* will be removed. This relay will then operate and connect battery to the ring side and ground to the tip side of the line, which will cause the operation of the supervisory relay in the cord circuit at the calling operator's position and give her a disconnect signal. This operator will then remove the connection, which will release relay *B* and restore the apparatus to normal.

Another auxiliary circuit which helps to reduce the labor of operation considerably is the shifting receiving circuit sometimes used at the recording positions, and shown in Fig. 49. This diagram shows two recording operator's positions and a multiple of three trunks; the

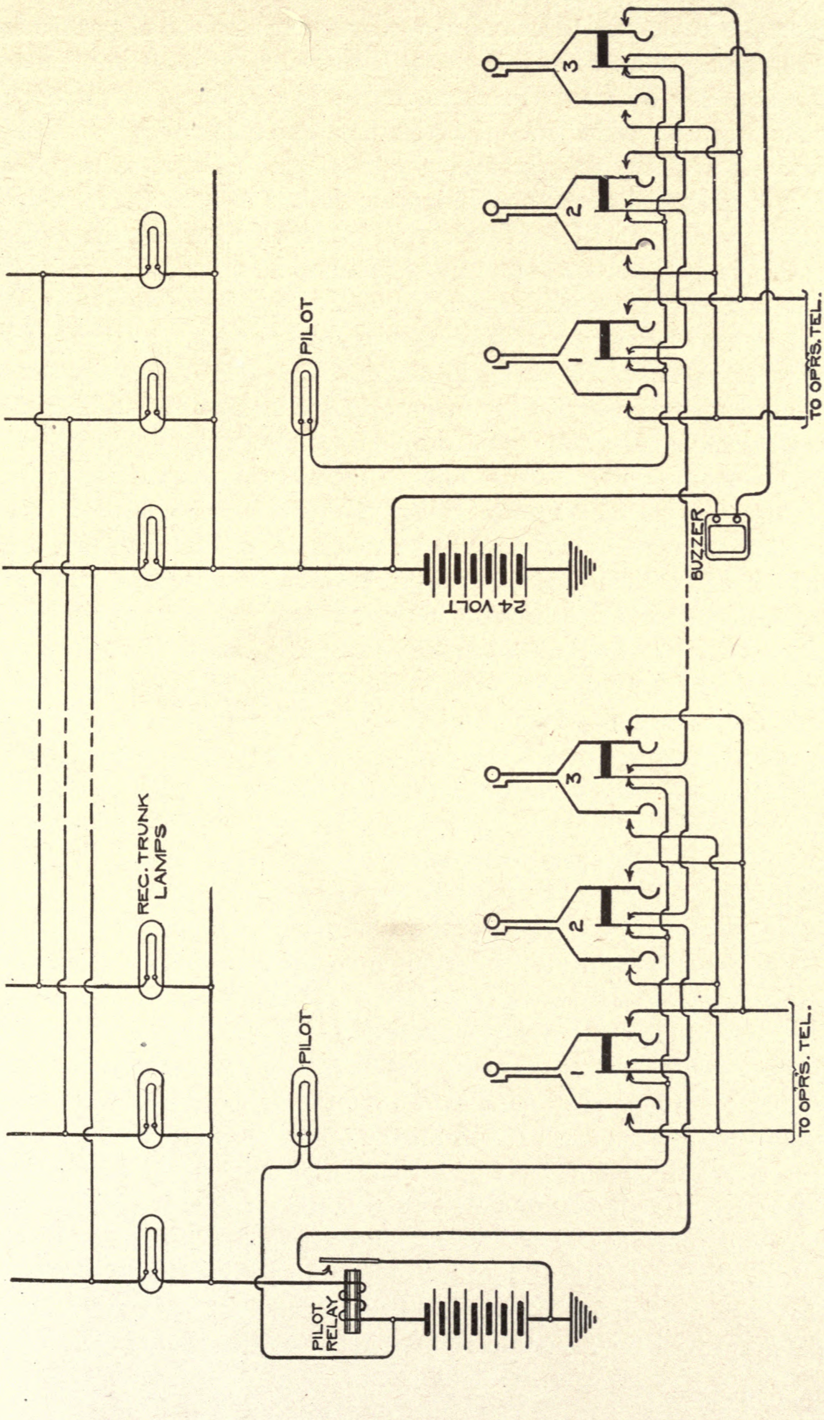


FIG. 49. — Shifting Receiving Circuit at Recording Positions.

general scheme can be extended to cover any number of positions. The primary purpose of this circuit is to switch an incoming call to the first idle position. Furthermore, each position is so arranged that it can be taken out of service and the calls which would be received switched automatically to the next position in service. This is of special advantage during the periods of light traffic, when only one or possibly two operators are necessary to handle the work; in this case, these operators can be grouped in any manner desired. This will become evident after the operation has been described. It will be noted that each recording lamp is wired through the pilot relay to battery. Hence an incoming call will light the recording trunk lamp and energize the pilot relay. Consequently, if key 1 is in its normal position, a circuit can be traced from the ground on the armature of the pilot relay, by way of the make contact, to the make contact in key 1, and thence through the pilot lamp to battery, thus lighting the pilot lamp. It may be well to state that although the circuit shows three cord circuits per position, the operator has use for but one; and the other two are installed only as a reserve in case of trouble. The keys of these reserve cord circuits are always kept in the listening position so as to permit the transfer of calls to the next position, as will be explained later on. Furthermore, a recording operator answers only when both the line and the pilot lamps light, the latter being the operator's individual signal.

An incoming call has been traced to the lighting of the pilot lamp in position 1; the operator at this position, upon seeing the lighted pilot lamp, will plug into the jack associated with the lighted trunk lamp, operate key 1 and answer the call. The act of plugging into the trunk jack will extinguish the trunk lamp and likewise the pilot lamp, as previously described. The operation of the key will open the break contact and close the make contact; and since keys 2 and 3 are also in the listening position, as before stated, their contacts will be in a similar condition. Assuming that while the first operator is answering a call, a second call comes in, the operation will be as follows: The trunk lamps will light at each position and energize the pilot relay; but the pilot lamp circuit at the first position is open at the keys and consequently the second pilot will light because a new circuit has been established from the contacts of the pilot relay, through the keys at the first position. This circuit can be traced from the ground on the armature of the pilot relay, by way of the make contact of this relay and the make contacts of keys 1, 2 and 3 at position 1, to the break contact of key 1 at position 2, and thence through the pilot lamp at position 2 to battery. The operator at position 2, upon seeing the lighted pilot lamp, will insert a plug in the jack associated with the lighted trunk lamp, thereby extinguishing the latter and the pilot. This operator will also have the keys of the two cords not in use in the listening position; hence the next incoming call will be transferred to the third or next idle operator in a manner identical with that just described. When all the keys in all the positions are thrown, the circuit through the buzzer will be closed, thus giving the overflow alarm; this will notify the supervisor that the number of operators at the recording position is inadequate to handle the traffic. It is understood, of course, that the bridging of the recording operator's set across the trunk will give the operator at a two-wire local board the usual cord supervision.

The circuits used in connection with the multiple-drop toll board have now been fully discussed; it remains to describe how the apparatus used with these circuits is distributed through the switchboard sections so as to give the best economy from an operating standpoint. Having this in view, there is shown in Fig. 50 a fully equipped toll-line terminal section, designed for an ultimate capacity of sixty toll lines. The usual method of distributing the apparatus is practically uniform for all sections; hence the description will be confined to a single section. It will be noted that all the drops have been placed above the other equipment, so as to occupy the most conspicuous position; furthermore, their operation is not as likely to be interfered with for obvious reasons. The clearing-out drops are mounted at the extreme top of the panels and are numbered to correspond with the cord circuits. Directly below these are the toll-line drops, numbered to correspond with the answering jacks beneath. Five toll lines per position are shown, this being about the average number of lines that one operator can handle. It is impossible to make any definite statement as to the number of lines that ought to be placed in one position, this being regulated entirely by local conditions and operating methods. The toll-line multiple is shown next below the line drops; it is good practice to place a designation strip immediately above the jacks, to facilitate proper numbering of the lines.

The outgoing trunks to the various local offices are just below the toll lines and are multipled across the board in a similar manner.

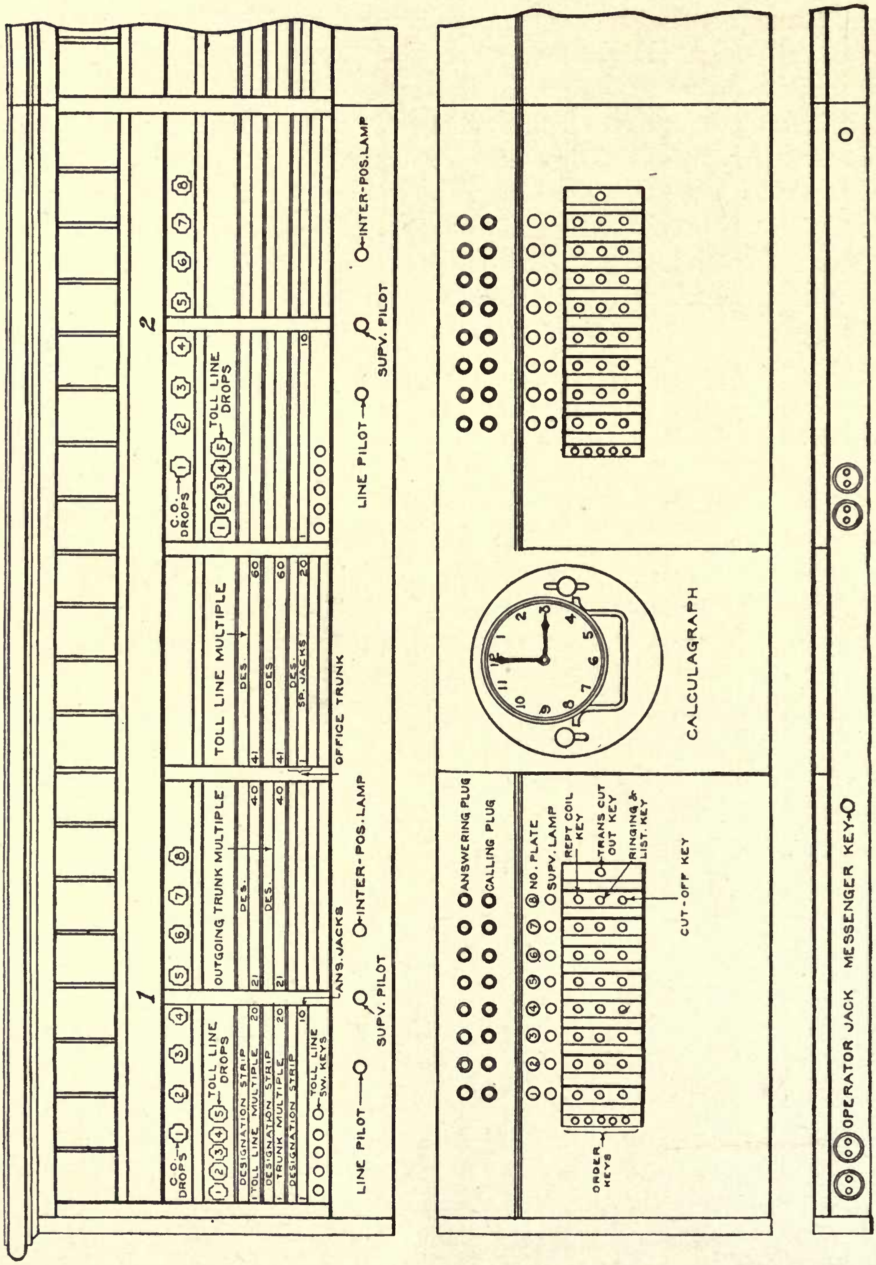


FIG. 50. — Jack and Key Equipment of a Toll-line Terminal Section in a Multiple-drop Switchboard.

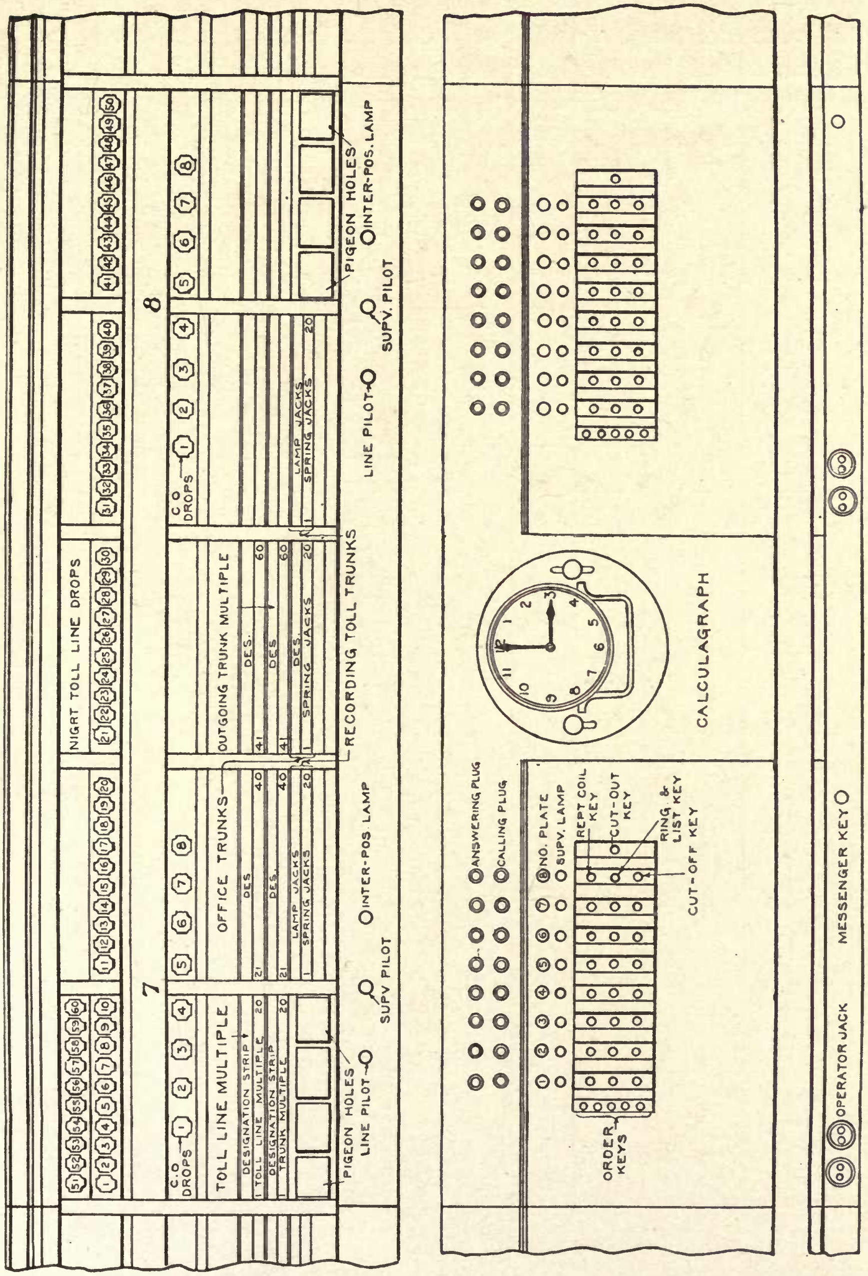


FIG. 51.—Jack and Key Equipment of a Combined Recording and Common-drop Section.

The drawing shows sixty of these trunks, which number at first thought might seem excessive, but this matter is regulated entirely by the volume of terminal traffic and, to some extent, by the operating methods. It is broadly true that the number of lines, of every kind, is governed by the maximum demand or busy hour.

The toll answering jacks are naturally placed at the bottom of the panel. In the extreme left panel of each position are shown the switches for transferring the toll lines from the terminal position to the night or common-drop position. The office and interposition trunks are shown in the middle panel. The line pilot, the supervisory pilot and the interposition trunk lamps are located in the pilot rail, where they are well isolated from the other equipment and thus conspicuous. It will be noted that the keyboard has been designed with sufficient width to give the operator plenty of room for handling tickets. The keys have been grouped in a manner identical with that mentioned in Chapter VI, for reasons there given. The calculagraph is mounted in the space between the two operators so as to be readily accessible to both. A messenger key is shown in the front rail beneath the keyboard. The messenger circuit and its operation will be fully explained in the next chapter. The top part of the section is occupied by pigeon holes for filing toll tickets.

Fig. 51 shows a combined recording and common-drop (or night) section. During the daytime this section is used for recording, while at night it is used as a common-drop section. The toll-line drops can be transferred to this section by means of the night switches at the terminal sections. It will be observed that the general layout of the section is similar to the one already shown, except that there is no regular line equipment and the pigeon-hole space is occupied by drops. The second panel is equipped in addition with a strip of twenty lamps and jacks for recording purposes. This type of section is very serviceable, since it is adapted for the recording work during the daytime and the line work at night, when the traffic is a minimum.

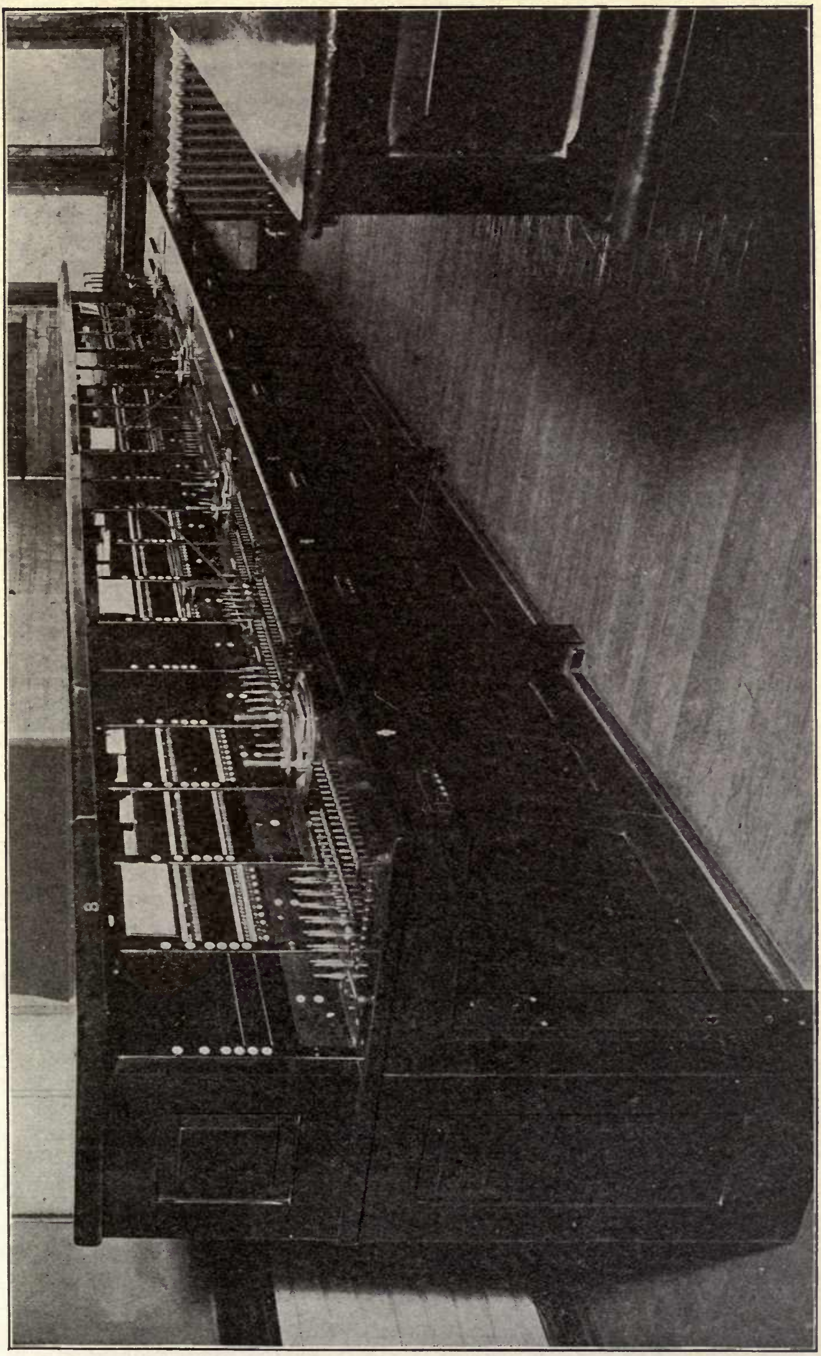


FIG. 52. — Multiple-lamp Toll Switchboard; American Telephone and Telegraph Company, at Lynchburg, Va.

CHAPTER VIII

MULTIPLE-LAMP TOLL SWITCHBOARDS

THE previous chapters have covered all the types of toll board equipment except that one which employs lamp signals exclusively. This type forms the subject of the present chapter. It has numerous advantages, chief among which are the diminished labor and greater speed of handling traffic, compact arrangement of panel equipment, and a system of visual busy signals without unprotected intervals.

Three separate types of multiple-lamp board are covered in the following subject matter, namely, the American Telephone and Telegraph Company's type, the Tri-state Telephone and Telegraph Company's type and that of the United States Telephone Company. Each of these types is fully explained for toll-to-local and local-to-toll connections. The other class of connection, from toll-to-toll, is substantially the same for all three equipments, at least in its essential features. This will be described first, therefore, in order to avoid repetition and also to condense as much as possible the subsequent descriptions, which are somewhat complicated at best.

General Type of Toll-to-Toll Connection. — A complete connection of this type is shown in Fig. 53. It will be noted that the general scheme employed in the line circuit is similar to the one used in a common battery subscriber's circuit, since the essential features of both are the line and cut-off relays. The line relay is normally bridged across the line, through one contact of the cut-off relay. The function of the latter, obviously, is to open the circuit of the former when the line is in use. The method of operation may be described as follows.

An incoming toll-line signal, or ring, will energize winding 1 of relay *M*, thereby drawing up its armature and completing three local circuits which can be traced as follows. The first one commences at the ground on armature 2 of relay *N* and passes by way of the break contact to the armature of relay *M*, and then through the line lamp to battery, which will light the lamp. The second circuit follows the

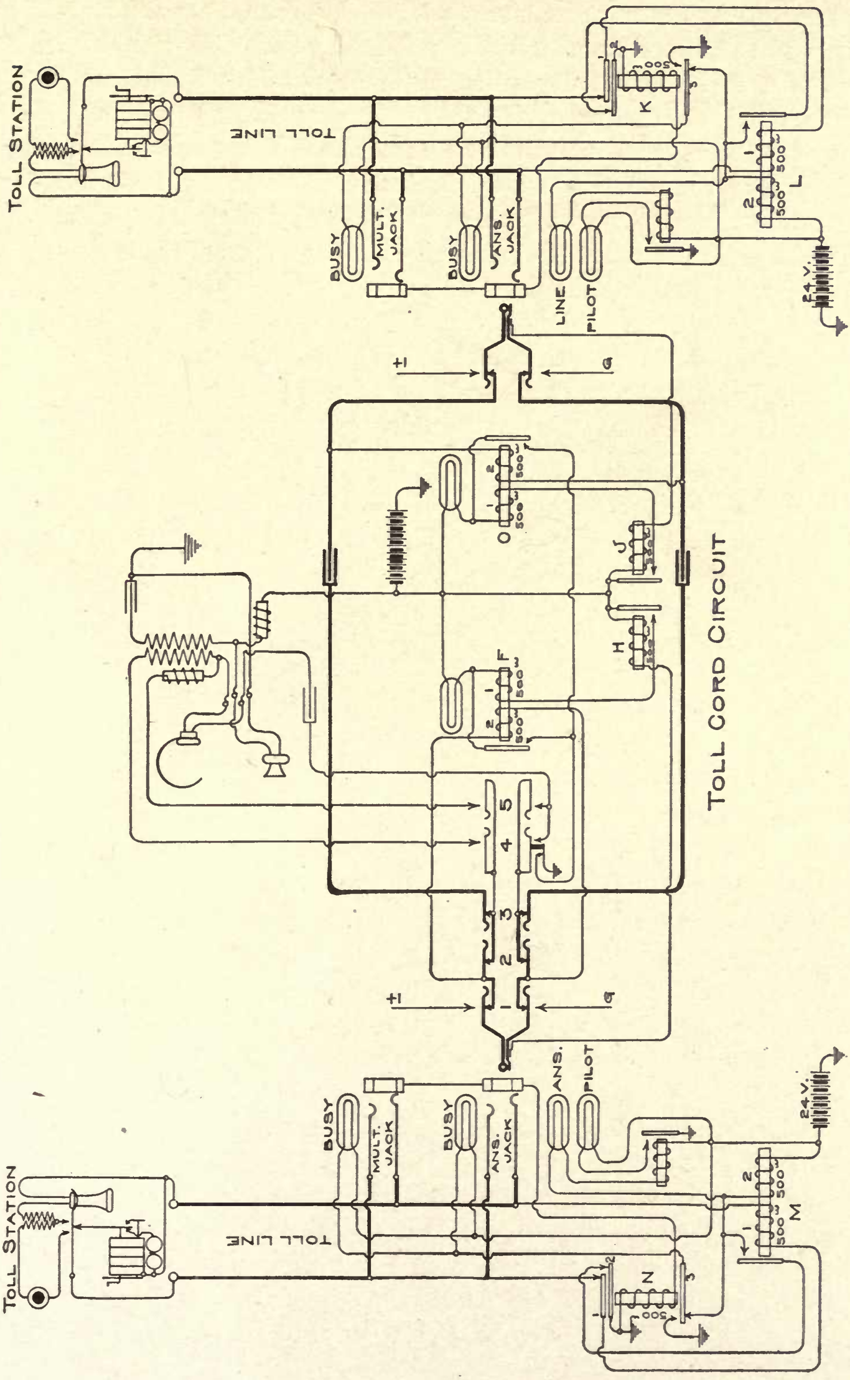


FIG. 53. — General Type of Toll-to-Toll Connection for a Multiple-lamp Toll Board.

same route to the make contact of relay *M*, but from that point it finds its way to battery through winding 2 of relay *M*. This circuit locks relay *M* in an operated position until the circuit is broken by the drawing up of armature 2 on the cut-off relay *N*. Thus it must be obvious that when a subscriber calls over the toll line, a single turn of the generator crank will lock the line relay *M* by means of winding 2 and, consequently, give a permanent line signal at the switchboard. The third circuit completed by means of the operation of the line relay is the one containing the busy lamps. This circuit can be traced to the make contact of the line relay as outlined above, from there to armature 3 of relay *N* and thence through the busy lamps to battery. Thus all the busy signals associated with this particular line will be lighted. These busy lamps are mounted above the multiple jacks of each line and will light as soon as a line signal is received, or an operator plugs into one of the jacks; they will remain lighted as long as the line is busy. It follows, therefore, that an operator can see at a single glance whether or not a line is busy.

Returning to the description of the operation, we find that the incoming signal has lighted the line lamp. The operator, observing the displayed signal, will plug into the answering jack associated with the lamp, operate her listening key 4 and determine what is desired. The act of plugging into the jack will close a circuit from the battery connected to the coil of relay *H*, over the sleeve of the cord and the jack, through the coil of cut-off relay *N*, to ground. Thus these two relays will be energized. The operation of relay *N* performs several functions. In the first place, the attraction of armature 1 opens the circuit of coil 1 of relay *M*, which was bridged across the line. Secondly, the attraction of armature 2 will remove the ground from the completed circuits which were established by the actuation of relay *M*; as a result, this relay will be released and the line lamp will be extinguished. The busy lamps will not be extinguished, however, because the ground connection removed by the attraction of armature 2 of relay *N* is reëstablished by the attraction of armature 3 of the same relay.

The operator, having actuated her listening key, is in a position to converse over the toll line. Upon being requested for a connection to another toll line, she will note the condition of the busy lamp and, if the line is idle, she will plug into the multiple jack with the calling plug of the cord in use and ring over the outgoing line. The act of plugging into the second line will complete a circuit which can be traced over the same general path as that outlined for the incoming call; this involves the operation of the cut-off relay *K* in the outgoing line and relay *J* in the cord circuit. If it is the duty of this operator to time the connection, she will proceed accordingly and exercise careful supervision; if not, she will pay no further attention until she receives a signal.

When the conversation is completed, disconnect signals may be received from either or both directions; the operation of the cord supervisory signals will be identical in either case. Hence the operation of but one circuit need be described. The circuit from the outgoing line is the one which is traced in the following. The current from the incoming signal will seek a path over the tip side of the line to the tip of the cord, through winding 2 of relay *O*, to the ring side of the cord and thence back to the ring side of the line. Thus relay *O* will be actuated, and locked in that position, in turn lighting the supervisory lamp and giving the operator a disconnect signal. The relay is locked by means of a circuit that can be traced from the ground on key 4, to the armature of relay *O*, through winding 1 of the same relay, to the make contact and armature of relay *J* and then to battery. The lamp is lighted by a circuit starting at the ground on key 4; from there it can be followed to the armature of relay *O* and then through the lamp to battery. When signals come in from each line, the operator will receive a double disconnect, thereby indicating that the conversation is finished; she will then take down the connection. The withdrawal of the plugs will open at both ends of the cord the circuits containing the cut-off relays *N* and *K* and the cord relays *H* and *J*, and therefore these relays will be de-energized. The release of the armatures of cut-off relays *N* and *K* will extinguish the busy lamps, while the return of the armatures of relays *J* and *H* will open the locking windings of relays *O* and *F* respectively; as a consequence the latter relays will be de-energized and the supervisory lamps will be extinguished. Thus the apparatus is all restored to its normal condition and ready for another connection.

Before leaving this class of connection, attention should be called to the fact that the locking windings of relays *F* and *O* each obtain ground from the break contact of the listening key 4. This is necessary in order that the operator may extinguish the supervisory lamp in case it is lighted by an incoming signal, without withdrawing the plug from the line jack. In explaining this, reference will be made to the answering end of the cord circuit only.

An incoming signal will lock relay *F* and thus light the supervisory lamp, as previously explained. The operator, upon seeing this signal, will operate the listening key 4 to answer. She thereby brings about the double result, first, of unlocking relay *F*, which in turn extinguishes the supervisory lamp due to the opening of the make contact at key 4, and second, of bridging her telephone set across the circuit. When the operator restores her listening key, the ground is again connected to the make contacts of relays *O* and *F*, in preparation for further supervision.

The cord circuit shown in Fig. 53 is adapted for toll-to-local as well as for toll-to-toll connections and the local trunking schemes are so designed that a two-wire trunk can be used without sacrificing the inherent advantage of ringing the local subscriber from the toll board. None of the two-wire trunking systems previously described were designed to accomplish this result. This operating advantage is made possible by placing the repeating coil in the trunk circuit at the local board. It is impossible to ring through this coil, but the ringing signals are automatically repeated at the local office. This feature is obtained, however, at the expense of great complexity in the trunk circuit; for it is the direct result of the successive operation of a series of relays, the functions of which will be explained later on.

Furthermore, as the line and cord circuits shown in Fig. 53 are applicable to practically all multiple-lamp toll boards now in common use, the remainder of the description of this type of equipment will be devoted to the trunking systems. The design of these systems varies according to the type of local board with which they are associated. There are three of them which merit a full description. A thorough understanding of the principles and operations of each will enable one to comprehend readily all others which may be encountered in actual practice, since the essential operating features of this type of board are fully covered. In the subsequent description, the system which is furnished by the Western Electric Company is considered first, inasmuch as it was the pioneer development in this class of equipment and the first to be used by an operating company. The lamp-signal toll circuits designed and used by the American Telephone and Telegraph Company have been taken as patterns for similar purposes in the independent field.

American Telephone and Telegraph Company's Equipment

(*a*) **Toll-to-Local Connection.** — A complete conventional circuit of a toll-to-local connection through a Western Electric Company's No. 1 toll board, as used by the American Telephone and Telegraph Company, is shown in Fig. 54. It will be observed that the toll cord circuit shown is equipped for the audible busy signal, while the line is furnished with the visual busy signal. The toll operator answers a lighted line signal by inserting the answering plug of one of the cord circuits. Upon ascertaining that a local subscriber is desired, she will communicate with the toll local trunk operator by means of an order circuit, informing the latter of the local number desired and obtaining from her a trunk assignment. The trunk operator will then test the multiple jack of the local line desired and, if idle, will insert the plug of the trunk assigned. The insertion of this plug will close a circuit from the ground at the cut-off relay *A*, through the sleeve relay *E* in the toll trunk, to battery. This will operate relay *E*, which in turn will close the tip strand of the toll trunk and will also close the circuit containing the disconnect lamp; this will light the lamp. However, as soon as the toll operator inserts the toll plug in the jack of the trunk assigned, relay *G* will operate, thereby opening the circuit containing the disconnect lamp; and as both operators will insert the plugs at practically the same instant, the lamp, in actual practice, will be in circuit for such a short interval that it will seldom come up to brilliance. The closing of the circuit that causes the operation of relay *G* will be explained later on.

The toll operator, upon inserting the calling plug of the pair of cords used to answer the incoming line call in the trunk jack will close a circuit from the ground on the 500-ohm resistance coil, over the sleeve strands of the trunk and the plug and thence through the coils of relays *L* and *M* to battery. The completion of this circuit will operate relay *L* and close the tip strand of the cord circuit. Relay *M*, however, will not operate because it is wound to a resistance of only 20 ohms and will not, therefore, receive enough current to be actuated when in circuit with the 100-ohm winding of relay *L* and the 500-ohm resistance coil. The act of inserting the toll plug will close another circuit, which can be traced from the negative side of battery attached to the coil of relay *G*, by way of the break contacts of the "make-before-break" springs of relay *H*, through the coil of relay *F*

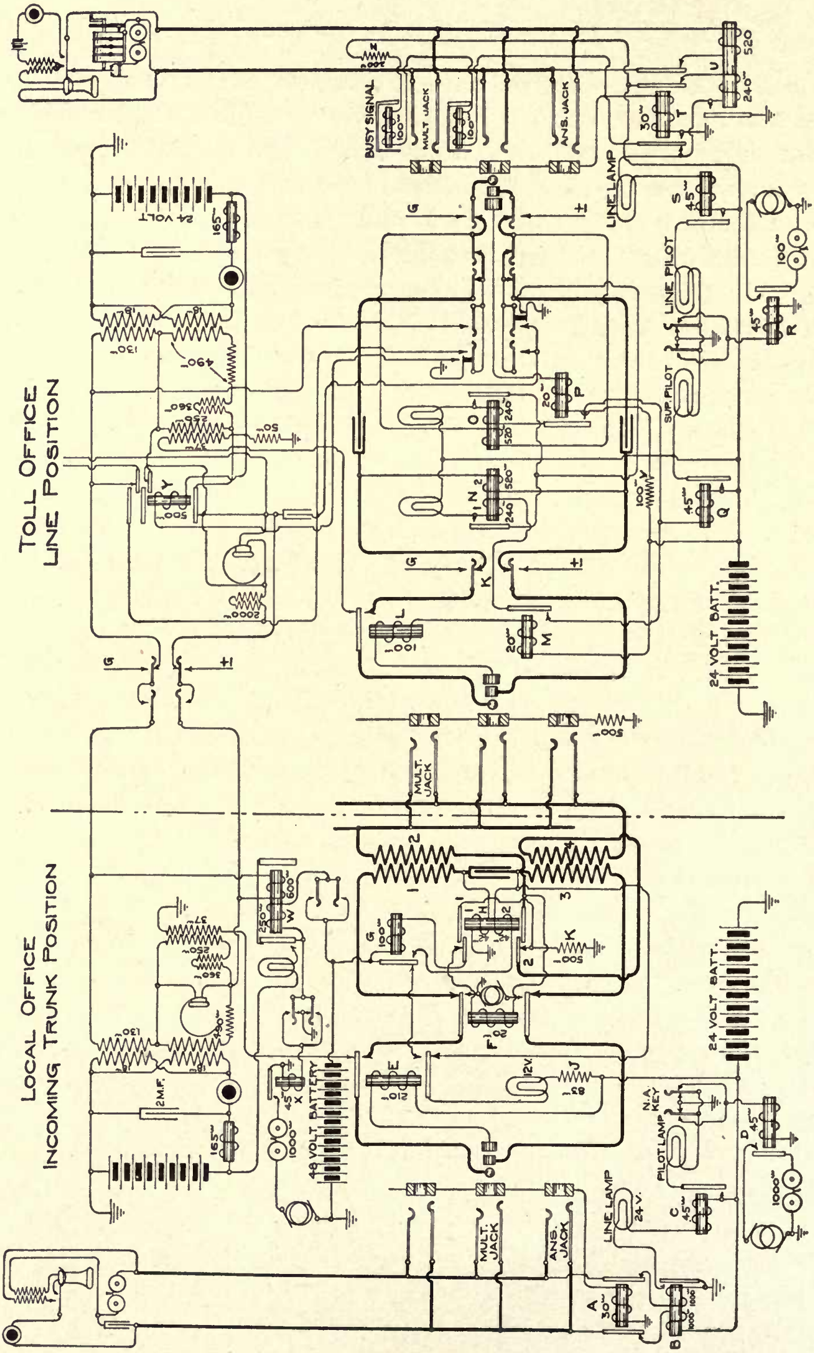


FIG. 54. — Toll-to-Local Connection Through a Multiple-lamp Board of The American Telephone and Telegraph Company's Type.

and winding 2 of the repeating coil, over the tip strands of the trunk and the cord circuits, through winding 2 of relay *N* and then by way of the ring strands of the cord and the trunk circuits, through winding 4 of the repeating coil and the other break contact of the make-before-break contacts of relay *H*, to the 500-ohm resistance coil *K* and finally to ground. The completion of this circuit will operate relays *G* and *N*, while relay *F* will not respond because it is wound only to 20 ohms and will not, therefore, receive enough current through the 520-ohm winding of relay *N*, the 100-ohm winding of relay *G* and windings 2 and 4 of the repeating coil. The operation of relay *N* will light the supervisory lamp in the toll cord circuit, while relay *G* will extinguish the disconnect lamp in the toll trunk as previously stated. The toll operator is now ready to ring the local subscriber. The operation of the ringing key *K* will close a circuit that can be followed from the ground on the tip spring of this key, over the tip strand of the cord and the trunk circuits, through winding 2 of the repeating coil, the coil of relay *F*, the break contact of the make-before-break contacts of relay *H*, and the coil of relay *G* to battery. The closing of this circuit will cause the actuation of relay *F*, for in this case the 100-ohm winding of relay *G* and the winding 2 of the repeating coil are the only resistances in series with the 20-ohm coil of relay *F*; and hence this relay will receive enough current for its operation. The operation of relay *F* will break the tip and the ring strands of the trunk and connect the plug end of the latter to the leads from the ringing generator; this will send ringing current out on the local subscriber's line.

It will be observed, therefore, that the toll operator can ring the local subscriber at will; and as this operator is usually in a position to devote her attention to a few calls at any given time, she will ring the local subscriber oftener, if he is slow in answering, than the trunk operator in the methods described in the previous chapter. The attendant delays in establishing a connection will be minimized under the present method.

When the local subscriber answers, there will be a flow of current from ground through winding 1 of relay *H* and winding 1 of the repeating coil, to the tip strand of the trunk and the line circuits, through the subscriber's instrument and back by way of the ring strands of the line and the trunk circuits, through winding 3 of the repeating coil, winding 2 of relay *H* and the make contact of relay *G* to battery. Therefore relay *H* will operate and actuate the two sets of make-before-break springs. The operation of the set of springs numbered 1 in the figure will first close a circuit which can be traced from ground through the 500-ohm resistance coil *K*, to the make contact of these springs and then by way of the coil of relay *G* to battery. Immediately after the making of the contact in this set of springs, the break contact will be operated, thus opening the through ringing circuit which traverses the coil of relay *F*, as previously traced. The make contact in this set of springs must be closed before the break contact in the other set is opened, so as to prevent a momentary release of relay *G*. This feature is essential to prevent the flashing of the disconnect lamp in the toll trunk circuit, which would happen should relay *G* be de-energized. The operation of the make contact of the make-before-break spring in set 2 closes the connection between windings 2 and 4 of the repeating coil and thus completes the talking circuit of this end of the trunk, which is normally open; while the opening of the break contact of this set of springs opens the circuit containing winding 2 of relay *N* (in the toll cord) at the ground connection and thus causes the release of this relay. The latter will open the supervisory lamp circuit and thus inform the toll operator that the local subscriber has answered. The toll operator will then proceed to complete the connection.

When the conversation is finished the incoming signal from the toll line will light the answering supervisory lamp in the cord circuit. The local subscriber will hang up his receiver and thus open the circuit containing relay *H*; the sets of springs numbered 1 and 2 will return to their normal position, which is required to close the circuit containing winding 2 of relay *N*. This relay will light the calling supervisory lamp in the toll cord circuit. The toll operator, upon seeing these disconnect signals, will take down the connections. The withdrawal of the calling plug from the trunk multiple jack will de-energize relay *G* and thus light the disconnect lamp at the local trunking position; this gives the trunking operator the disconnect signal. She will then take down the connection and thereby restore the apparatus to its normal condition.

Before leaving this particular circuit it seems advisable to call attention to the two battery voltages that are employed. It will be noticed that the local end of the trunk is equipped with a 48-volt battery, while the remainder of the circuit operates from a 24-volt battery. This 48-volt battery at the local end will increase the current through the subscriber's transmitter and thus materially improve the transmission.

(*b*) **Local-to-Toll Connection.** — A complete conventional recording circuit used with the Western Electric Company's No. 1 multiple-lamp toll board is shown in Fig. 55, to which reference will be made in the ensuing description. A local subscriber who desires toll service will call the office in the usual manner. The local operator will then transfer the call to a recording operator. This is accomplished by means of a special cord known as "the tone-test cord," two of which are installed in each local operator's position. When the local operator determines that a toll connection is desired, she will test the multiple jack of one of the recording trunks with the calling plug of the pair of cords just used to answer the call. Upon finding an idle trunk she will insert the calling plug of one of the tone-test cord circuits in the jack of the idle trunk line and will also insert the answering plug of the tone-test cord circuit in the multiple jack of the calling subscriber's line, removing the answering plug which was originally inserted in the answering jack in response to the call. The local operator is now relieved of all further work in the establishment of the connection, since she simply obeys the disconnect signals in the tone-test cord circuit; the local subscriber has been switched to a recording position at the toll board. By referring to Fig. 55 it will be observed that the tone-test cord circuit is equipped with double supervision. The act of inserting the answering plug of this cord circuit in the multiple jack of the subscriber's line will not light the white supervisory lamp, because the subscriber has his receiver off the hook; relay *E*, therefore, is energized and the lamp is shunted by a low resistance. The insertion of the plug, however, will place a tone signal on all the multiple jacks associated with this line; and thus should another operator test the line, she will be informed by the tone-test that the line is being held for toll service. The tone-test is a low alternating potential placed on the sleeve of the tone-test plug, by means of the interrupter and the step-down transformer shown in the circuit. This potential reaches the sleeve of the line by means of a path that can be traced from battery, through the low winding of the transformer, to the make contact and armature of relay *E*; and then by way of the resistance coils *H* and *G*, the sleeve of the cord and plug, the sleeve of the multiple jack, and the coil of the cut-off relay to ground. An

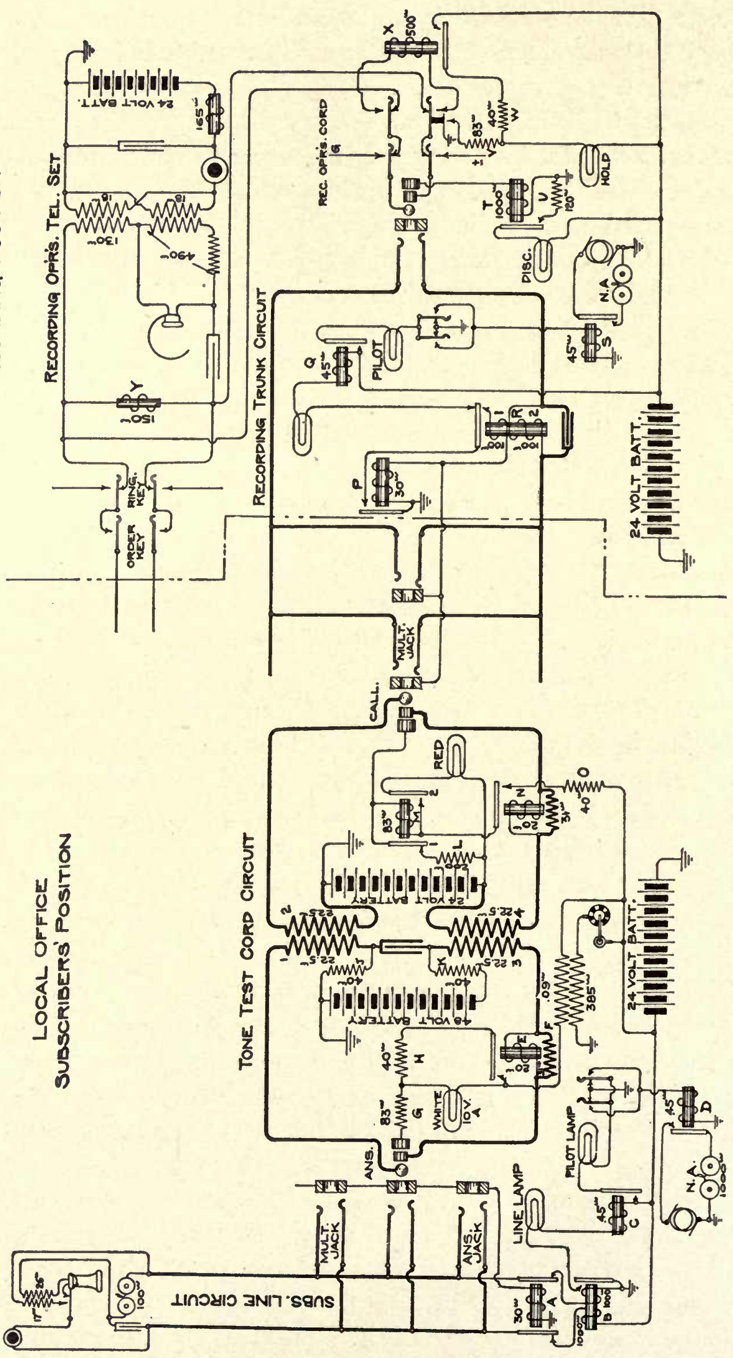


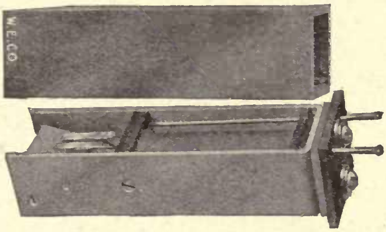
FIG. 55. — Recording Trunk Circuit Used by the American Telephone and Telegraph Company.

alternating potential is impressed on the circuit thus completed, due to the pulsating current from the interrupter which flows through the primary of the transformer and acts inductively on the low-wound secondary. Thus an operator, in testing a line on the sleeve of which this potential exists, will receive, instead of the customary busy click, a note or hum, the pitch of which will depend upon the rapidity of the interruptions. It is necessary to use the transformer because a direct connection with the interrupter would produce a very loud note of exceedingly harsh quality.

It has been pointed out that the white lamp associated with the answering plug of the tone-test cord will not light and this is true also of the red lamp associated with the calling plug. When the operator inserts this plug in the jack of the recording trunk circuit, the only signaling circuit closed is the one from battery through the resistance coil *L*, to the break contact and armature 1 of relay *M*, the sleeve of the cord and the recording trunk circuit, through the winding of relay *P* to ground. Relay *P* is thus energized and will light a lamp at the recording operator's position which is associated with the trunk. The recording operator, upon seeing this signal displayed, will insert the plug of one of her cord circuits in the jack of the trunk. The act of inserting the plug of the recording cord will not cause any change in the condition of the apparatus, but the operation of the listening key will cause a flow of current from the negative side of the battery through winding 4 of the repeating coil, the winding of relay *N* and then over the ring strands of the cord and the trunk, through winding 2 of relay *R*, over the ring strand of the recording trunk and cord circuit, through the winding of relay *X* and then by way of the tip strand of the recording cord and trunk and the tone-test cord, through winding 2 of the repeating coil and finally to ground. Thus relay *X* in the recording cord circuit, relay *R* in the recording trunk circuit and relay *N* in the tone-test cord circuit will be energized. The operation of relay *X* will place a 40-ohm shunt around the " holding lamp " in the recording cord circuit, and therefore this lamp will not light when the listening key is actuated. The operation of relay *R* will open the circuit containing the lighted lamp in the recording trunk, and this lamp, consequently, will be extinguished; this relay is self-locking and thus prevents the re-lighting of the recording trunk lamp. This locking circuit can be traced (bearing in mind that relay *P* has been previously operated) from the ground on the armature of relay

P, through the make contact of this relay, and the armature, make contact and winding 1 of relay *R*, to the sleeve of the trunk and tone-test cord circuits, then through the winding of relay *M*, the armature and make contact of relay *N* (previously operated), through the 40-ohm resistance coil to battery. Relay *M* is thus energized and will close a circuit from the battery in the tone-test cord, through the red lamp, armature 2, the make contact and coil of relay *M*, the sleeve strand of the tone-test cord, the recording trunk circuit and through the winding of relay *P* to ground. The red lamp contained in the circuit just completed will not light, however, due to the shunting action of the 40-ohm resistance coil *O*, which is placed in parallel with the lamp by the armature contacts of relay *N*. The recording connection has now been traced to a point where the recording operator is in a position to converse with the local subscriber and all the signals in the connection are extinguished. The recording operator will now obtain from the local subscriber the information required to make out the regular toll ticket. After this the operator has two methods of procedure at her disposal, the choice between them depending upon whether or not she has reason to believe that the connection can be completed with little delay. In case she thinks that it will take considerable time to establish the connection, she will tell the local subscriber to hang up his receiver and wait until he is called. The act of hanging up the receiver will open the circuit containing relay *E* in the tone-test cord, thus releasing the relay and thereby removing the shunt around the white disconnect lamp, which will then be displayed. The local operator will not heed this signal, however, as the red disconnect lamp is the governing signal upon which the removal of the connection depends. The recording operator, having told the subscriber to hang up his receiver, will pass the toll ticket to a line operator and remove the plug from the recording trunk jack. The withdrawal of the plug will open the circuit containing relay *N*, which was previously traced. The release of this relay will remove the shunt circuit around the red disconnect lamp in the tone-test cord and this lamp will be lighted. The lighting of the lamp signifies to the local operator that the recording operator is through with the connection and the former will clear the same. As the toll ticket is now in the hands of the regular line operator, she will take care of the connection, the recording operator having nothing further to do with it.

However, when the recording operator, upon making out the toll ticket, has good reason to believe that the toll connection can be established at once, the procedure is different. In this case, she will place herself in communication with the trunking operator at the local board and ask for a trunk assignment. Thereupon, the trunk operator will assign a trunk and pass the number to the recording operator who will place it upon the toll ticket. The trunk operator, in the meantime, will test the multiple jack of the local line and find the tone-test due to the presence of the tone-test cord in the multiple jack at the answering operator's position. The trunk operator will insert the trunk plug in the multiple jack of the local line. The recording operator will withdraw the plug from the recording trunk and insert it in the multiple jack of the assigned trunk. The withdrawal of this plug will give the answering operator the disconnect at the tone-test cords, as in the previous case. The recording operator, upon inserting the plug in the multiple jack of the assigned trunk, will be able to communicate with the local subscriber and thus assure herself that the connection has been properly completed. She will then pass the toll ticket to the proper line operator. Should the subscriber desire to signal the recording operator, he can do so by actuating his receiver hook, which will make and break the circuit through the coil of relay *X*, and in turn make and break the shunt around the holding lamp in the recording cord circuit; this will flash the lamp and attract the operator's attention.



Alternating-current Relay.

The operation of this system has now been traced to the point where the line operator takes up the connection. This operator, upon receiving the toll ticket, will know immediately whether or not the local trunk for the connection has been assigned, by an inspection of the ticket. In case no trunk assignment has been placed on the ticket, she will know that the trunk has not been assigned and that the calling subscriber is not waiting on the line. In the last case, she will proceed to obtain the distant subscriber desired. When this subscriber has been secured, she will put up the rest of the connection in a manner identical with that previously described for the toll-to-local connection.

In the first case, when the toll operator sees the trunk assignment on the ticket, she knows the recording operator has ordered up the connection and that the local subscriber is waiting on the line. Under these circumstances she will first insert the answering plug of one of the cord circuits in the multiple jack of the assigned trunk and then insert the calling plug in the toll line and complete the connection at once, if possible. If a delay is unavoidable she will tell the local subscriber to hang up his receiver and wait until called. The act of inserting the answering plug in the assigned trunk jack will close a circuit that can be traced from the ground through the winding of relay *T* in the recording operator's cord circuit, to the sleeve of the toll operator's cord circuit and through the windings of relays *L* and *M* to battery. This will operate relay *T*, thereby lighting the disconnect lamp in the recording operator's cord circuit. The lighting of this lamp will inform the recording operator that the line operator has taken up the connection and the former, therefore, will take down the connections at her position.

Another incoming ring-through trunk circuit used by the American Telephone and Telegraph Company in connection with the Western Electric Company's No. 1 type toll switchboard is shown in Fig. 56. In this circuit a different scheme is used to ring around the repeating coil. The circuit also shows the method of equipping these trunks when party-line service is given, by means of which the local trunk operator selects the proper ringing current required to call the desired party-line subscriber. The work of the line operator in ringing a party-line subscriber is consequently identical with that required to ring a direct-line subscriber. Due to the special features that are contained in this circuit, a description of its operation will probably be of value. In following the description of this circuit it should be remembered that it operates in conjunction with the circuits shown in Fig. 54 and replaces the trunk circuit in that diagram.

The toll-line operator will communicate with the local trunk operator by means of an order circuit and obtain a trunk assignment as before. The trunk operator will then test the local line; in case it is idle, she will assign the trunk and insert the trunk plug in the multiple jack.

This operation will complete a circuit from the ground at the cut-off relay, by way of the sleeve conductor of the jack and the trunk, through the winding of relay *E* and the trunk lamp to battery. This will light the disconnect lamp in the trunk circuit and also cause the operation of relay *E*, which in turn will close the tip strand of the trunk circuit. In the meantime, however, the toll operator will have inserted the calling cord in the trunk jack assigned by the trunk operator. This will have completed a circuit from battery through winding 2 of relay *G*, by way of the make-before-break spring 2 of relay *C*, winding 3 of the repeating coil, the ring strand of the trunk and the toll cord, through the bridged winding of the supervisory relay, the tip side of the cord and the trunk, winding 1 of the repeating coil, the make-before-break contact 1 of relay *C* and then by way of winding 1 of relay *G* to ground. The completion of this circuit will cause the operation of the supervisory relay in the cord, thereby lighting the supervisory lamp; and it will also cause the operation of relay *G*. The operation of the latter will extinguish the trunk lamp that was previously lighted by the insertion of the trunk plug; and as the toll-line operator and the trunk operator will complete their connections at practically the same time, the trunk lamp will seldom respond. The circuit that "shunts out" the disconnect lamp can be traced from the battery on the

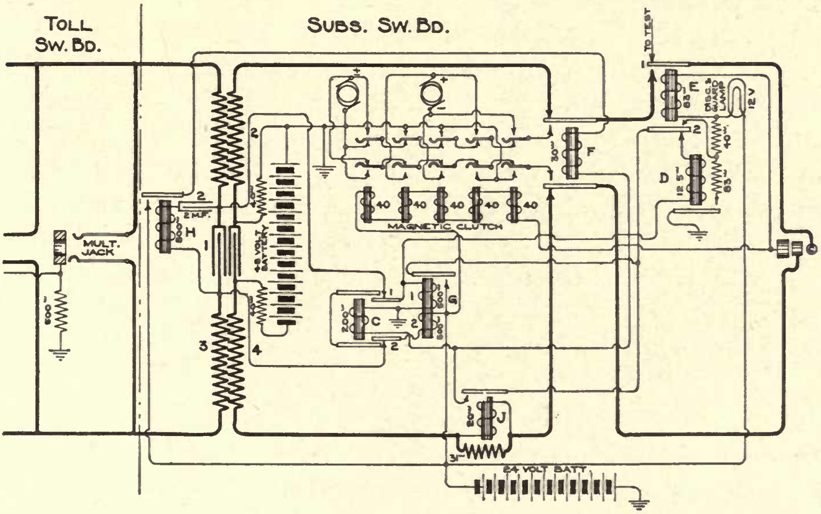


FIG. 56. — Incoming Toll Trunk of the American Telephone and Telegraph Company's Type, Showing Four-party Through Ringing.

make contact of relay *G*, by way of the armature of this relay, to armature 2 of relay *E*, and then (bearing in mind that this relay was operated the instant the trunk plug was inserted) by way of the make contact and the 40-ohm resistance coil, the winding of relay *E* and the sleeve of the trunk and the local line, to the ground on the winding of the cut-off relay. In case the toll operator puts up her end of the connection first, the disconnect lamp in the trunk circuit will light, and remain lighted until the trunk operator puts up the other end of the connection. When the toll operator inserts the plug in the assigned trunk jack, relay *G*, as we have seen, will be operated. This will complete a circuit from the battery connection on the make contact of that relay to its armature and then, remembering that relay *E* is inactive, by way of the armature and break contact of this relay, to the coil of relay *D* and coil 1 of relay *G* to ground. The establishment of this circuit will lock relay *G* until relay *E* is energized; it will also energize relay *D*, which in turn will light the disconnect lamp in the trunk circuit. Therefore, since relay *G* is locked until relay *E* is energized, the disconnect lamp in the trunk will remain lighted until the trunk operator puts up the connection, even though the toll operator should withdraw the toll plug from the assigned trunk jack.

The local trunk operator's work in putting up a connection with a direct-line subscriber consists merely of inserting the trunk plug into the multiple jack of the line. When a party-line subscriber is desired, however, the trunk operator, after inserting the plug, must set the ringing key to call the proper subscriber. When this key is depressed it will be held in the operated position by the coil of the magnetic clutch, which is energized when the trunk plug is inserted, by means of a circuit traceable from the ground on the coil of the cut-off relay, by way of the sleeve strand of the local line and the plug, through the clutch coil to battery. The selective ringing buttons in this key will remain depressed until they are released by the demagnetization of the clutch coil, upon the withdrawal of the plug.

The toll operator is now ready to ring the local subscriber. She will next operate the ringing key, which will send alternating current over the trunk circuit to the local office. This current will energize relay *H* and thus complete a circuit that may be traced from the battery connection on the make contact of this relay, by way of its armature, to the coils of relays *F* and *C* and thence to ground. This will energize these two relays. The operation of relay *F* will be equivalent to actuating the ringing key at the trunk position, for the make contacts of this relay are connected to the source of ringing current, and the break contacts will cut off the switchboard end of the trunk, to prevent ringing back over the circuit in the direction of the toll office. The operation of relay *C* will open the circuit which feeds current through windings 1 and 2 of relay *G* to the toll end of the trunk circuit, thus disconnecting the battery from this part of the circuit while the toll operator is ringing. The opening of this circuit will not cause the release of relay *G*, however, as the path through the toll end of the trunk is substituted by the make-before-break contacts at relay *C*. It is thus obvious that the operation of relay *F* will ring the subscriber, and as the actuation of this relay is under the control of the toll operator, she can ring at will. When the local subscriber answers, thereby bridging his telephone set across the line, current will flow over the tip strand of the trunk and the line circuit, through the subscriber's instrument, back over the ring side of the line and the trunk and thence through the coil of relay *J* to battery. Relay *J* will thus be energized and will close a circuit from the battery connection on the make contact of relay *G*, to the armature of this relay, then by way of the armature and make contact of relay *J* and the coil of relay *C* to ground. Relay *C* will consequently operate and attract the make-before-break springs 1 and 2. The contacts of these two sets of springs will maintain the circuit through the coils of relay *G*, which was previously closed through the bridged winding of the supervisory relay in the toll cord; the trunk portion of this circuit is cut off by the operation of the break contacts of the two sets of springs. The opening of the circuit through the bridged winding of the supervisory relay in the toll cord circuit will extinguish the supervisory lamp. This will notify the toll operator that the local subscriber has answered. She will then proceed with the connection as previously outlined.

When the toll conversation is finished the disconnect signal from the local subscriber will be received in the manner next described. The subscriber, upon hanging up his receiver, will open the line circuit and thereby release relay *J*. This in turn will de-energize relay *C*. Restoring relay *C* to its normal condition will again feed current from the local office over the trunk circuit and thence through the bridged winding of the supervisory relay in the toll cord circuit. This relay will give the toll operator the disconnect signal, and she will take down the connection. The removal of the connection at the toll board will de-energize relay *G*, which in turn will remove the shunt circuit (previously traced) around the disconnect lamp. This lamp will then light, thereby giving the local trunk operator a disconnect signal, whereupon she will take down the connection and restore the apparatus, to its normal condition.

Tri-state Telephone and Telegraph Company's Equipment

(*a*) **Toll-to-Local Connection.** — The circuits that have been described thus far, in connection with the multiple-lamp toll board, outline one of the practices of the American Telephone and Telegraph Company and constitute one of the three general systems previously referred to. The second general type which we shall now consider is the system used by the Tri-state Telephone and Telegraph Company in their toll office at St. Paul, Minn.; a view of the switchboard is shown in Fig. 57. This system was installed by the Kellogg Switchboard and Supply Company and operates with the Stromberg-Carlson local boards at Minneapolis and St. Paul. The local boards are equipped with what, practically speaking, is a two-wire system, since the sleeve and ring conductors are short-circuited by the ring of the plug. A conventional diagram of the toll-to-local connection for this type of equipment is shown in Fig. 58, the operation of which will be explained briefly in the following.

When the toll operator receives an inward toll call, she will communicate with the local trunk operator and ask for a trunk assignment. The trunk operator, thereupon, will select a trunk, operate the testing key and test the multiple jack of the local line called for. In case the line is idle, she will plug into the jack and restore the testing key to normal. This will close a circuit from the ground on winding 1 of the cut-off relay, by way of the tip strands of the line and the trunk circuits, through the winding of relay *L* to battery. Relays *L* and *Q* are consequently energized. The attraction of armature 1 of relay *L* will complete a circuit that can be traced from the ground on the disconnect lamp, to the armatures and break contacts of relays *M* and *K* and the make contact and armature 1 of relay *L* to battery. The completion of this circuit will light the disconnect lamp. In the meantime, however, the toll operator will have received the assignment and inserted the calling plug in the trunk jack. This will complete a circuit which is traceable from the battery on the coil of relay *S*, by

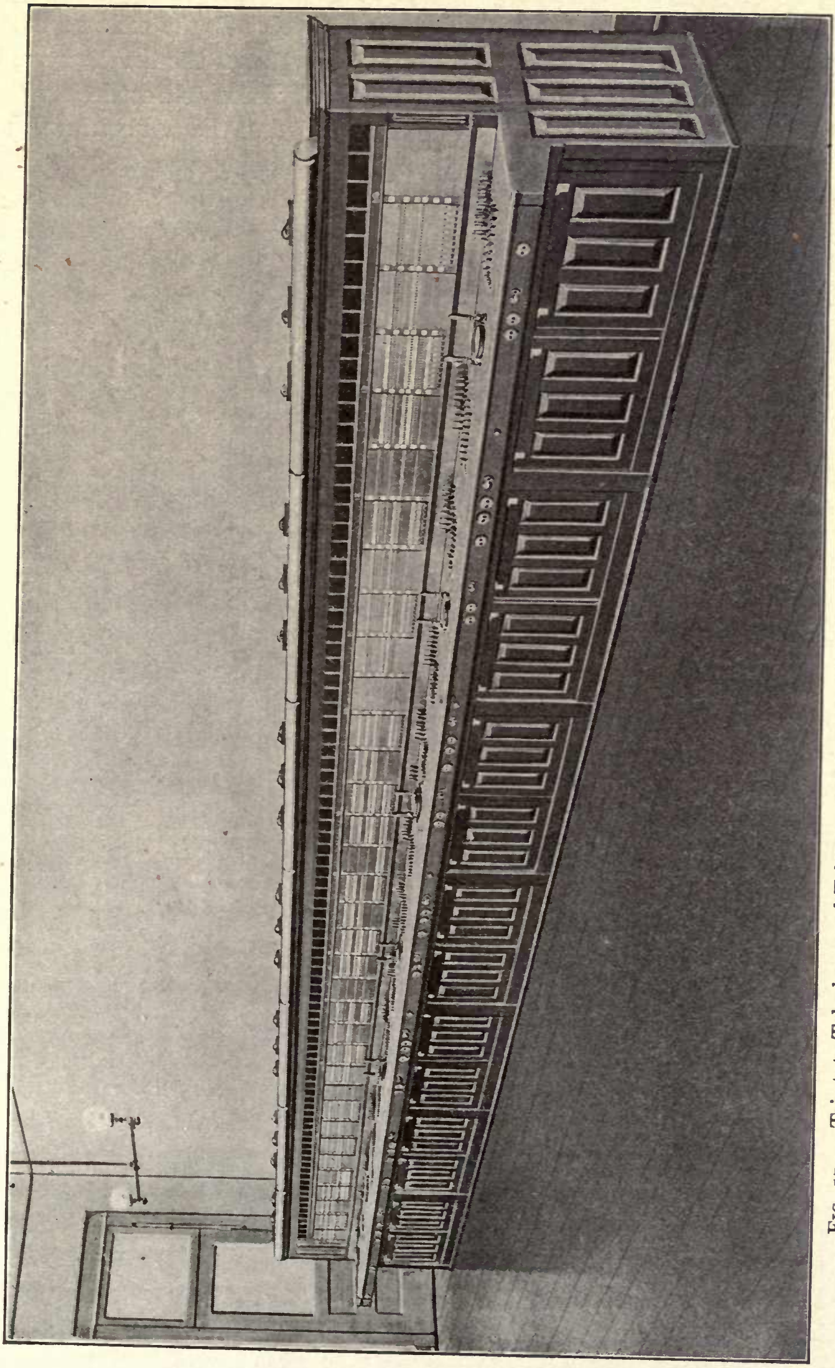
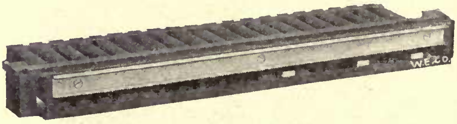


Fig. 57. — Tri-state Telephone and Telegraph Company's Multiple-lamp Toll Board, in Use at St. Paul, Minnesota.

way of the make contact and armature 2 of relay *L*, the coil of relay *M*, the break contact and armature 1 of relay *H*, to the tip strand of the trunk circuit, thence over the tip strand of the toll cord circuit, through winding 1 of relay *F* to the ring strand of the toll cord; from there it can be followed over the ring strand of the trunk circuit to armature 2 and the break contact of relay *H* and through retardation coil *J* to ground. Relays *M* and *F* will thereupon operate, while relay *S* will remain normal, due to the fact that it is low-wound and will not receive sufficient current to operate when in series with all the resistances that are contained in the circuit just outlined. However, due to the operation of relay *M*, the disconnect lamp in the trunk circuit will be extinguished, whereas the operation of relay *F* will light the supervisory lamp in the toll cord. The connection has now been traced to the point where the toll operator is ready to ring the local subscriber. The act of ringing will close a circuit traceable from the ground on the tip spring of the ringing key, by way of the tip strands of the cord and the trunk, to armature 1 and the break contact of relay *H*, then through the winding of relay *M*, armature 2 and the make contact of relay *L* and the winding of relay *S* to battery. It will be noted that this circuit follows the same path to the tip of the ringing key as the former circuit containing relay *S*, which was completed when the toll operator inserted the plug. However, the latter circuit contains less series resistance by the amount of winding 1 of relay *F*, winding 3 of the repeating coil and the winding of retardation coil *J*, because it passes to ground at the make contact of the ringing key, whereas the other circuit was completed to ground at the retardation coil *J*. An increased amount of current will consequently flow through the winding of relay *S*, which will therefore be actuated. Then as the make contacts of this relay are wired to the source of ringing current, the operation of the ringing key in the toll cord circuit will ring the local subscriber in the same manner as described in the last two circuits.



A Strip of Twenty Visual Busy Signals.

The local subscriber, upon answering the call, will complete a circuit

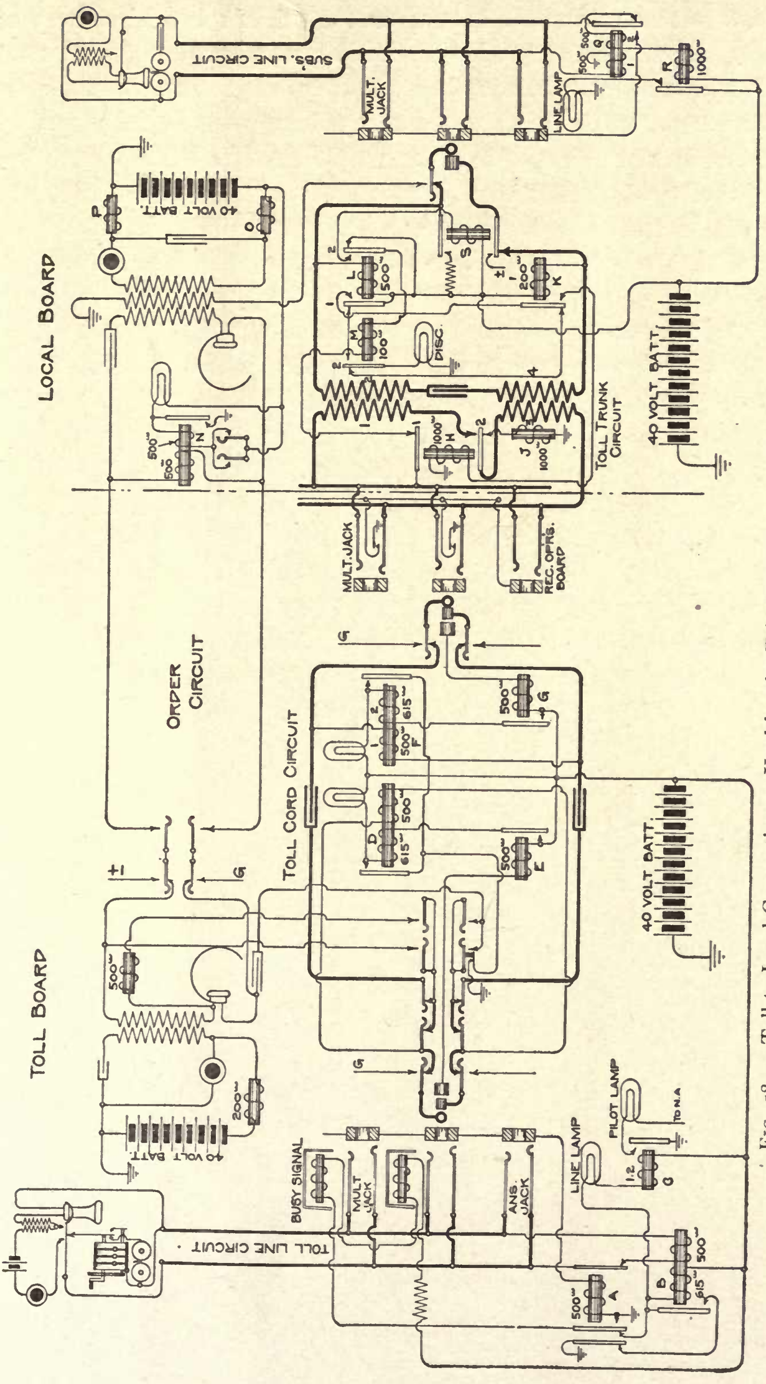


Fig. 58. — Toll-to-Local Connection as Used by the Tri-state Telephone and Telegraph Company.

which is traceable from the battery on the coil of relay K, by way of the ring strands of the trunk and the line circuits, through the subscriber's instrument, returning over the tip of the line and through the coil of the cut-off relay Q to ground. Relay K will subsequently operate and close a circuit that is traceable from the battery on armature 1 of relay L, to the make contact of this relay, over the armature and make contact of relay K and thence through the coil of relay H to ground. Relay H, therefore, will operate and open the circuit previously traced which contains the supervisory lamp in the toll cord; this will inform the toll operator that the local subscriber has answered. Should the toll operator plug into the trunk jack before the trunk operator plugs into the subscriber's multiple jack or *vice versa*, the disconnect lamp associated with the trunk at the local end will light, but will be extinguished again as soon as both operators have completed the connection.

When the subscribers have completed their conversation, the disconnect signal from the toll line will be received in the usual manner. The local subscriber, upon hanging up his receiver, will open the circuit containing relay K. This in turn will de-energize relay H, thus closing the circuit containing the supervisory lamp in the toll cord circuit. Upon obtaining the double disconnect signal the line operator will take down the connections. This will open the circuit containing relay M, previously traced, and the release of this relay will light the disconnect lamp in the trunk circuit. The trunk operator will thereupon take down the connections.

(*b*) **Local-to-Toll Connection.** — A conventional diagram of the circuits used in putting up a local-to-toll connection with this system is shown in Fig. 59. In the operation the local operator, upon receiving a request for a toll connection, will insert the calling plug of the pair used to answer the call in the multiple jack of an idle recording trunk. This will light the lamp associated with the trunk at the recording operator's position, due to the operation of relay H which is bridged across the tip and ring strands of the circuit. The supervisory lamp in the local cord circuit will not light, however, due to the actuation of relay F, through the coil of which current is supplied to the bridged relays of the trunk circuit; from the latter point the circuit can be followed to the ground on retardation coil N. It will be observed that relay L is also bridged across the trunk circuit. This relay will not operate, however, when in parallel with relay H, because of the

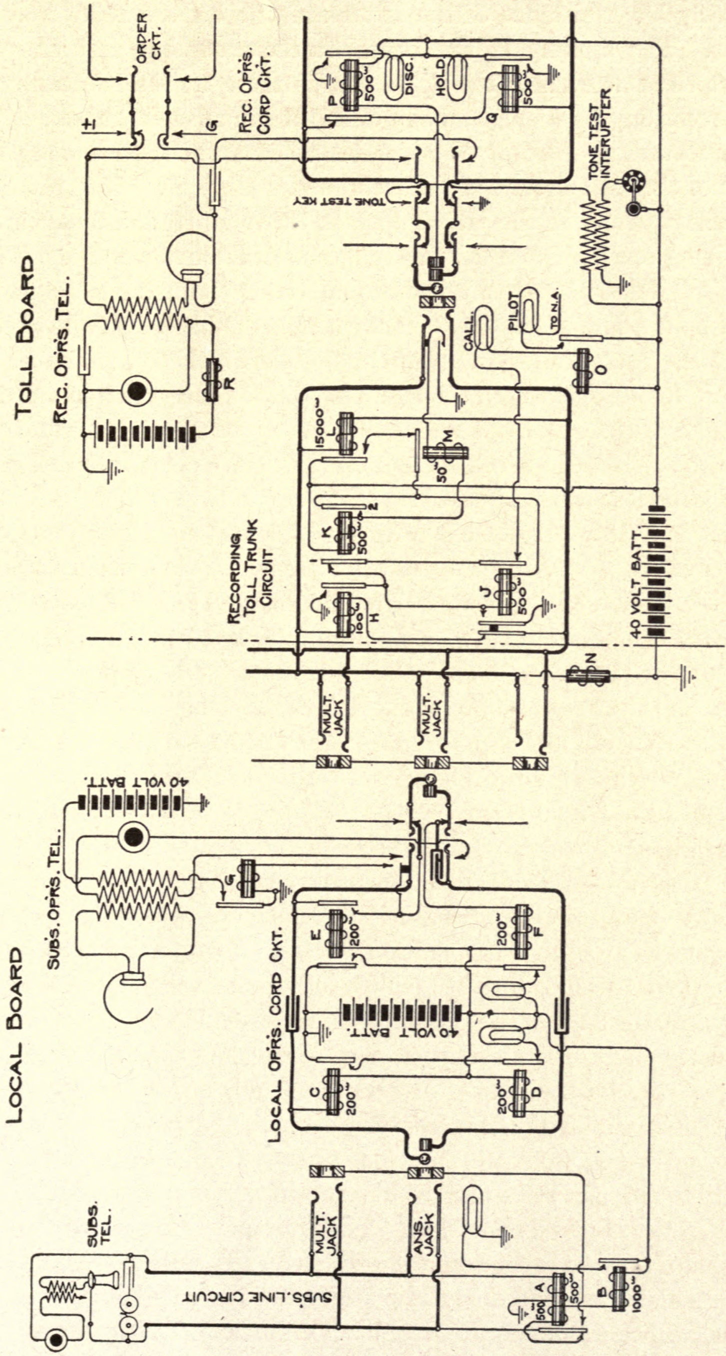


FIG. 59. — Toll Recording Connection, Used by the Tri-state Telephone and Telegraph Company.

relatively low resistance of the latter and the high resistance of the former. The lighting of the lamps at the recording positions will attract the attention of the operators, as these trunks are multipled at all recording positions, and any operator can answer the call.

The recording operator who answers will insert the answering plug of one of the cord circuits in the recording trunk jack. This will close the make contact in the jack, which in turn will close a local circuit containing relays *M* and *K*; the operation of armature 1 of the latter relay will open the circuit containing the recording lamp and extinguish it. The attraction of armature 2 of this relay will close a circuit that may be traced from the ground on the make contact of relay *H* to its armature, then to the coil of relay *J*, armature 2, the make contact and the coil of relay *K* to battery. Thus relay *J* will be operated and will open the bridge circuit containing relay *H*; it will also close a circuit that can be traced from ground to the make contact and the coil of this relay, to the armature and the make contact of relay *K*, and thence through the coil of the latter to battery. Thus the ground on the make contact of relay *H*, which was originally necessary to operate relay *J*, is finally replaced by the ground on the armature of the latter. The closing of the circuit by means of the ground on the armature of relay *J* will lock this relay and also relay *K*. The insertion of the recording plug into the trunk jack will operate relay *Q*, which is bridged across the cord circuit; this will cause the lighting of the " hold lamp " in the recording cord circuit. Since the low-resistance bridge containing relay *Q* replaces the low-resistance bridge that was opened by the operation of relay *J*, it follows that relay *L* will not receive the required operating current; but at the same time sufficient current will flow through relay *F* in the subscriber's cord circuit to hold it in the closed position and thus prevent the lighting of the supervisory lamp in this circuit.

Only one-half of the recording cord circuit has been shown on the drawing; the other half is shown in Fig. 60 and is identical with Fig. 59, with the exception that no listening or tone-test keys are provided. The recording operator is now in a position to converse with the local subscriber and she will consequently obtain the information necessary to fill out the required toll ticket. Then in case the recording operator has good reason to believe that it will take some time to complete the connection, she will tell the local subscriber to hang up his receiver and that he will be called when his connection is ready.

The recording operator will then remove the plug from the recording trunk jack, which will extinguish the "hold lamp." This act will also open the make contact in the jack, and disconnect the ground from the circuit containing relays *M* and *K* in series. Relay *M* will thus be released, but relay *K* is included in the locking circuit containing relay *J* and will thus remain closed. The withdrawal of the recording plug also removes the low-resistance circuit containing relay *Q*, which acted as a shunt to the bridged circuit containing the high-resistance relay *L*; hence the latter will now receive sufficient current for its actuation. The operation of this relay will close a circuit through the armature and break contact of relay *M* and the make contact and armature of relay *L*, which will short-circuit the winding of relay *K*. The latter will consequently be released, whereas relay *J* will remain locked until the subsequent release of relay *L*. Furthermore, as the circuit containing the high-wound relay *L* is now the only bridge across the trunk circuit, relay *F* in the cord circuit will not receive sufficient current to hold up its armature; it will therefore drop back to normal and light the disconnect lamp in the local operator's cord circuit. Then, since the local subscriber has been instructed to hang up his receiver, the other disconnect lamp in the cord circuit will also be lighted, and the local operator upon receiving these double disconnect signals will take down the connections. This act will release relay *L* and open the locking circuit containing relay *J*, thus restoring all the apparatus to its normal condition.

The recording operator will then pass the toll ticket to the line operator, who will proceed to obtain the subscriber desired and complete the connection in the same manner as that just outlined in the description of the toll-to-local connection shown in Fig. 58.

However, if the recording operator has reason to believe that the connection can be completed at once, she will hold the local subscriber on the line and put a tone test back over the recording trunk, by operating the tone-test key in the cord circuit. This will not give a disconnect signal at the local operator's cord circuit, because the resistance of the secondary winding of the tone-test transformer is low enough to allow sufficient current to flow through the winding of relay *F* and thus prevent the lighting of the disconnect lamp. The circuit through the secondary of the tone-test transformer will also act as a shunt around the high-wound relay *L* in the trunk circuit and thus prevent its operation.

The recording operator will next place herself in communication with the local trunk operator, giving the latter the number of the local subscriber desired; at the same time she will give the designation "tone," which denotes that the trunk operator will find a tone on the multiple jack of the local line. The trunk operator then selects the trunk to be used, tests the multiple jack of the local line and receives the tone test. This will inform her that the line tested is the one desired and she will therefore insert the plug. The recording operator, upon receiving the trunk assignment, will insert the calling plug of the pair used to answer the call in the assigned multiple trunk jack. She will next remove the answering plug from the recording trunk jack, thereby lighting the calling supervisory lamp in the local operator's cord circuit, as explained; the latter will then take down the connections and thereby restore all the apparatus in the recording trunk circuit to its normal state.

A diagram of the connection as it now stands is shown in Fig. 60 from which it will be seen that the recording operator is connected direct to the local subscriber's line by means of the calling end of the recording cord and the incoming toll trunk circuit. The recording operator will now send the toll ticket to the proper line operator, who will plug into the multiple jack of the assigned trunk and hold the same until the connection is ready. As soon as the line operator plugs into the assigned trunk, she will close the local make contact in this jack and thereby complete a circuit from ground by way of the sleeve strand of the trunk and cord, through the winding of relay P' to battery. The operation of this relay will cut off the bridged supervisory relay Q' and light the disconnect lamp associated with the recording cord. The recording operator, upon seeing this disconnect signal, will take down the connection. The toll operator will then handle the call in the manner previously described for a toll-to-local connection.

United States Telephone Company's Equipment

(*a*) **Toll-to-Local Connection.** — The discussion of the third and last trunking system used with the multiple-lamp toll board will now be taken up. This system contains a distinctly unique feature which is not used in either of the other systems. It will be observed by referring to Fig. 61, which shows the conventional circuit of a toll-to-local connection, that the local trunk operator is equipped with a

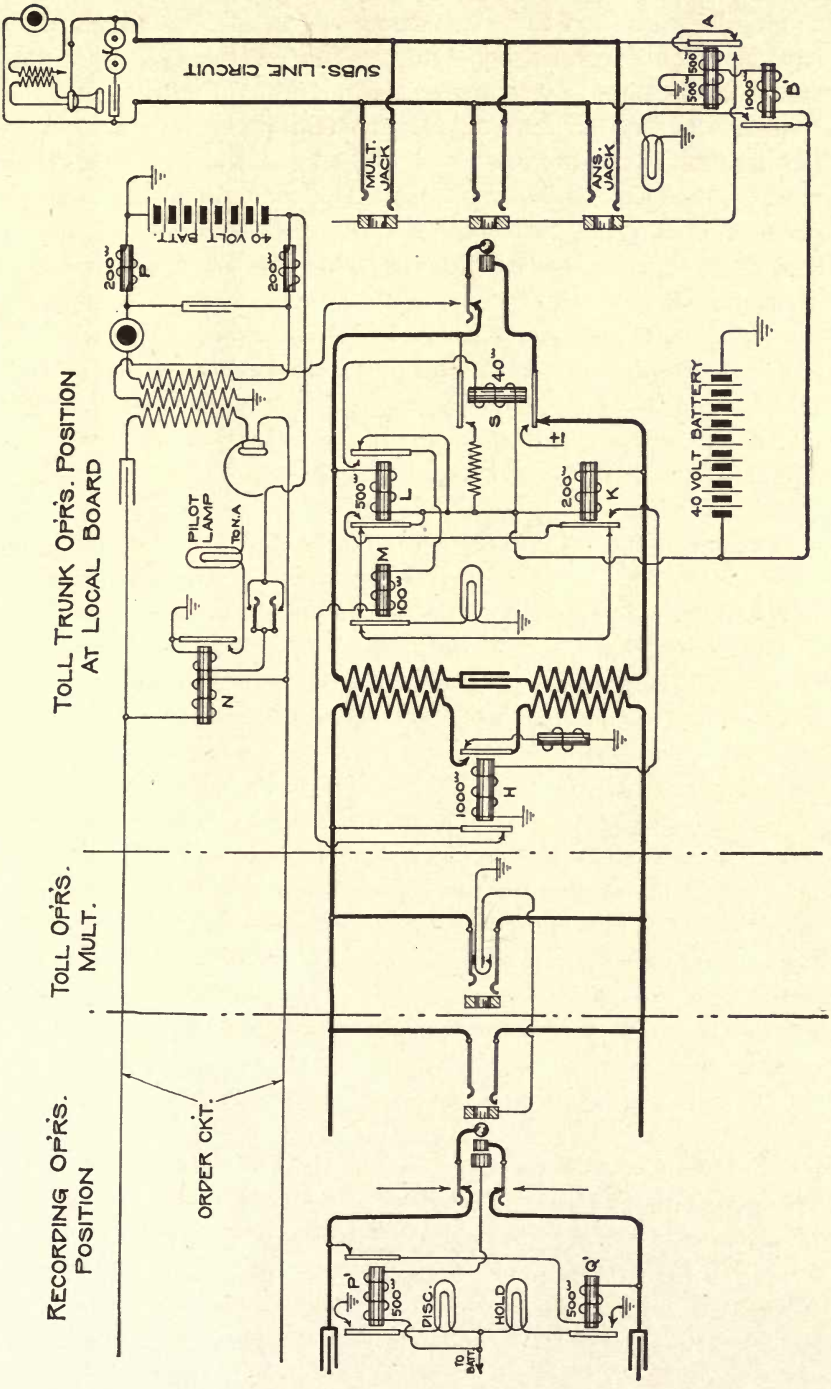


Fig. 60. — Toll Recording Connection, Used by the Tri-state Telephone and Telegraph Company.

ringing lamp as well as a disconnect lamp. The trunk circuit is equipped for through ringing, however, and this ringing lamp merely serves to indicate to the trunk operator whether or not the line operator has succeeded in obtaining a response from the local subscriber. When the line operator disconnects and the local subscriber hangs up his receiver, the trunk operator will receive a double disconnect signal in place of the single signal in the previous systems. The use of this double disconnect signal seems hardly necessary, inasmuch as the toll operator has absolute control of the connection and therefore the signal which she gives is controlling and sufficient.

The system that is next described in connection with Figs. 61 and 62, is used by the United States Telephone Company in its toll board at Cleveland, Ohio, in conjunction with a Kellogg Switchboard and Supply Company's two-wire local board.

In handling an incoming toll call the line operator will place herself in communication with the local trunk operator by means of an order circuit, informing her of the local number desired. The trunk operator will then test the multiple jack of the local line; if it is not busy she will insert the plug of one of the trunk circuits into the jack, and at the same time give the line operator the assignment. The act of plugging into the jack causes several operations, which will be taken up in the order in which they occur. In the first place, it will be found that a circuit has been completed from the ground at the cut-off relay in the subscriber's line, by way of the ring strand of the jack and the trunk, through the coil of relay *A* to battery. This will cause the actuation of the cut-off relay and also relay *A*. Armature 1 of relay *A* will close the tip strand of the trunk and thereby remove the busy test connection, while armature 2 will complete a circuit which may be traced from ground by way of the make contact of the armature of relay *B* and thence through the break contact of this relay to the ringing lamp and battery, causing the lamp to be lighted. However, the attraction of armature 2 of relay *A* has also completed a circuit which can be traced to the armature of relay *B* and then by way of the break contact of this relay, through the coil of relay *C* to battery. This will cause the actuation of relay *C*.

It is now essential to take into consideration the condition of the toll end of the circuit in order to understand the functions of relay *C*. In case the local trunk operator completes the connection before the line operator does so, it will be found that the disconnect lamp at the

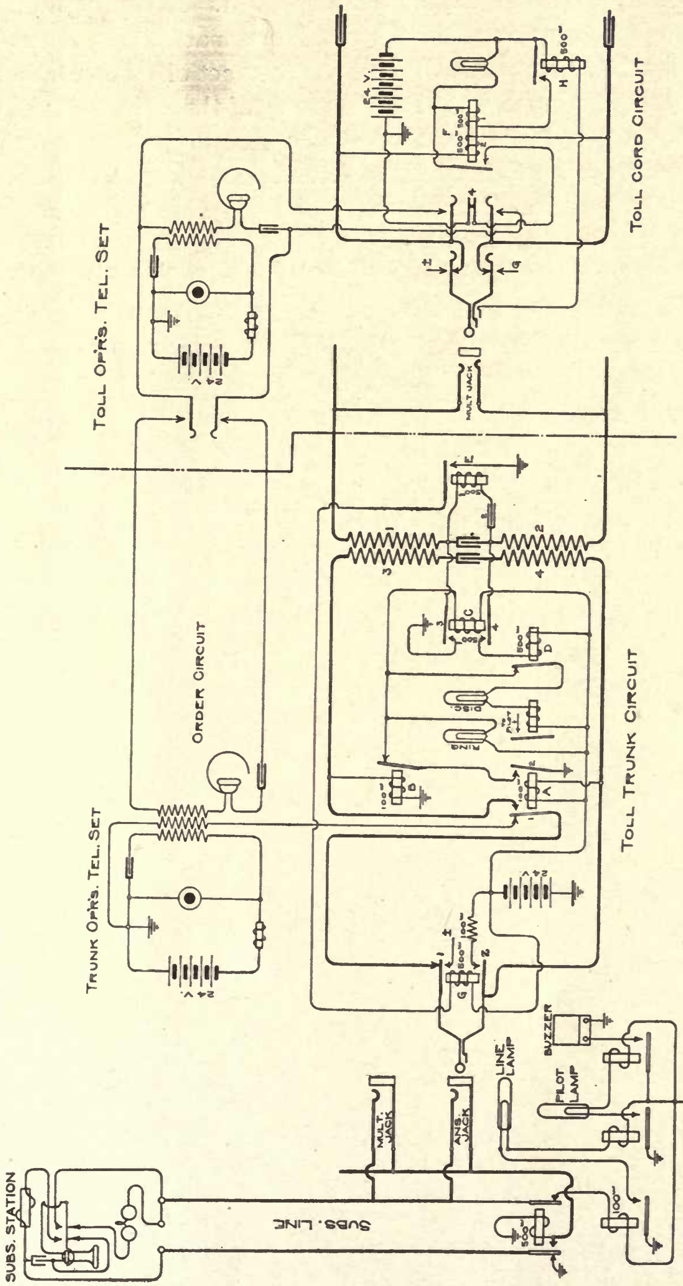


FIG. 61. — Toll-to-Local Connection of the United States Telephone Company's Type, Used at Cleveland, Ohio.

trunk position will be lighted, as next explained. Returning to relay *A* we can trace a circuit from the ground on armature 2 to the armature of relay *B*, then by way of the break contact of this relay to the break contact of relay *D* and thence by way of the armature and the disconnect lamp to battery. However, in case the toll operator has previously inserted the plug in the trunk jack, the conditions are materially changed; in this case a circuit has been completed from the ground on armature 3 of relay *C*, to winding 1 of the repeating coil, over the tip strands of the trunk and the toll cord circuit, through winding 2 of relay *F*, thence by way of the ring strand of the cord and the trunk circuit, through winding 2 of the repeating coil to armature 4 of relay *C*, then by way of the make contact of this relay through relay *D* and finally to battery. The completion of the circuit just outlined will cause the actuation of relays *F* and *D*; relay *F* will light the lamp in the toll cord circuit and relay *D* will open the circuit containing the disconnect lamp. This will inform the trunk operator that the toll end of the connection has been properly completed. It will be clear from the foregoing that in case the toll operator completes her end of the connection prior to the completion of the local end, the ringing lamp will be the only one to light in the trunk circuit; should the connections be put up in the reverse order, both the ringing and the disconnect lamps will light, the latter being extinguished when the toll operator completes her end of the connection. The connection has now been traced to the stage where the toll operator is ready to ring the local subscriber.

It will be evident that whenever the toll operator actuates the ringing key, relay *E* will be energized and will complete a circuit which can be traced from the ground on the make contact of this relay, by way of its armature to the coil of relay *G* and thence to battery. Thereupon relay *G* will be energized and the operation of its armatures will fulfill the functions of a local ringing key at the trunk position. In case the local switchboard is equipped with selective ringing for party-line service, each trunk circuit is provided with a master key, as shown in the American Telephone and Telegraph Company's circuit in Fig. 56. The trunk operator is called upon to help in the operation of ringing only when a party-line subscriber is desired; and even in that case, the operation consists merely of depressing the master key.

When the subscriber answers, relay *B* in the trunk circuit will be energized, due to the completion of the following circuit; from the ground on the coil of relay *B*, through the make contact and armature 1 of relay *A*, to the tip of the cord and plug, thence over the tip strand of the line circuit, through the subscriber's set, returning over the ring strand of the line and the trunk circuit and through relay *A* to battery.

Relay *B* performs several operations. In the first place, it opens the ground connection in the circuit containing the ringing lamp, thereby extinguishing the lamp and informing the trunk operator that the subscriber has answered. Secondly, it will disconnect the ground from the circuit containing relay *C* and therefore this relay will release. The last operation will open the circuit that has previously been traced through the toll cord circuit. Thus relay *F* will release and thereby extinguish the supervisory lamp, which will inform the toll operator that her subscriber has answered. The release of relay *C* will also cause the release of relay *D*, in preparation for the subsequent receipt of a disconnect signal. This now concludes the operation, up to the point of commencing conversation over the toll line.

When the conversation is finished, the local subscriber will hang up his receiver and a disconnect signal should be received from a distant toll operator. The latter will light the supervisory lamp in the toll cord circuit as explained in the description of the toll-to-toll connection. The act of hanging up the receiver at the local station will release relay *B* in the trunk circuit and complete the ground connection for the circuit containing the ringing lamp and the circuit containing relay *C*. The actuation of relay *C* will complete the circuit through relay *F* in the toll cord circuit and thus the second supervisory lamp will be lighted. However, the disconnect lamp in the trunk circuit will not light, since the circuit which energized relay *F* also contains relay *D* and the latter will open the circuit containing the disconnect lamp. When the toll operator receives the disconnect signals mentioned, she will remove the connections. This will open the circuit through relay *D* and the latter will close the disconnect lamp circuit at the local board. The trunk operator now has a disconnect signal from each end of the circuit and will therefore take down the connections, which will release relay *A* and restore the apparatus to its normal condition.

(*b*) **Local-to-Toll Connection.** — The recording trunk circuit used by the United States Telephone Company differs from the previous systems in the respect that no provision is made for holding the local subscriber while the connection is being established. In this system all trunk assignments are obtained by the line operator and the work of the recording operator is confined entirely to noting the details of the call on the ticket. The recording circuit is shown in Fig. 62. The trunk jacks at the local switchboard are multipled in each section. When the local operator receives a request for a toll connection, she inserts the calling plug in the jack of an idle trunk and rings the recording operator. This will light the calling supervisory lamp at the recording board, which remains lighted until the recording operator answers. Thus the work of the local operator in handling a recording connection is the same as that required in a local connection. The local operator, by ringing on the recording trunk, will energize winding 1 of relay *A*. This will lock the armature by means of a circuit which can be traced from battery, through winding 2, via the armature and make contact of relay *A*, to the break contact and armature of relay *B* and then to ground. The operation of relay *A* will light the recording trunk lamps at the recording positions and the call will be answered by any of the operators. The insertion of the plug of one of the recording cords will complete a circuit from the battery connection on the sleeve conductor of the cord, through the winding of relay *B* to ground. Relay *B* will operate and open the locking circuit of relay *A*, thus extinguishing the recording lamps. When the recording operator has obtained the desired information, she will instruct the subscriber to hang up his receiver and wait until he is called. She

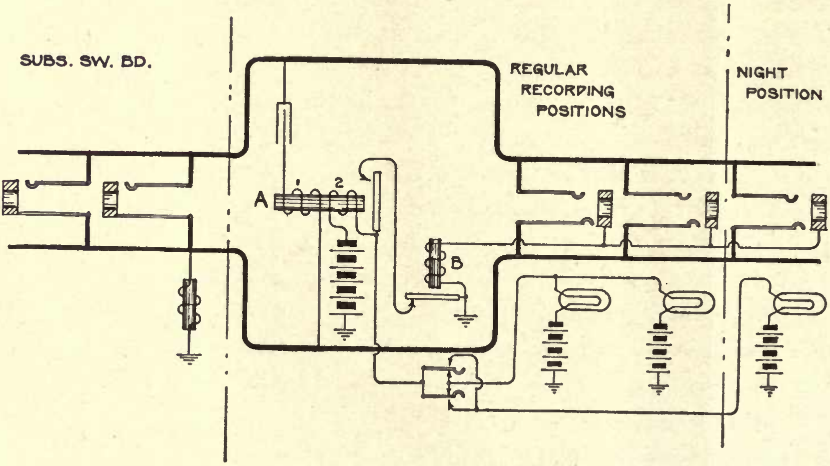


FIG. 62. — Toll Recording Circuit, Used by the United States Telephone Company at Cleveland, Ohio.

will then remove the connection, thereby restoring the trunk apparatus to its normal state and at the same time lighting the calling supervisory lamp in the local cord circuit. The subscriber, upon hanging up his receiver, will light the answering disconnect lamp, thus giving the local operator the complete disconnect signal. The ticket made out by the recording operator is passed to the proper line operator, who will proceed as described for the toll-to-local connection.

Auxiliary Toll Board Circuits. — In connection with the multiple-lamp toll board, it seems advisable to describe a type of interposition trunk and a messenger circuit sometimes used with this equipment. A detailed description will also be given of the method of cabling and the general scheme of cross-connection at the distributing frames.

The purpose and advantages of an interposition trunk have been fully described in Chapter VII in connection with the magneto-multiple board. The trunk of this type shown in Fig. 63 will therefore be described with reference only to the method of operation. In order to make the narrative as simple as possible, only one-half of a toll operator's cord circuit is shown at each end of the trunk. The trunk jacks at the calling end are multipled in each section of the board, while the jack at the answering end is located at some particular section.

Whenever an operator desires to communicate with some other operator in the office, she will plug into the multiple jack which is numbered to correspond with the position at which the trunk terminates. The act of plugging into the jack causes several operations, which will be described in the order of occurrence. In the first place, the busy lamps associated with the multiple jacks will all be lighted, due to the fact that the plug closes the make contact at the jack. This contact closes a circuit from the ground on the make spring in the jack, through all the busy lamps (in parallel) to battery. This guards the trunk while in use. In the second place, a circuit is completed from battery, by way of the coil 2 of relay *B*, to the break contact and armature 1 of relay *A*, to the ring strand of the trunk circuit and thence by way of the ring strand of the calling operator's cord circuit, through winding 1 of relay *D′*, to the tip strand of the cord circuit, over the tip strand of the trunk, to armature 3 of the break contact of relay *A*, through winding 1 of relay *B* and then to ground. The completion of the above circuit will energize relays *B* and *D′*. Relay *D′* will light the calling operator's supervisory lamp in the usual manner. Relay *B* will com-

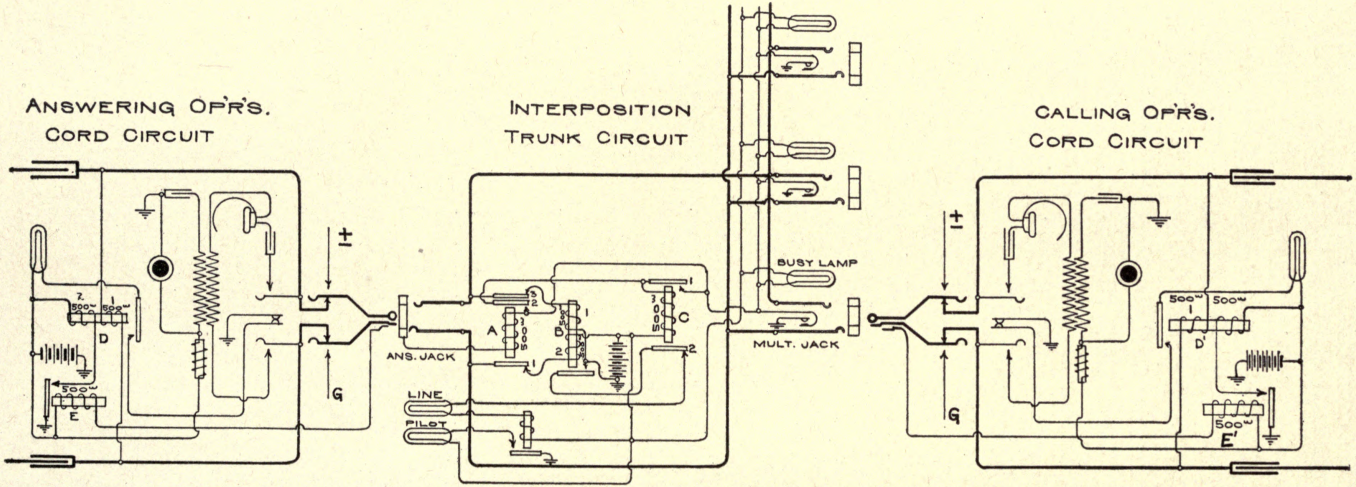


FIG. 63. — Interposition Trunk Circuit, Used by the United States Telephone Company in Their Exchange at Cleveland, Ohio.

plete the answering lamp circuit, which can be traced as follows: from ground, by way of the make contact and armature of relay *B*, to the armature and break contact of relay *C* and thence through the answering lamp and the pilot relay to battery. This lamp will signal the called operator to answer. The act of plugging into the answering jack will complete a circuit from battery through the coil of relay *E*, over the sleeve strand of the cord circuit, to the sleeve of the trunk jack, thence by way of the coil of relay *A*, to the make contact of the multiple trunk jack and then to ground. Thus relays *A* and *E* will be energized. The actuation of relay *A* will open the circuit containing winding 1 of relay *D′*, due to the operation of the break contacts at armatures 1 and 3. Therefore relay *B* will release and open the line lamp circuit; relay *D′* will also release and extinguish the supervisory lamp in the calling operator's cord circuit, thereby informing her that the other operator has answered. The calling operator thereupon actuates her listening key and is thus in a position to converse with the operator called. Armature 2 of relay *A* completes another circuit which can be traced as follows: from the ground on the make contact of the trunk multiple jack, to the make contact and the armature 2 of relay *A*, through the winding of relay *C* and thence to battery. Thus relay *C* will be energized and armature 1 will lock the relay, until the calling operator withdraws the plug, by means of a circuit that can be traced from battery through the winding to armature 1 and the make contact, thence to the make contact in the trunk multiple jack and from there to ground. After the operators have completed their conversation, they will withdraw the plugs. When the answering operator disconnects, the circuit containing relay *A* will be opened and the relay will release, thus completing again the circuit through the coils of relay *B* in the trunk circuit and relay *D* in the calling operator's cord circuit, which will light the supervisory lamp. The trunk line lamp will not relight, however, due to the fact that relay *C* is locked. When the calling operator disconnects, however, the jack contact is thereby opened and relay *C* is released; at the same time the circuit containing relay *B* is opened, thus restoring the apparatus to its normal condition.

For the convenience of the operator located at the toll board and for the purpose of distributing the toll tickets, each section at the toll board is equipped with a messenger key. The purpose of this key, as the name implies, is to call messengers. These messengers carry telephone directories and any other essential material from one operator to another, and also distribute the toll tickets, at the direction of the recording operators, among the proper line operators.

The operation of the messenger circuit is as follows: Whenever any operator desires to call a messenger, she actuates the messenger key, located in the lock rail; this closes a circuit containing a lamp situated in an annunciator, that is located in a conspicuous part of the operating room. The closing of this circuit will light the lamp and thus display the position number of the operator requiring messenger service. This will attract the attention of a messenger, who will respond to the call. As soon as the messenger reaches the operator signaling, the messenger will restore the key to normal and thus extinguish the lamp. Messenger service as outlined above is used in all toll offices, except some of the very large offices of the American Telephone and Telegraph Company. In these latter exchanges a system of tubes is installed by means of which the tickets are distributed pneumatically.

In this instance, each section of the toll board is provided with tubes to receive and deliver tickets. All tickets that are to be delivered to the various line operators for completing connections are first delivered to the ticket distributing operators, through the tubes leading from the recording board. The distributing operators in turn send the tickets to the proper line operators by means of tubes to the line positions. The distributing position forms a general clearing house for all tickets. These tubes are rectangular in shape, with an opening of about one-eighth of an inch and a width equal to that of the toll ticket. All joints in these tubes must be carefully made so as to avoid any catching or tearing of tickets and sharp turns are to be guarded against. Each ticket is folded back at one end so as to be caught by the air suction in the tube and carried to its destination. These tubes are stacked in a manner similar to multiple cables, in a runway which ordinarily extends over the top of the switchboard sections. The accompanying illustration, in Fig. 64, clearly shows the ticket tube runway and the ticket distributing board. This board is located centrally between the two lines of toll sections and is elevated to a height about equal to the top of the toll board. The ticket receiving and sending boxes, at the various line positions, are mounted in the middle panel of each toll section.

Wiring of a Toll-line Terminal. — The method of cabling and the distribution of apparatus about to be explained is shown in Fig. 65;

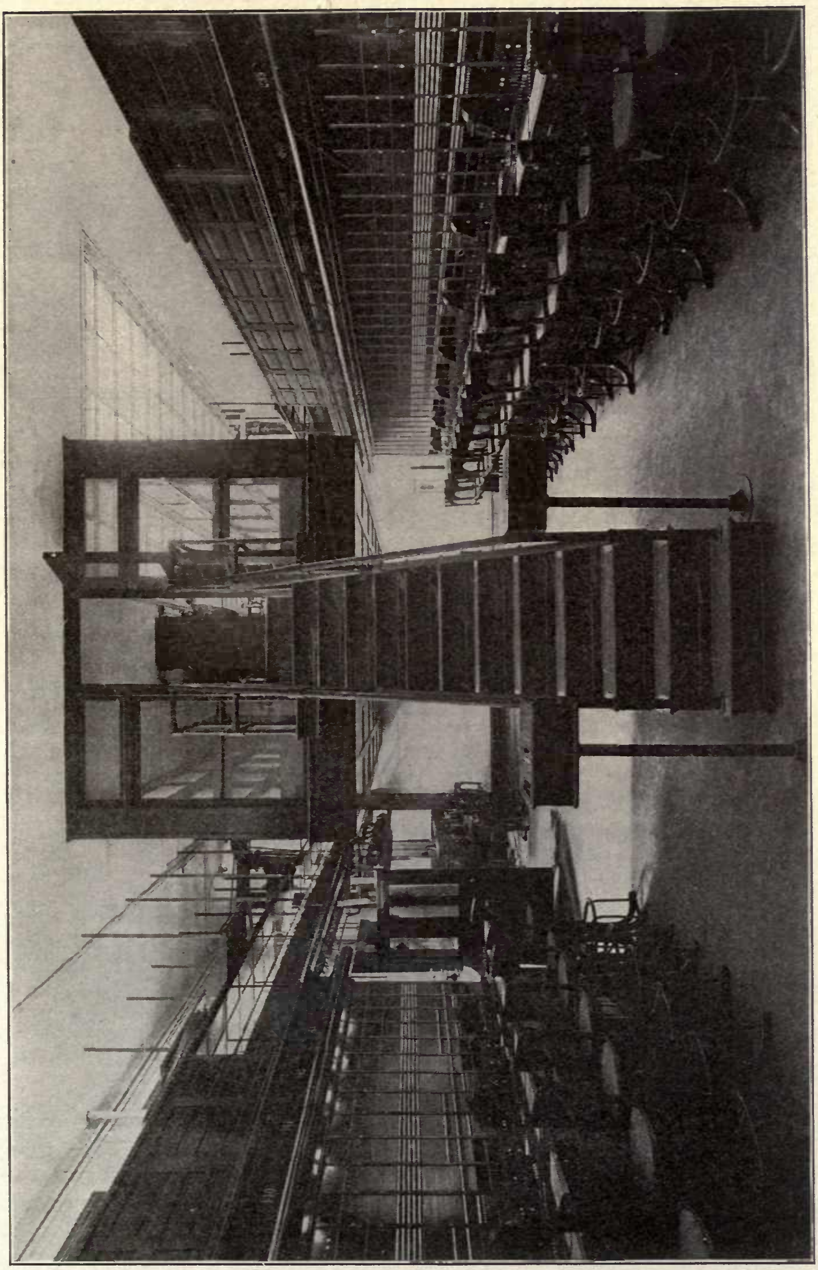


FIG. 64. — Multiple Toll Board of the American Telephone and Telegraph Company at Philadelphia, Pa., Showing Pneumatic Ticket Distributing System.

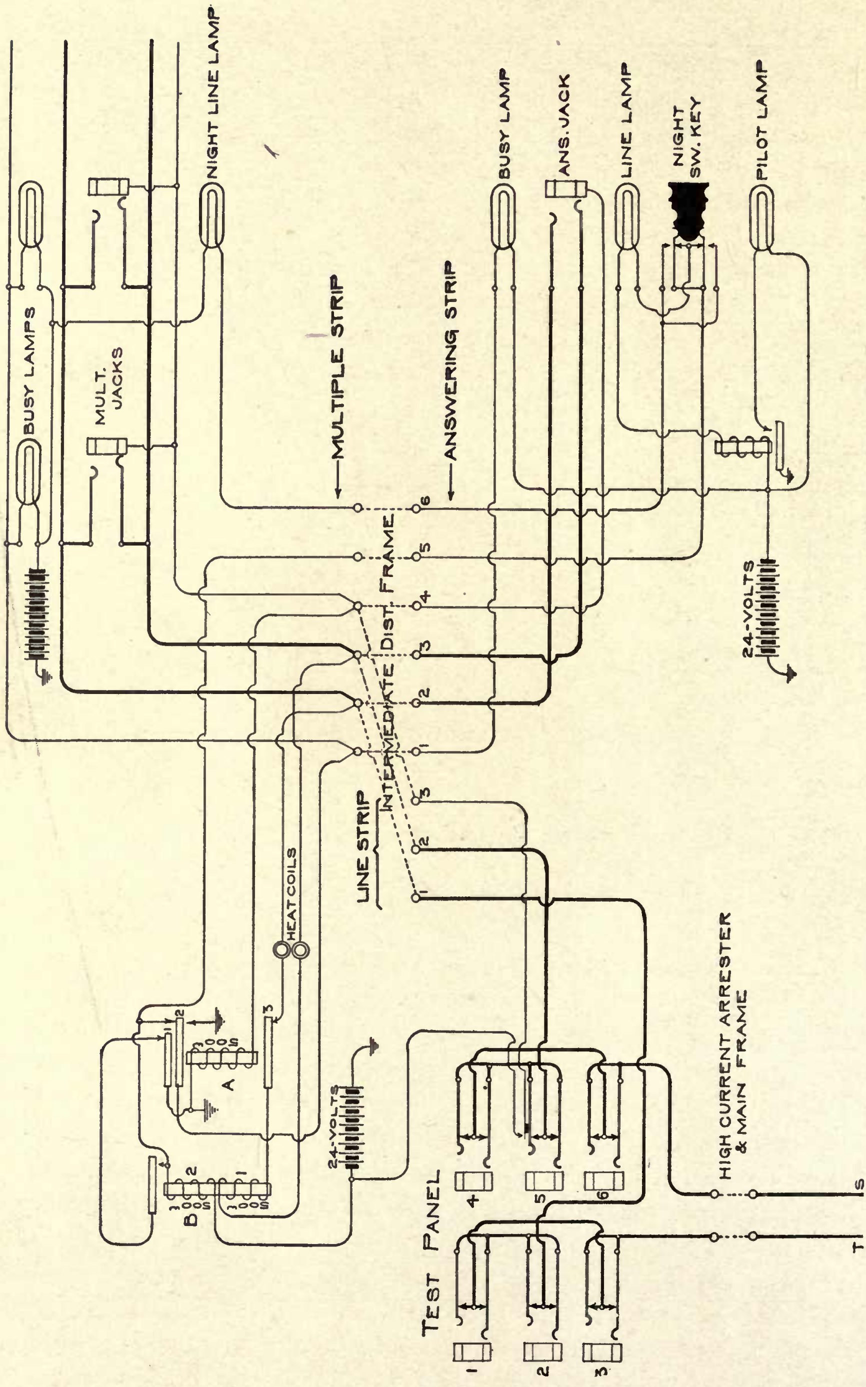


FIG. 65. — Detail of Wiring of a Toll Line Terminal in a Multiple-lamp Toll Board.

it is applicable to any system that has been described and is the standard method of wiring a toll-line terminal. It is also standard practice in wiring toll switchboards to use talking conductors as large at least as No. 19 B. & S. gauge, while the signaling conductors are usually No. 22 or No. 24 B. & S. gauge; No. 22 is preferable for mechanical reasons.

It will be noted by referring to the figure that the toll line, upon entering the office, is carried first to the high-current arresters on the main distributing frame. The protection at this point consists of line fuses and carbon block lightning arresters similar to those shown in Fig. 66. The toll line is then cross-connected to the switchboard side of the frame and from there carried to the test panel. The uses of this panel will be touched upon but briefly at present, as a full explanation will be given in a subsequent chapter. It will be noted that each line entering the office is associated at the panel with six spring jacks, three for each side of the line. These jacks are grouped in pairs and a suitable twin plug is furnished with the cord circuits at the panel. The object of employing three pairs of jacks is as follows. In case a plug is inserted in jacks 3 and 6, the switchboard end of the line circuit is cut off by means of the break contacts in the jacks and the cord circuit is connected directly to the outgoing line. If the plug is in-

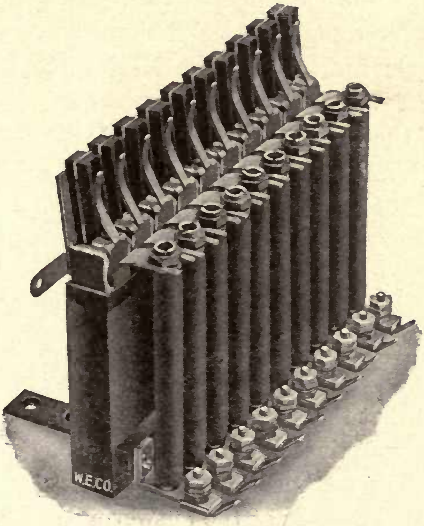


FIG. 66. — High Potential and Abnormal Current Arresters.

serted in jacks 2 and 5 a similar condition exists, with the exception that the busy signals associated with the line at the toll board are now displayed. The circuit containing the busy signal is completed by means of the make contact in jack 5. When a plug is inserted in this jack, a circuit can be traced from battery through the jack contact to the intermediate distributing frame and thence by way of the jumper through the cut-off relay *A* to ground. Thus the cut-off relay is energized and the busy lamp is lighted, as explained in connection with Fig. 53. In case the plug is inserted in jacks 1 and 4, it will be noted that the line side of the circuit is cut off and the switchboard side is connected direct to the cord circuit. The object of these arrangements will be fully explained later; jack pair 1 and 4 and pair 3 and 6 are used for compositing and simplexing, while 2 and 5 are used by the wire chief for testing the toll line and 1 and 4 for testing the office.

Having traced the line to the test panel, we find that it is next carried to the intermediate distributing frame. The cable carrying the lines over is usually a 33- or a 63-wire cable, as lines are usually grouped for convenience in units of ten or multiples thereof; the three spare conductors are for emergency use. The distributing frame end of the cable terminates in a three-point terminal block and is cross-connected to the multiple terminal strip on the switchboard side of the frame.

It will be noted that the answering side, as well as the multiple side, of the line circuit terminates at the distributing frame in six-point terminal strips. The method of cabling to these strips is as follows. The tip and the ring springs of the answering jacks are connected to clips 2 and 3 of the answering terminal strip by means of a pair of No. 19 B. & S. wire carried in the "intermediate to answering" cable. Terminal clips 1 and 4 receive the wires from the busy lamp and the sleeve of the answering jack, respectively, and are run as a pair in a separate cable. Terminal clips 5 and 6 connect with the night switching key by means of a pair of wires in a third cable. The three cables last mentioned each contain ten service pairs and one spare pair. The cable which contains the talking conductors should be composed of No. 19 B. & S., as stated above, and the other two cables of No. 22 B. & S. gauge. Although it is customary to install sufficient cable to care for ten answering jack equipments, this by no means signifies that ten lines are to terminate at one operator's position.

It is customary, for various reasons, to furnish equipment in the answering jack space for more lines than ordinarily can be handled by the operator. The principal reasons for this are, first, that standard apparatus for the answering jack equipment is usually made in strips of ten; and second, should trouble develop in one of the lines between the frame and the answering jack, a spare terminal can be substituted by cross-connecting at the intermediate frame.

Having disposed of the answering terminal strip, attention will now be directed to the multiple terminal. It will be noted that on this terminal clips 2 and 3 are reserved for the tip and the ring of the multiple jack. In addition to the pair of conductors leading to the answering jack, there is a pair which leads to the heat coils at the relay rack. These heat coils may be located on the relay rack itself, in which case the question of cabling is somewhat simplified; or they may be located on the main distributing frame. When located on the main frame they are usually, for convenience in mounting and manufacturing, made up as standard sneak current and lightning arresters, like those used in local offices. In the latter case, it is customary to use dummy carbons in place of the standard carbons and micas. These heat coils serve to guard against sneak currents which might get past the fuses at the high-current arrester frame and thus damage the relay equipment.

Returning to the cabling, it will be observed that clips 1, 4 and 5 are also cabled to the relay rack; these wires are carried in a single cable as one pair and one single wire. There now remain but three wires on this terminal that have not been accounted for, namely, one to the busy lamp, one to the sleeve of the multiple jack and one to the night line lamp. The first two are wired in a cable as one pair and the third is wired in another cable as a single conductor; they take terminals 1, 4 and 6 respectively.

Having accounted for all of the wires on the terminal strips at the frame, the next consideration is the method of cross-connecting. The cross connections or "jumpers" are indicated in the figure by dotted lines. A toll circuit is similar to a local subscriber's circuit in the respect that the relay equipment is associated with the multiple; therefore, the wires from the test panel are cross-connected to the tip, ring and sleeve clips of the multiple terminal strip. Springs 1 and 6 of the multiple terminal strip are cross-connected to clips 1 and 6 of the answering strip.

For the purpose of making these connections more clearly understood, an incoming call will be traced in detail.

An incoming signal (alternating current) from the toll line will take the following path. Starting from the high-current arrester on the line side of the main frame, it passes through the jumper and the terminal spring, to the make contacts of jacks 3, 1 and 2 respectively and then to clip 1 of the three-point terminal. Thence it may be traced by means of the jumper to clip 2 on the multiple terminal, through the heat coil to the make contact of armature 3 of relay *A*, to coil 1 of relay *B* and through the other heat coil; it next passes to clip 3 of the multiple terminal, over the jumper wire to clip 2 of the three-point terminal, through the three jacks in the test panel and back to the main frame. Consequently relay *B* will be energized and permanently locked, due to a circuit that may be traced from battery to coil 2 of relay *B*, thence to the make contact and the armature of the same relay, to the break contact and armature 1 of relay *A* and then to ground. This will light the line lamp and the busy lamps. The circuit containing the busy lamps can be traced from the ground on armature 1 of relay *A*, by way of the break contact, to the armature of relay *B* and its make contact, to the break contact and armature 2 of relay *A* and thence to clip 1 of the multiple terminal. Commencing at this point the lamps associated with the multiple jacks are wired in multiple to battery; whereas the circuit for the answering busy lamp can be traced through the jumper connected to clip 1 on the answering terminal and thence through the lamp to battery.

The line lamp circuit can be traced from battery through the pilot relay and the switching key to clip 5 of the answering terminal, from there through the jumper to the same clip on the multiple terminal, thence to the make contact and the armature of relay *B*, to the break contact and armature 1 of relay *A* and finally to ground. In case the night switch is operated it will be observed that the circuit is shifted to the make contact of the switch; from here it can be traced to clip 6 on the answering terminal, through the jumper to the multiple terminal and through the night line lamp to battery. When the operator answers by plugging into either the multiple jack or the answering jack, it follows, since the sleeves of these jacks are connected by the jumper from clip 4 of the multiple terminal to the same clip on the answering terminal, that the cut-off relay *A* will be operated and the line lamp extinguished. This is due to the fact that battery is connected to the sleeve of the plug; and therefore, the act of inserting the plug completes the circuit to clip 4 and the coil of relay *A* to ground. The operation of relay *A* disconnects the signaling apparatus from the line and transfers the ground connection of the busy lamp circuit to armature 2 of relay *A*, as was explained in connection with Fig. 53.

CHAPTER IX

TOLL CONNECTIONS TO LOCAL AUTOMATIC SYSTEMS

The interconnection of toll lines with local lines which terminate in an automatic switchboard, and *vice versa*, has, to a great extent, complicated the toll switchboard used for this class of service. This complication arises from the fact that means must be provided whereby a toll operator can complete a connection with subscribers connected to the automatic system and each such subscriber must be able to reach the toll board. The latter operation is not especially complicated as all automatic telephones are now provided with an extra number on the dial, which, when selected, connects the subscriber, by means of a trunk, direct to the toll board. There are two general schemes of reaching the automatic subscriber from the toll board; the one most generally used provides the toll operator with a calling dial, by means of which she can select the subscriber through the switches in the same manner that one automatic subscriber selects and calls another. This scheme, while very satisfactory for small boards, is too slow in operation for large toll offices.

The other method referred to involves considerable extra expense, as all the local lines must be carried through a switching panel before they reach the automatic switches. At the switching panel each line passes through a double cut-off jack. This method is used in the plant of the Citizens' Telephone Company, at Grand Rapids, Michigan. Fig. 67 gives a view of their toll operating room, which shows at the extreme left a switching panel similar to the one referred to above. The circuits of a toll board in which this scheme is used may be of any standard type. When a call for an automatic subscriber is received, the toll operator will communicate, over an order circuit, with the local switching operator, who will assign the trunk to be used and then insert the trunk plug in the jack connected with the line called for. The insertion of the plug in the jack cuts off the automatic switch associated with the line and renders it " busy " to all other calls. The toll operator then has a direct connection to the line called for.

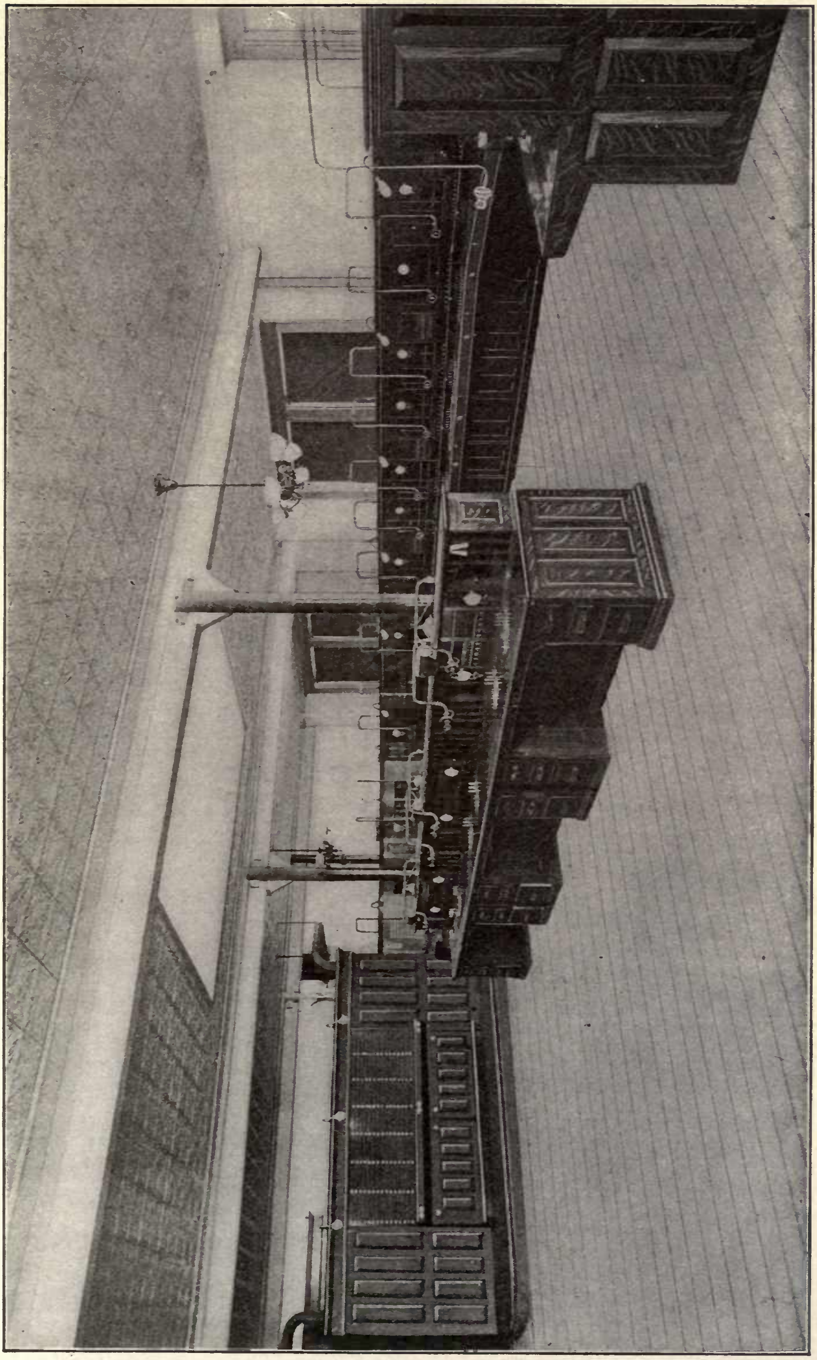


Fig. 67. — View of Toll Operating Room, at Grand Rapids, Michigan.

Each of the above schemes has individual advantages. The first one costs considerably less to install than the second, but is slower in operation. The second method has an additional advantage in the respect that the automatic switches are entirely eliminated from the connection. This last-mentioned feature may seem of minor importance, but the omission of each additional contact and length of cable from the toll connection is a distinct advantage.

One of the earliest and largest boards of the first general type was designed and built by the Kellogg Switchboard and Supply Company and installed at Dayton, Ohio. Some idea of the general arrangement of the apparatus can be had by referring to the accompanying illustration, Fig. 68. At the time this board was designed there was practically no data that would serve as a guide in planning the trunk circuits. The trunks naturally constituted the all-important and novel feature in this work and this undertaking was therefore viewed with considerable interest. This board has now been in use for a number of years and has given good service. The circuits are of sufficient interest to merit a description.

Fig. 69 shows a diagram of the connection from a toll line to an automatic subscriber's line. The toll end of the connection is completed in the usual way. The line operator, upon receiving an inward call, tests the outgoing trunk multiple and inserts the calling plug in the first idle trunk. This completes a circuit through relays *A* and *B*. The attraction of armature 3 of relay *B* completes a circuit through relay *C*, but as these two relays have no immediate effect upon the operation they will not be considered until later. The operator is now ready to select the automatic subscriber. This is accomplished by the operation of key 1, which connects the calling cord with the automatic dial. The operator can now actuate the dial and select any subscriber desired, in the manner that one automatic subscriber selects another. When the conversation is completed the disconnect signal from the toll line is received in the usual manner. The automatic subscriber upon placing his receiver on the hook connects each line conductor to ground momentarily. This ground connection can be traced to battery through each winding of relay *F*. The subsequent actuation of relay *F* completes a circuit from the ground on the make contact and the armature of this relay through one winding of relay *E* to battery. Relay *E* is thereby energized and completes a circuit which may be traced from ground on the break

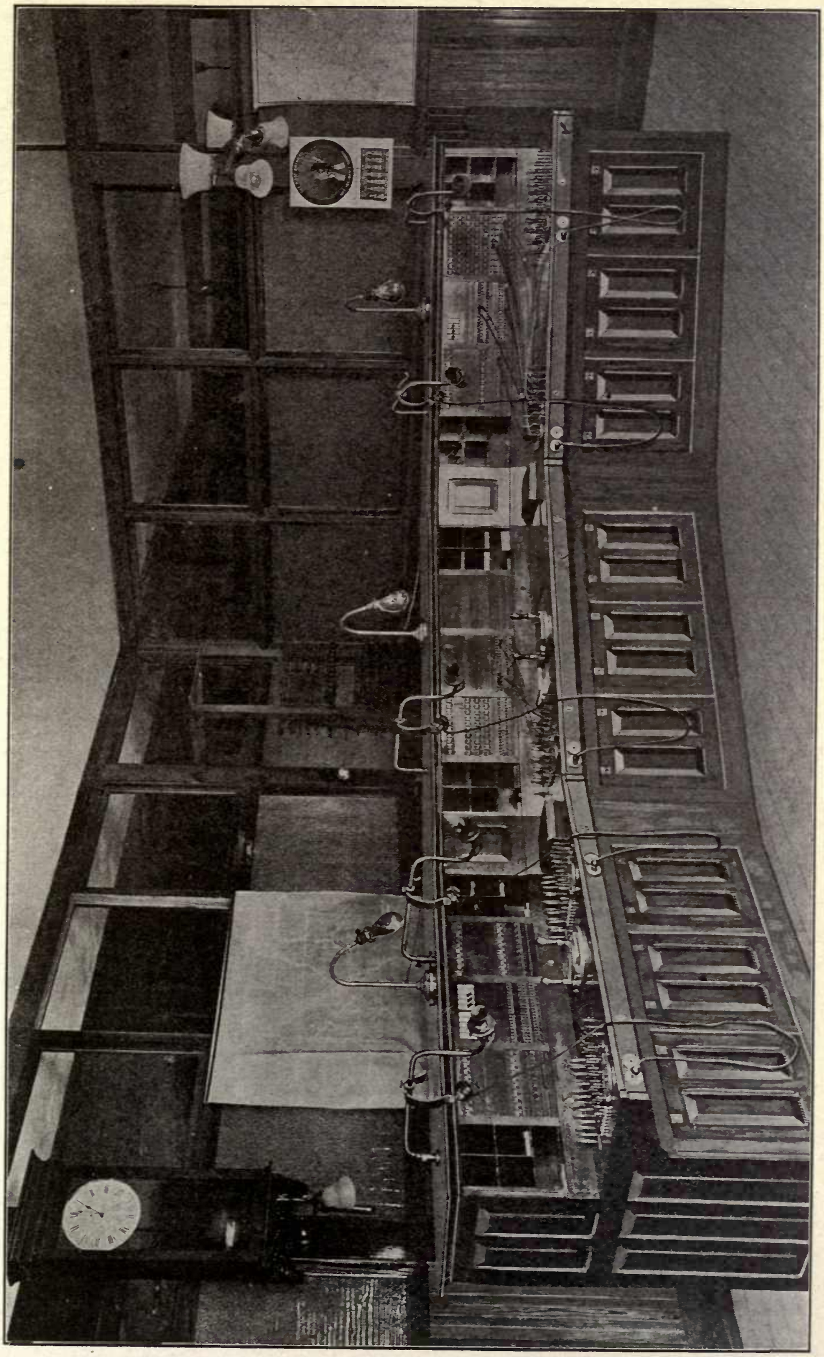


Fig. 68. — View of Toll Operating Room, at Dayton, Ohio.

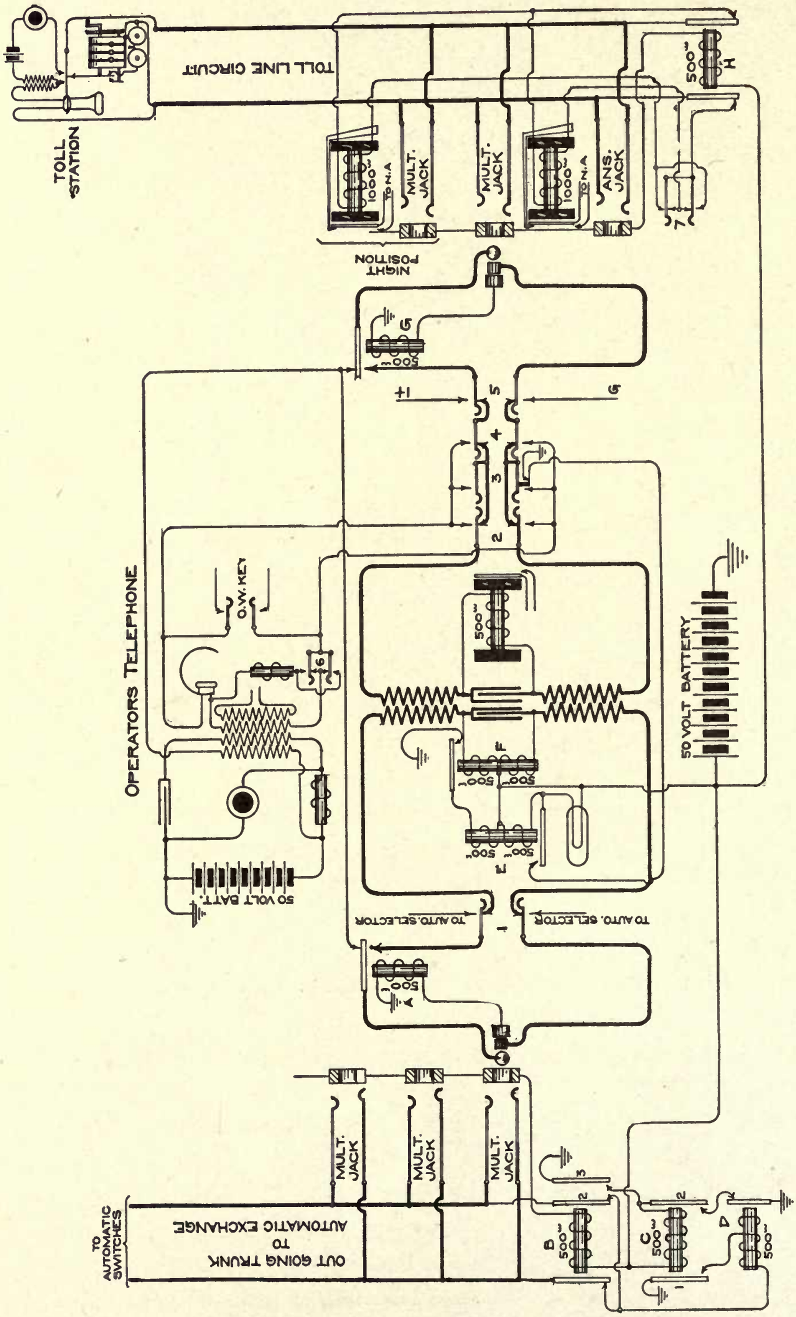


FIG. 69. — Diagram of a Toll to Automatic Connection, at Dayton, Ohio.

contact of key 3 to the make contact and the armature of relay *E* and through the other winding of this relay to battery. This circuit holds the relay in a closed position until key 3 is actuated, as relay *F* will remain closed for only a very short interval. The operation of relay *E* also completes a circuit from ground through the disconnect lamp to battery, thereby notifying the operator that the automatic subscriber has hung up his receiver. The operator will then take down the connection, which will release relay *B*. Relay *C* is still closed, as the circuit through this relay is completed by the ground connected to the back contact of relay *D*. As soon as relay *B* releases, a ground is placed on the line conductors of the trunk circuit by way of the armature of relay *C*, through the winding of relay *D* and the back contacts and the armatures 1 and 2 of relay *B*. This ground connection causes a flow of current from the automatic switches, which energizes relay *D* and thus removes the ground connection from the circuit containing relay *C*. The release of relay *C* will remove the ground from the coil of relay *D*, which will likewise release and restore the trunk circuit to its normal condition. The purpose of the ground connection on each side of the trunk circuit is to disconnect the automatic switches. Relay *D* in the trunk circuit is provided with a copper shell over the iron core, which makes it sluggish in action. This is necessary so that it will not release before armature 2 of relay *C* has fallen back, which will prevent the reëstablishment of the circuit through this relay.

When the toll call originates with an automatic subscriber, the procedure is naturally different. The toll board is provided with a number of recording trunks which are connected to the automatic switches in a manner similar to that of a subscriber's line. When an automatic subscriber wishes to make a toll call, he selects the number marked " toll " on his dial and presses the ringing key. The operation of the dial causes the automatic switches to select an idle recording trunk. Fig. 70 shows a diagram of this trunk circuit. The operation of the ringing key will allow current to flow through the recording trunk relay, thereby completing a circuit through the locking winding, which will hold the relay in an operated position until the ground connection is removed by the insertion of the answering plug. The operation of the relay also completes a circuit through the lamp signal, which will attract the recording operator's attention. When the operator plugs into the recording jack the lamp will be extinguished.

She will then actuate her listening key and upon ascertaining the details of the call will tell the subscriber to hang up his receiver and wait until called. The toll ticket is then passed to a line operator, who completes the call in the manner described in connection with the circuit shown in Fig. 69.

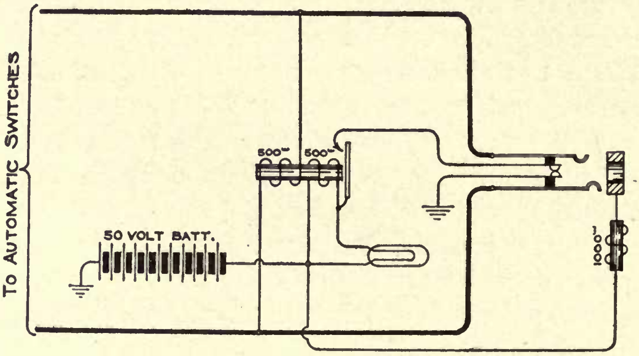


Fig. 70. — Diagram of a Recording Toll Trunk, at Dayton, Ohio.

Toll boards used in connection with automatic local exchanges are usually equipped with one or two positions for handling the rural business. In the Dayton boards these connections are dealt with in the same manner as the toll connections. When a toll subscriber desires a rural connection, however, the call must be trunked to the rural position because the rural lines are not multipled. Fig. 71 shows the trunk used for this class of service. When the toll operator receives a call for a rural subscriber she will communicate over her order circuit with the rural operator, giving the latter the number

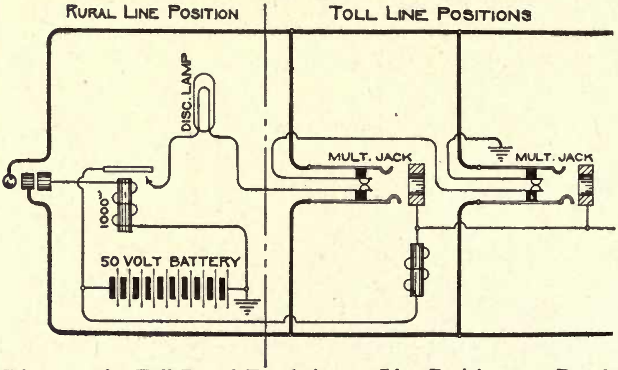


Fig. 71. — Diagram of a Toll Board Trunk from a Line Position to a Rural Position, at Dayton, Ohio.

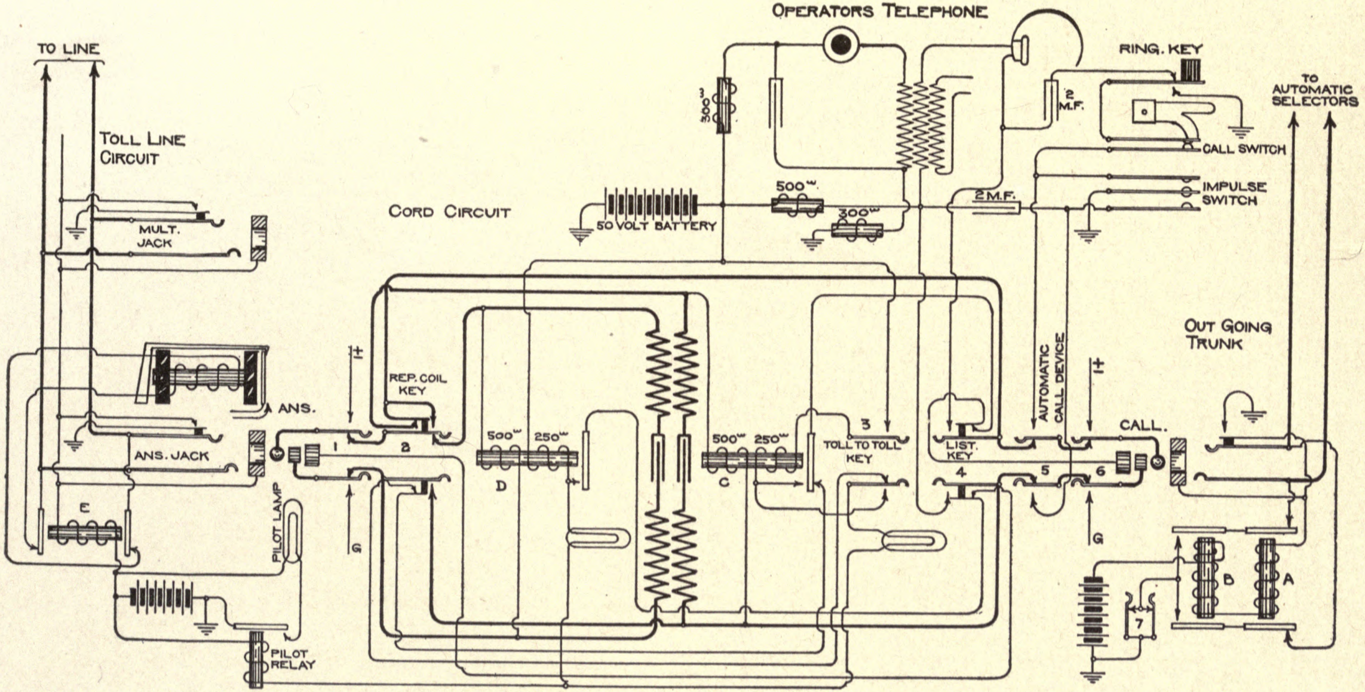


FIG. 72. — Diagram of the Automatic Electric Company's Toll to Automatic Connection.

of the subscriber desired. The rural operator in turn assigns the trunk and inserts the plug in the jack of the called-for line. This will light the disconnect lamp associated with the trunk at the rural position. The lamp will be extinguished, however, as soon as the toll operator takes up the trunk. She then rings the rural subscriber in the usual way. When the conversation has been completed and the toll operator has received the disconnect signal, she will take down the connection and thereby complete a circuit through the disconnect lamp at the rural operator's position. This operator, upon seeing the disconnect signal, will remove the trunk plug, thereby releasing the relay and opening the lamp circuit.

The toll circuits designed by the Automatic Electric Company for small toll installations merit a special description, inasmuch as they do not correspond exactly with any of the systems described before. Fig. 72 shows their toll-to-automatic connection. It will be observed that the cord circuit is of the lamp signal type, while the line is of the drop type. These circuits are very similar to those described in the two preceding chapters. The ground connection for operating the cut-off relay, the supervisory lamp and the locking winding of the cord relay is obtained in this case through a make contact on the multiple line jack. While this is a very ingenious scheme, it is questionable whether the saving in relays is not offset by the cost of the additional contacts in the jacks, and the extra wiring. The operation of the circuit, with the exception of a few variations in the trunks, is practically the same as that at Dayton. It will be noted that when the plug is inserted in the trunk jack, a circuit is established from the ground on the make contact at the jack, through relays *A* and *B* to battery, thus energizing the relays. When the operator withdraws the plug, these relays are released and this serves to release the automatic switches. The armatures of relay *A* fall back immediately, but as relay *B* is slow-acting it continues to hold its armatures for a short interval, thereby connecting ground to each side of the trunk, which serves to release the automatic switches. The operation of this circuit depends upon the slow action of relay *B*. It would seem that this feature of the circuit is somewhat marginal, while the circuit shown in Fig. 69 is positive in its action because the ground connection is necessary to release the trunk relays. Key 7 is used to prevent a disconnect at the switches in case the operator should wish to change cords.

CHAPTER X

SUPERVISORY EQUIPMENT AND TOLL CHIEF OPERATOR'S DESK

THE requirements of toll operating are ordinarily much more exacting than those of local operating and the personnel of the operating force should be correspondingly better. The need for supervision, at a toll board, is especially prominent because of the comparatively complex nature of the operator's work; and of course the reasons which make supervision so essential in local operating are present also in this case. The operating room organization nominally consists of a chief operator in charge, a group of immediate subordinates who are termed monitors, or supervisors, and under each of the latter a group of operators.

The chief operator is essentially an executive in all but the small offices, where she probably assumes also the duties of a supervisor. The work of real supervision falls naturally on the supervisors. Each supervisor has charge of a subdivision of the operating force and is responsible in her division for the prompt dispatch of traffic, under the rules, and the enforcement of discipline. The routine work of the supervisor consists largely of overseeing her operators, watching for and preventing unnecessary delays, giving personal help as needed and occasionally handling calls herself when irregularities arise.

Supervision in general is of two kinds, one of which has just been described; the other is of a secret character, effected by means of listening circuits connected to toll lines, trunks and operators' telephone circuits. The latter naturally requires special equipment, varying according to the size and needs of each office. This chapter deals particularly with such equipment and its arrangement. There is also some equipment for the use of the chief operator and the supervisors in routine work, which will be included in the following treatment.

The supervisor's equipment is very simple, consisting of a breastplate transmitter and head receiver, which she wears continually while on duty. She is always ready, therefore, to plug into an operator's jack and take up a situation which the operator herself is incapable of handling. However, since the supervisor is normally passing back and forth behind her group of operators, it becomes necessary to have some scheme whereby an operator can attract the supervisor's attention if necessary. For this purpose, the board is equipped with a supervisor's trunk, which is a special line multipled through that portion of the board comprising the supervisor's division. This circuit is equipped with any suitable calling device of the audible type, which is mounted at some convenient place on the wall of the operating room. When any operator desires the aid of the supervisor, she will plug into the supervisor's trunk jack and ring. This will attract the attention of the supervisor, who will answer by inserting her telephone plug in the jack of a special equipment conveniently located in her part of the operating room. This equipment may be either separate entirely from the board, as shown by the pedestals in the frontispiece, or it may be connected to jacks located in the key-shelf rail. When several supervisor's circuits are installed, the audible signals are made distinctive, so as not to be confusing. Where the toll board is a small equipment, say of four or five positions, the supervisor can readily be called without the use of special apparatus; but in a large office some systematic method of calling, such as the one described, is necessary to avoid confusion and disturbance.

The circuit shown in Fig. 73 illustrates a supervisor's trunk that has been used quite extensively and will serve as an example of the type of equipment required for such work. A detailed description of the operation of this circuit follows. When an operator desires to call her supervisor, she inserts the answering plug of a pair of cords in the supervisor's trunk multiple jack, and then rings. This will naturally actuate the bell *B*, which is bridged directly across the tip and ring strands of the trunk circuit, and the supervisor will thereupon insert her telephone plug in the nearest answering jack. However, should the supervisor be engaged and thus not able to give the call immediate attention, the toll operator may proceed with other work, since the supervisory lamp associated with the cord used in calling will light as soon as the plug is inserted in the trunk jack, and it will remain lighted until the supervisor answers, or the plug is withdrawn from the jack. The insertion of this plug completes a circuit which may be traced as follows: from ground through one winding of relay 4, to the break contact and the armature *A* of relay 3, over the tip

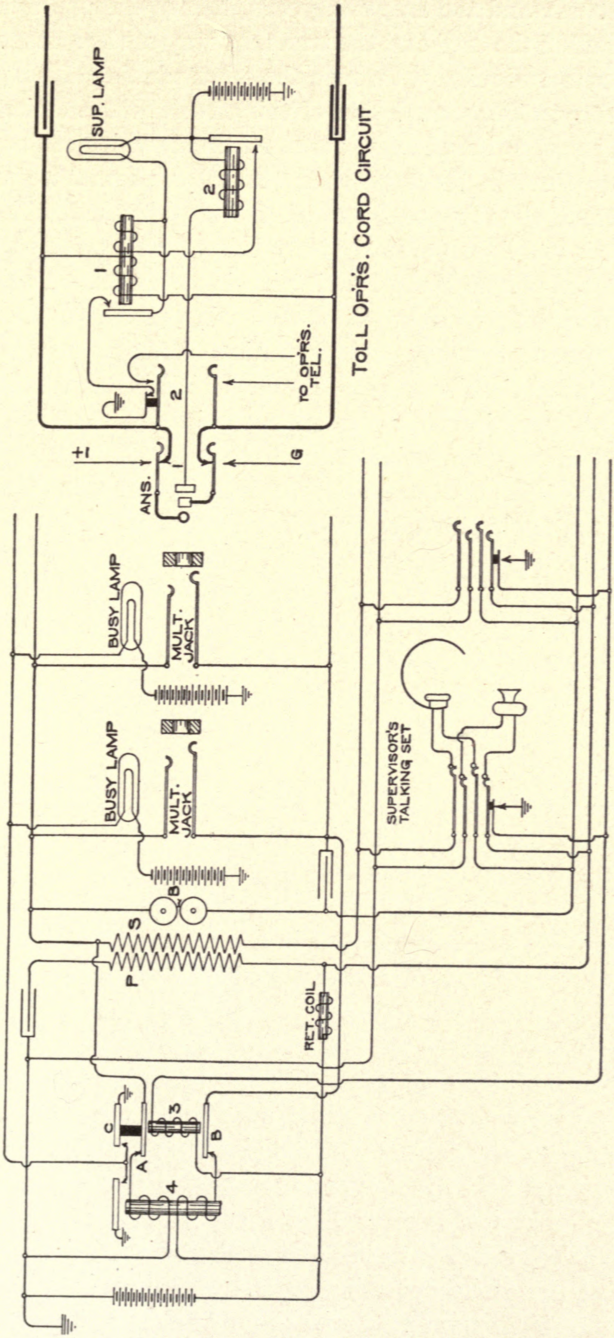


FIG. 73. — Diagram of a Toll Supervisor's Trunk Circuit.

side of the trunk and the answering cord, thence through relay 1 to the ring strand of the cord and the trunk, by way of the armature and the break contact of relay 3, through the other winding of relay 4 and then to battery. The completion of this circuit will energize relays 1 and 4. The actuation of relay 1 closes a circuit which can be traced from battery through the supervisory lamp, the armature and the make contact of the relay and through the break contact of key 4 to ground. This will light the supervisory lamp. As soon as the supervisor inserts the plug of her set, a circuit will be completed which can be traced from the ground on the make spring of the telephone jack through relay 3 to battery. The operation of relay 3 will open the supervisory relay circuit outlined above, which in turn will release relay 1. The supervisory lamp in the cord circuit, therefore, will be extinguished thereby informing the toll operator that the supervisor has answered. The operator then actuates her listening key, thus completing the talking circuit. When the conversation is completed, listening key 2 will be restored to normal and the plug of the supervisor's set removed from the jack; this will relight the supervisory lamp in the cord circuit. The lamp will remain lighted until the operator takes down the connection, which will restore the apparatus to its normal condition. The talking circuit is of the standard type used with the breastplate equipment and, therefore, can be passed without further comment.

Relay 4 of the circuit performs a double function; it not only feeds current to relay 1 in the cord circuit, but the attraction of its armature completes the battery circuit through the busy lamps, thus notifying the other operators that this trunk line is in use. As soon as the supervisor inserts the listening plug in the answering jack, relay 3 is operated, which thereby releases relay 4. This will not extinguish the busy lamps because the circuit is now completed by armature *C* of relay 3. Consequently the busy lamps never allow the circuit to remain unguarded, for as soon as the toll operator inserts a plug in any one of the trunk multiple jacks the busy lamps will light, and they will remain lighted as long as a plug remains in either jack.

The equipment for a chief operator's position is much more complicated than that just described for a supervisor, and is generally installed in a desk which is so situated as to give the chief operator a clear view of the entire operating room. However, in a very large toll office, the chief operator's duties are of such a character that she is given a private office; in that case she usually leaves the details of supervision and discipline in charge of an assistant. In such cases the chief operator devotes her entire time to the general management of the operating force, such as employing new operators, preparing reports, attending to complaints and keeping records of the individual work and conduct of the operating force.

In the smaller exchanges it is considered good practice to keep the chief operator in the operating room, so that she will be always in touch with the details of operation. The chief operator's desk is equipped with circuits and apparatus by means of which she can instantly reach any operator in the room, either to speak to her or to observe the manner in which she is handling her work. In the following description these circuits will be considered individually and a detailed analysis will be given of the operation of each.

Fig. 74 shows a circuit giving the necessary connections for chief operator's listening and monitoring taps. It will be noted that the chief operator's end of the circuit terminates in a double-throw key of the cam type, which results in a very neat and compact arrangement. There are many desks in which these taps terminate in spring jacks, thus necessitating the use of a cord and plug to complete a connection. This is not as convenient as the arrangement shown in the figure. In the wiring of the chief operator's tap, the induction coil at each operator's position must be equipped with a tertiary or third winding for secret supervision. This circuit is used when the chief operator wishes to listen to any conversation that the toll operator may be engaged in, without the operator's knowledge. The theory upon which the operation of this circuit is founded may be compared to the operation of a transformer with an open-circuited secondary.

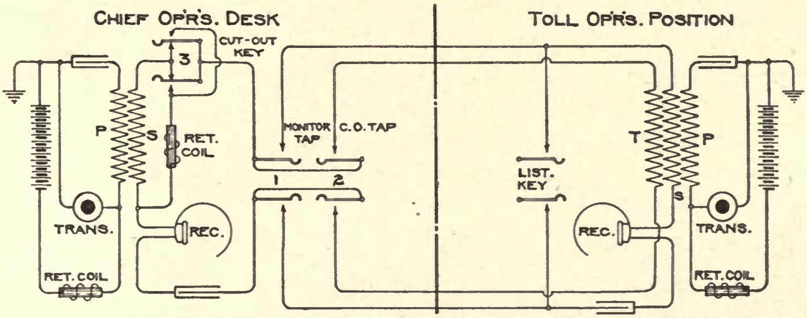


FIG. 74. — Diagram of Chief Operator's Listening and Monitoring Taps.

It is a well-established principle of transformer action that when the secondary circuit is open, that is, of infinite resistance, the current flowing in the primary meets the full primary impedance. This is due to the fact that the flux set up in the core of the transformer by the current flowing through the primary produces a counter electromotive force in the primary winding which limits the flow of current. But when the secondary circuit of the transformer is closed the current in the primary will increase, due to the current flowing in the secondary which cuts down the counter electromotive force referred to above.

In the case at hand, the induction coil, or transformer as it may be called, has three windings, the primary winding of low resistance and few turns, the secondary winding of higher resistance and a greater number of turns, and the tertiary winding of still higher resistance and a still greater number of turns. It is obvious, first, that when the toll operator is talking, the primary coil is the one producing the fluctuations of magnetic flux in the core, which act on the secondary and tertiary windings of the coil; and secondly, when the subscriber is talking, the secondary coil produces the fluctuations, which in turn act on the primary and tertiary windings. But the tertiary circuit contains no source of E.M.F. and it therefore produces no impulses in the primary or secondary when it is opened and closed. A very slight click can be observed under favorable conditions, but it is probably due to the effects of electrostatic capacity between the windings. Ordinarily the click cannot be observed. In order to make certain that the operator cannot detect supervision, a primary cutout key is installed in the chief operator's telephone set, to prevent the picking up of room-noise or disturbance.

The monitor's tap, as shown in Fig. 74, is wired in parallel with the toll operator's talking set; and, therefore, when the monitoring key is actuated, the chief operator can speak to the operator and give her such instruction or aid as may be required. By means of this circuit, the chief operator can connect instantly with any operator and thus avoid the delay which would naturally arise if she were required to use a trunk circuit.

Another scheme which helps to reduce the work of the chief operator is the so-called instruction circuit. This circuit is shown in Fig. 75 and is used by the chief operator when she desires to issue general instructions to several or all of the operators, simultaneously. The operation of this circuit is briefly as follows. When the chief operator desires to issue general instructions, she will operate the instruction key, which not only bridges her telephone set across the trunk line, but also completes a circuit through relay *A*; the operation of the relay establishes a circuit through the instruction lamp at each toll operator's position. When this signal appears, the operator knows that general instructions are to be issued and she consequently operates her instruction key. This extinguishes the instruction lamp and at the same time bridges her telephone set across the trunk circuit. The chief operator may have one of these circuits for each group of three or four sections, thereby enabling her to instruct six or eight operators at a time; or the circuit may be common to the entire board. The utility of this circuit is self-evident, for it is a means of giving new instruction to all operators instantly.

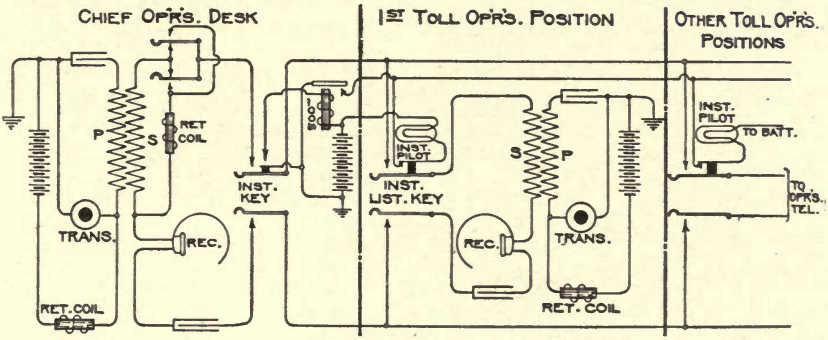


FIG. 75. — Chief Operator's Instruction Circuit.

Another circuit which good practice places at the chief operator's desk is the interposition trunk. This circuit has previously been described in Chapter VIII. It is almost unnecessary to point out that these circuits afford a temptation to the operators to carry on personal conversations. To avoid the abuse of these circuits, they should be multipled at the chief operator's desk and preferably be equipped with visual busy signals, for convenience in supervision.

The circuits which show the promptness with which the operators at the board are handling connections, are the line and supervisory pilot taps. These circuits are shown in Fig. 76, from which it will be observed that the pilot lamps in each position are multipled in the chief operator's desk. Therefore, whenever a call is received at any particular position, both the line pilot lamp at the position and the corresponding lamp at the chief operator's desk will light; in case the lamp remains lighted longer than a proper interval, the chief operator will cut in on the monitor's tap and determine the cause. The same applies if the supervisory pilot lamp remains lighted too long.

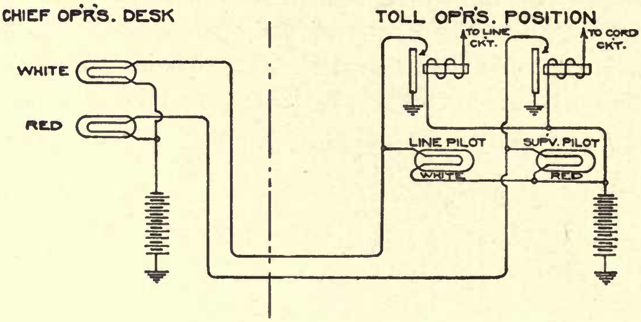


FIG. 76. — Chief Operator's Pilot Taps.

In all exchange work more or less trouble is experienced from improper listening by the operators. In some instances the rules have been so strict as to cause the discharge of an operator detected in so doing. To assist the chief operator in watching operators who are suspected of this practice, her desk is sometimes equipped with a circuit similar to the one shown in Fig. 77. The lamp at the desk end

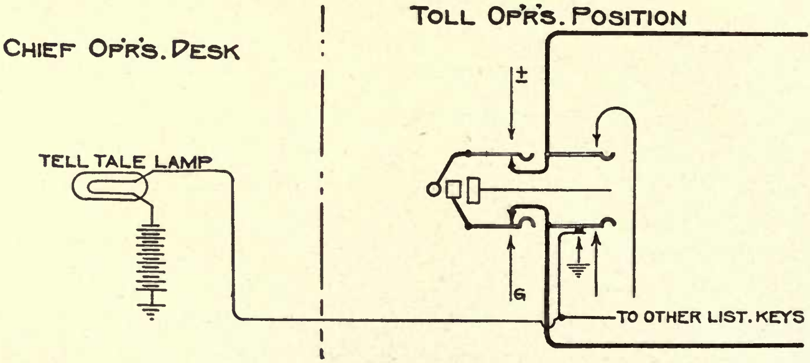


FIG. 77. — Chief Operator's Tell-tale Circuit.

of the circuit will light whenever a bridged listening key is thrown in any cord circuit of a given position. If this lamp lights and remains lighted for some time, the chief operator's suspicions will be aroused and she will operate her tap key, which permits her to listen to the conversation without attracting the attention of the operator.

While the wiring of these circuits is quite simple, it is often a difficult problem to determine the best method of carrying the leads from the various toll operators' positions to the chief operator's desk. A convenient method of handling the pilot and listening taps is to carry the wires from the various positions to some common point, such as the first position of the board, where they should be connected to a suitable connecting rack. They may then be carried in a factory-made cable, through a duct under the floor, to the desk. It is always advisable to have the various ducts between the desk, the main board and the frames installed during the construction of the building; but as exchanges are not always installed in new buildings, this is frequently impossible. Consequently the installer, at times, meets with some very trying conditions, especially where the floors in the building are of tile or cement.

Some engineers specify that all taps shall be carried to the intermediate distributing frame. However, this seems unnecessary for the pilot and listening taps, since there is very little, if anything, to be gained by such procedure; in nearly all cases the cables which carry these taps must be taken back over the same route before they enter the duct leading to the desk. The only real advantage in having these taps looped through the intermediate distributing frame is convenience in testing; but with circuits as simple as these, the testing which will be required after the board is put into operation is almost negligible.

It will be noted that all the circuits described above were designed for key-equipped desks, in place of jacks and cords. The reason for this is obvious; it is a well-known fact in switchboard operation that the cord is the weakest part of the equipment, and moreover, the key-equipped desk offers an additional advantage in the respect that it requires no equipment on the top of the desk, thus giving the chief operator ample writing space. When all the circuits ordinarily equipped with jacks are provided instead with keys, the equipment is placed in a turret which is mounted on the top of a flat-top desk, thus making a very neat and compact arrangement.

In addition to what has been said regarding the chief operator's desk, it might be well to add in conclusion that space is usually provided for pigeon holes and bookstalls. It is also customary to furnish the desk with card filing cases. These are located in the drawers or in neat receptacles arranged in the top of the desk in such a manner that the cards are flush with the top of the writing shelf.

CHAPTER XI

TOLL WIRE CHIEF'S DESK

SATISFACTORY means must be provided for making the necessary line and switchboard tests in toll as well as in local systems. There are two general methods of accomplishing this purpose; first, by means of a suitable testing equipment at the test panel; and secondly, by the use of an entirely separate equipment known as the "wire chief's desk."

The first of the methods above mentioned is nearly universal practice in offices of considerable size and this is especially true of the American Telephone and Telegraph Company's plant, since most of their lines are either composited, simplexed or phantomed. Special apparatus must be connected to the circuit when a telephone line is to be used for any of these additional purposes and this is best accomplished by wiring the line through special spring jacks provided for the purpose at the test panel. As this spring-jack equipment is essentially the same for line testing as for the latter purpose, it is undoubtedly better and more economical practice to do all testing at the panel. Some engineers maintain that the installation of a wire chief's desk, in addition to a test panel, is essential; but since the pioneer in this field, the American Telephone and Telegraph Company, has not adopted it to any extent, it will be best to examine the question carefully in the light of individual requirements. Telephone companies whose lines connect only the smaller towns and on whom the demand for morse service is very limited, do not require a morse panel. The wire chief's desk finds a proper and logical place in these offices, for there the desk serves the double purpose of a testing equipment and a morse panel, as the amount of telegraph work is so limited that it can be handled readily by the wire chief personally.

The wire chief's desk should be located in a position that will make the distributing frames and the other apparatus in the terminal room as accessible as possible, thereby reducing his work to a minimum. It is also very essential that the toll equipment be wired so that the wire chief can readily and speedily connect his testing apparatus to any toll line entering the office. In toll work this is accomplished in two ways. The first and most satisfactory method is to multiple the toll lines through the desk by means of cut-off jacks, which concentrates all the lines at this point; the second method employs direct trunks to the toll board and the test panel. The first method adds additional line resistance by virtue of the cable necessary to wire the lines to and from the desk, and further, the additional jack contacts increase the probability of trouble. The second method is slow because the wire chief must procure the aid of an operator in setting up a test connection. However, in all but the larger exchanges, one person can readily handle all panel connections in addition to making the usual tests; and, therefore, it is much more convenient in such cases to have the combined equipment.

The testing equipment furnished for a wire chief's desk is practically identical with that furnished at the test panel; but the arrangement is not the same and the circuits are different due primarily to the fact that more attention is given to making satisfactory tests of the office equipment.

The more important circuits furnished at the desk are the testing cord, which is equipped with the necessary keys, voltmeters and morse instruments for making all tests incidental to the proper maintenance of the toll lines; the trunks to the toll boards, terminating at that point in cords and plugs, so as to furnish ready means for testing through the toll board; and similar trunks wired to the arrester side of the main distributing frame, for testing in or out. Lines to the other desks in the office should also be furnished.

The design of the various desk circuits is dependent, to some extent, on the type of circuits used at the toll board; but the ultimate results to be accomplished are identical in any case. Flexibility in these circuits is of paramount importance; a desk may be equipped with the best of testing instruments and other apparatus, and yet the wire chief may find it practically impossible, or at least extremely awkward, to make certain tests, because of the faulty circuit design. The circuits which are shown in the following diagrams are designed to operate in conjunction with a lamp signal switchboard. These circuits can be adapted, with but slight changes, to any type of board, the lamp signal equipment being chosen for illustration because it represents the best and most modern toll practice.

The desk wiring of a toll line is shown in Fig. 78. It will be observed that the line is wired direct from the main distributing frame to a pair of cut-off jacks 1 and 2 at the desk and is then looped to jacks 3 and 4; from there it is cabled to the intermediate distributing frame, and then cross-connected to the switchboard terminals. The reason for connecting the jacks as shown will be given with the narrative of operation of the testing circuit. Many schemes of wiring the line circuit have been devised. Another method is to carry the lines from the main distributing frame direct to the intermediate frame, from which point they are looped through the desk. The object of the latter arrangement is to provide means for cutting the wire chief's loop out of circuit. This is readily accomplished by switching the jumper wires at the intermediate frame direct to the switchboard terminals, in place of the desk terminals. The advantage of this scheme comes into play when trouble develops in the cable or jacks in the desk loop; but since the probability of this is extremely rare in so simple a circuit, it is doubtful whether this wiring is a profitable investment. Furthermore, the additional cable required for this wiring increases the line resistance to some extent, and this is objectionable in case no direct benefit results. One of the fundamental principles of toll board design consists in keeping the office resistance of the line as low as possible.

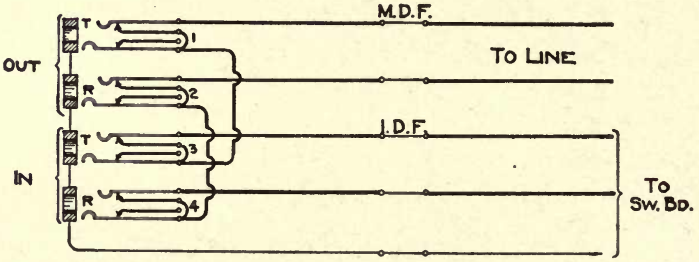


Fig. 78. — Wiring of Toll-line Circuit at Wire Chief's Desk.

The jacks shown in Fig. 78 can be arranged in the desk in two general ways. The first of these methods is to place the four jacks associated with any one line in a vertical row. These jacks are usually mounted twenty per strip, four strips being used for each twenty lines. This arrangement of jacks and the general face equipment of a one-position desk are shown in Fig. 79. The second method of jack

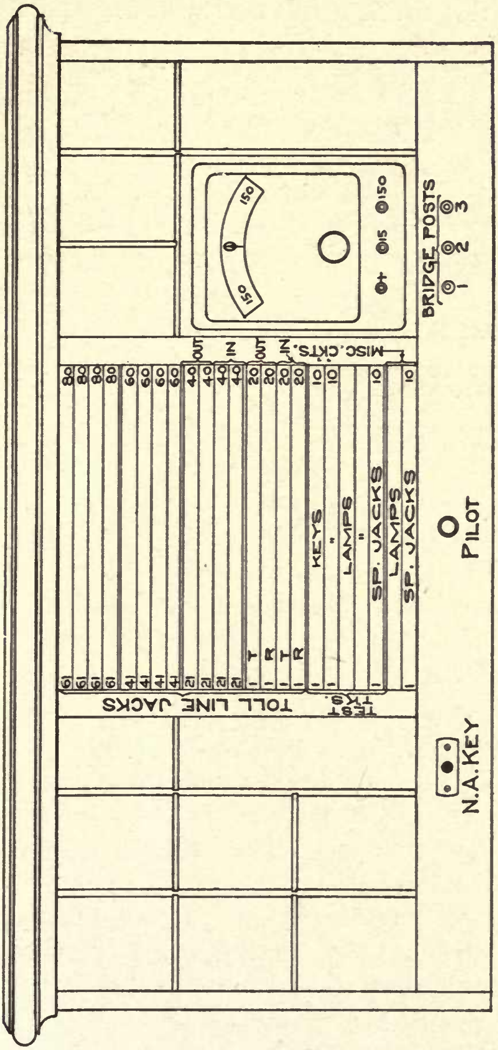


Fig. 79. — Face Equipment of a Wire Chief's Desk.

arrangement is shown in Fig. 80, in which the jacks are mounted in pairs. Both methods are in general use and there is very little choice between them.

Reference will now be made to the testing circuit shown in Fig. 81. At first glance this circuit will appear rather complicated; but upon closer investigation, it will be observed that it is composed of several simple circuits, combined for convenience in operating and for the greatest possible reduction of the amount of equipment required. The operation of this circuit is briefly as follows. When the wire chief desires to make a test on a toll line, he will insert the tip and ring plugs of the test circuit in the corresponding pair of "in" and "out" jacks which are shown in Fig. 78; the latter circuit will have to be referred to in conjunction with the test circuit to get a clear understanding of the operation. It is immaterial which pair of jacks is used with this test, as means are provided in the testing circuit itself to switch the testing apparatus to the line or to the switchboard. In what follows it will be assumed, for the sake of clearness, that the plugs have been placed in the pair of "out" jacks. The insertion of the plugs in the jacks will not open the line, since

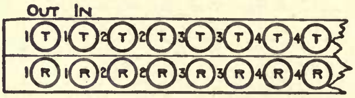


FIG. 80. — Arrangement of Jacks at Wire Chief's Desk.

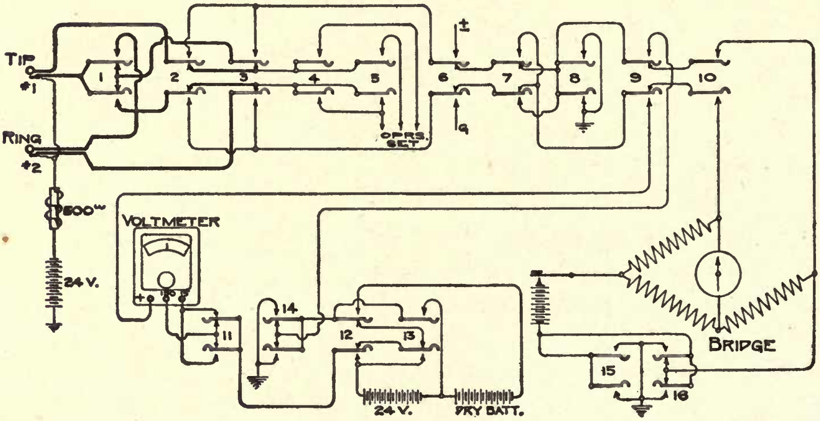


FIG. 81. — Wire Chief's Testing Circuit.

the tip and ring conductors of each plug are normally connected by means of the key wiring in the test circuit. These connections, for each plug, can be traced from the tip of the plug through the lever and break springs of key 2, then successively through the same springs of keys 3 and 1, and thence to the ring conductor of the same plug. Thus far the test circuit merely fulfills the functions of the local contacts in the line jacks themselves, but the wire chief may now connect his telephone set across the line, by the operation of key 5, and thus determine whether or not the line is busy. This is accomplished, as will be evident from what has preceded, without in any way disturbing the service; and it also provides a ready means of determining the actual working conditions of the line. If the wire chief, upon bridging his telephone set across the line, finds it not in use, he can proceed with the test without fear of being disturbed from the switchboard end, since the insertion of the test plugs in the line jacks will place battery on the sleeves; this will cause the operation of the cut-off relay in the line circuit, which in turn will close the circuit containing all the busy signals at the toll board.

The different keys in the testing circuit perform the following functions:

Key 1 converts the circuit into such form that tests can be made over the tip plug in conjunction with a testing trunk circuit which will be fully explained in what follows.
Key 2 switches the testing equipment to the " out " line.
Key 3 switches the testing equipment to the " in " line.
Key 4 is the regular listening key.
Key 5 is utilized in listening-in on a line quietly, as previously explained, that is, without battery.
Key 6 is employed when it is desired to place ringing current on the line.
Key 7 provides means for reversing the tip and ring sides of the circuit, so that either side of the line may be tested readily.
Key 8 is used in connecting ground to one side of the circuit.
Key 9 switches the voltmeter into the circuit.
Key 10 connects the bridge to the line.
Key 11 switches the circuit from the high to the low scale of the voltmeter.
Key 12 connects the high-voltage battery into the voltmeter circuit.

Key 13 connects the low-voltage battery into the voltmeter circuit.

Key 14 grounds one side of the voltmeter circuit.

Keys 15 and 16 are used in performing certain bridge tests.

The numbers used in designating the various keys do not indicate that they are grouped in that particular order in the desk, but have been used merely to aid the explanation. The keys of a testing circuit should be so arranged as to best facilitate the work of testing. For example, the keys associated with the voltmeter circuit should be grouped together, and those used in the bridge test should form another group.

The voltmeter shown in the circuit is almost always permanently mounted in some convenient part of the desk, and is usually placed either in the jack panel or in the space immediately to one side of this panel. A portable type of instrument is often used for the purpose; and as these instruments are usually calibrated for horizontal operation, it is imperative to specify that they shall be calibrated for vertical mounting, when placed as indicated in the face equipment shown in Fig. 79. The instrument best suited for this work is one with a double scale, which gives a wide range with accurate readings. It is also convenient to have a meter that reads in each direction from zero, which often prevents a bent needle; this also makes the operation faster, since no care need be exercised in connecting the proper polarity to the instrument. A meter having a double scale of 15–0–15 and 150–0–150 has been found quite satisfactory for this class of work; but some prefer an instrument with a higher scale, such as 30–0–30 and 300–0–300.

The bridge used with the test circuit should be of the portable type, as there is no convenient place in the desk for mounting it permanently. When required in making a test, it can be placed on the top of the desk and connected to the binding posts, which are shown on the face equipment in Fig. 79. These posts may be mounted either on the key shelf or in the face of the board below the voltmeter. A drawer in the lower part of the desk is frequently designed for storing the bridge when not in use. Some wire chiefs prefer to have the bridge permanently wired and placed on a separate table, so that no time will be wasted in putting it into service.

Another convenient method of mounting the bridge is to build a shelf at the right-hand end of the desk, about six inches below the surface of the key shelf. This keeps the instrument within easy reach of the operator and at the same time out of the way.

Another testing circuit which is usually installed in the wire chief's desk is shown in Fig. 82. This circuit is used for making preliminary tests, such as determining whether a line is grounded, open or crossed. The test plug 1 shown in this circuit is used only when a test panel is installed in addition to a wire chief's desk. The function of this plug is to connect the wire chief's morse equipment to any leased wire or telegraph line at the test and morse panel. Thus, when keys 1, 2 and 3 are operated, the apparatus connected to the test plug will be directly in series with the wire chief's morse set. This circuit can be traced from the tip of the test plug, through the make contact of key 3, to telegraph relay *R*, thence through the telegraph key and the make contact of key 1 to battery; while the ring side of the plug can be traced to the second make contact of key 3 and then through the make contact of key 2 to ground. The tip and ring plugs 1 and 2, respectively, are used for line tests at the wire chief's desk. When these plugs are inserted in the respective tip and ring jacks of a toll line, the preliminary tests for a ground, an open or a cross can be made as follows. Key 3 remains in its normal position. Then if key 1 is operated, the current will pass to the tip line wire by means of the following circuit: from battery to the make contacts of key 1, through the telegraph key and relay *R*, to the tip plug, out on the tip of the line, returning by means of the ring of the line, through the break contact of key 3, to the make contacts of key 2, and thence

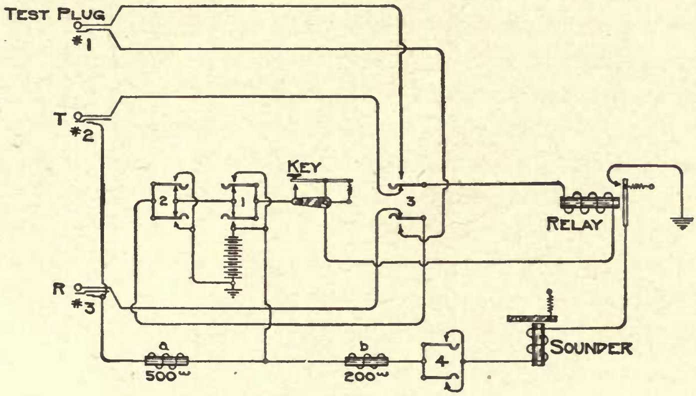


FIG. 82. — Circuit for Preliminary Tests.

to the open break contacts of key 1. It must be evident, therefore, that if a ground exists anywhere on the line, the telegraph relay *R* will be energized, thus indicating the condition to the wire chief. In the test for an open circuit, keys 1 and 2 are both actuated; this will complete a circuit from battery through the telegraph relay *R*, to the tip of the line and thence back over the ring of the line to ground. Then, if the line is open, the telegraph relay will not operate. In case a lineman has been sent out to clear the trouble and has opened the circuit at the distant end, the actuation of the telegraph relay will indicate that the line wires are crossed. It might be well to explain that the resistance coil *B*, which is in series with the sounder, is furnished merely to cut down the flow of current, thereby avoiding the necessity of a low-voltage battery.

Thus far no circuits have been shown by means of which tests can be made directly from the toll board. However, it is often quite advisable to test out a toll line from the switchboard; and it is also convenient at times to trunk the wire chief's test circuit, shown in Fig. 81, to the toll board, so that all switchboard apparatus will be accessible to the testing circuit. This is accomplished by means of the testing trunk shown in Fig. 83. These trunks terminate at the toll board in cords and plugs; and the plugs are so placed that they can be inserted easily in the last multiple jack of any line, thus enabling the wire chief to test the line throughout the entire multiple.

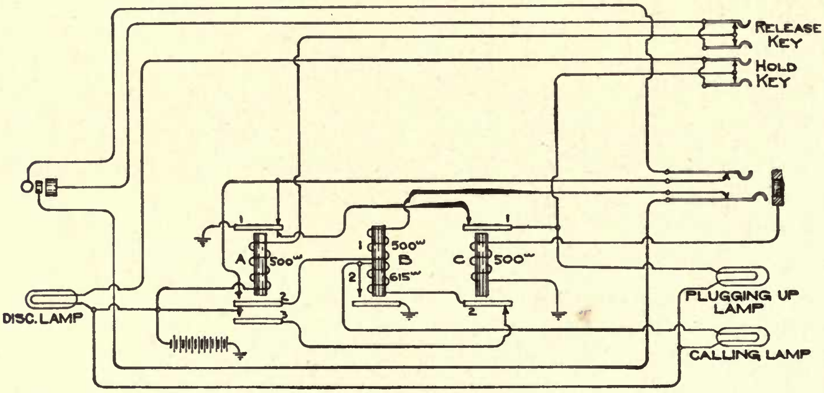


FIG. 83. — Wire Chief's Testing Trunk.

The operation of this test trunk may be outlined as follows. Whenever any operator discovers a line in trouble, she will immediately report it to the supervisor or the chief operator, who in turn will fill out a "trouble slip" and send it to the wire chief. At the same time she will order the plug of one of the testing trunks inserted in the last multiple jack of the line in trouble. The insertion of this plug will complete a circuit which is traceable from battery through the coil of relay *A* and the springs of the release key, to the sleeve of the plug, thence to the sleeve of the line jack and through the cut-off relay to battery. The closing of this circuit will cause the operation of relay *A* in the trunk and the cut-off relay in the line circuit. The operation of the latter will actuate all the busy signals associated with this line. The actuation of relay *A* will complete two circuits: first, one from ground to the armature of the relay, then by way of the break contact and the armature of relay *C*, through the "plugging up" lamp and thence to battery; second, a circuit from ground by way of armature 1 of relays *A* and *C*, through the springs of the holding key and the disconnect lamp to battery. The completion of these two circuits will light the disconnect lamp at the toll board and the "plugging up" lamp at the wire chief's desk. The wire chief, upon seeing the lighted lamp, will insert the tip testing plug of the test circuit (shown in Fig. 81) in the jack associated with the lamp. This will close a circuit which is traceable from the battery connection on the sleeve of the test plug, to the sleeve of the trunk and then by way of the coil of relay *C* to ground. Thus relay *C* will be energized and the attraction of armature 1 will open the two lamp circuits just traced, extinguishing the signals. The wire chief will now actuate key 1 of the testing circuit, which will disconnect the tip and the ring strands of the cord from each other and switch them direct to the tip and the ring conductors of the test circuit. The wire chief will then make a preliminary test and in case he finds the switchboard end clear, with trouble out on the line, he will operate the holding key and withdraw the test plug from the jack. The operation of the holding key will open the disconnect lamp circuit, previously described, and consequently prevent the re-lighting of the lamp. The "plugging up" lamp at the desk will re-light, however, due to the fact that the withdrawal of the test plug will open the circuit through relay *C*, thus releasing armature 1 of the relay and thereby closing the circuit through the lamp. The reason that this lamp is kept in a lighted condition is to remind the wire chief that a circuit is up for test. The lineman can readily call the wire chief on this line by ringing across the circuit with a standard test set. The alternating impulses generated by the test set will seek a path which can be followed from the ring of the line to the ring of the test cord and plug, through the break contact in the jack at the desk, through winding 1 of relay *B*, thence by way of armature 2 and the make contact of relay *A*, to the tip break contact in the desk jack; from there it can be traced to the tip of the test cord and back over the tip of the line. The alternating current which flows in the circuit just outlined will cause the operation of relay *B*, which will lock. This locking circuit can be traced from the ground on the armature of the relay, through winding 2, then by way of the break contact and the armature 2 of relay *C*, to armature 3 and the make contact of relay *A* and finally to battery. The attraction of the armature of relay *B* will also close the circuit through the calling lamp, thereby attracting the attention of the wire chief. Relay *B*, when once operated, will remain energized until released by the wire chief. This may be done by actuating the release key, which will open the circuit through the coil of relay *A*; the release of this relay will, in turn, release relay *B*, at armature 3 of the former. The locking circuit will likewise be opened when the wire chief plugs into the test jack, since this operation will energize relay *C* and open the circuit at armature 2. The latter is the usual method of extinguishing the calling lamp, since it places the wire chief in communication with the lineman. The former method is installed for auxiliary purposes only. When the trouble is cleared, the wire chief will remove the test plug and restore the holding key to normal, thereby lighting the

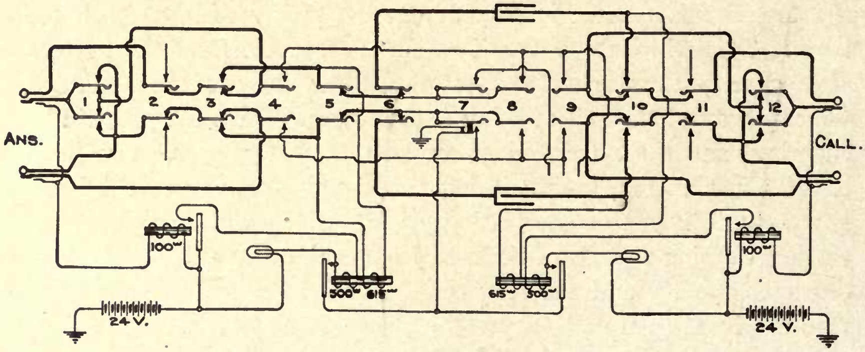


FIG. 84. — Wire Chief's Cord Circuit.

disconnect lamp at the toll board. The operator in charge, upon seeing the lamp, will remove the trunk plug and thereby restore all the apparatus to its normal condition.

Oftentimes the wire chief will have occasion to interconnect two lines, and for this purpose the desk should be equipped with one or two connecting cords. The cord circuit should embody, among others, the features which are peculiar to the wire chief's equipment alone. These features can be observed by referring to the circuit shown in Fig. 84 and comparing the plug arrangement at each end of this circuit with that shown in the testing circuit in Fig. 81. It will be noted that they are the same, that is, they are so connected normally that they can be inserted into the line jacks without disturbing the line continuity. When the board is provided with audible

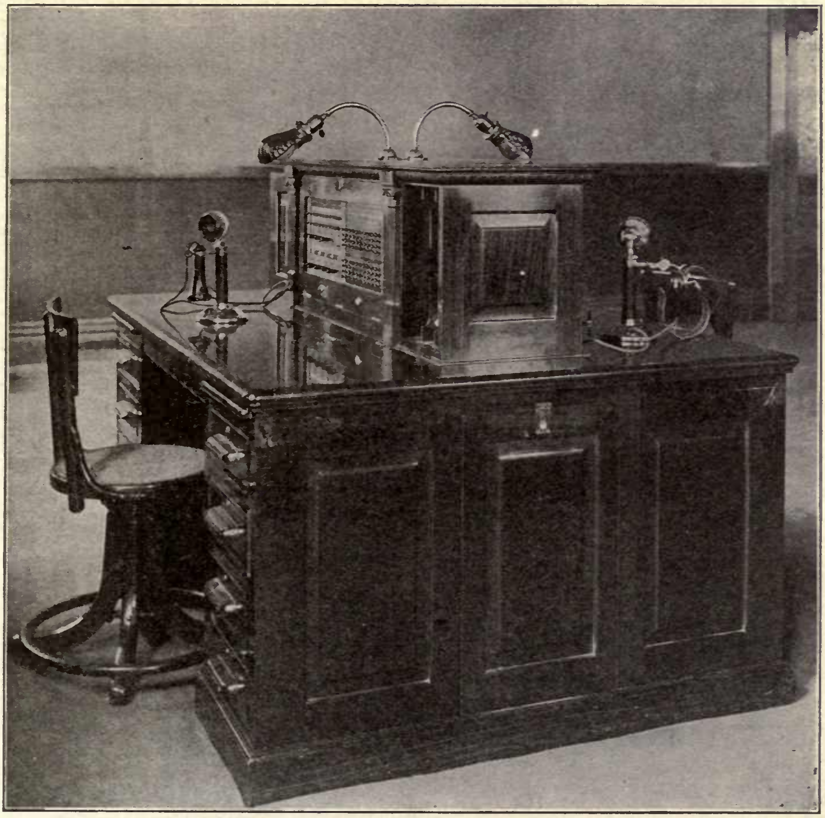


FIG. 85. — Two-position Toll Wire Chief's Desk.

instead of visual busy signals, this arrangement is not required, because the wire chief can test the line before plugging in, to determine whether or not it is busy.

After determining that the line is idle, the wire chief will operate keys 3 and 10, which will connect the cords at each end of the circuit. This connection is practically the same as a connection put up at the toll board and the disconnect signals are obtained in the usual manner. The principal use for a circuit of this kind is to get a call through from the line to the toll board, when the line circuit between the desk and the board is out of order. The wire chief may also use this circuit for talking to his men on lines which have been plugged up for test.

For the convenience of the wire chief in reaching the operators at the toll board, or the chief operator, and *vice versa*, it is customary to provide several trunks for intercommunication; a very satisfactory plan is to multiple the inter-position trunks through the wire chief's desk. The wire chief's telephone set, pilot and night alarm circuits are essentially the same as those used at the standard line position. The general arrangement of apparatus at a wire chief's desk can be readily observed from the two-position desk shown in Fig. 85.

CHAPTER XII

SIMPLEX SYSTEMS

THE economy of a wire plant which results from the ability to transmit telephone and telegraph messages simultaneously over a single circuit is of the greatest importance commercially. The added cost of apparatus in systems for simultaneous transmission is insignificant compared with the added revenue. Such apparatus has been used most extensively in toll systems, in which the derived telegraph circuits have been leased largely for private use.

The demand in this country for private telegraph circuits, or leased lines as they are called, is considerable. They are employed by stock and grain brokers very extensively and often by large industrial concerns who have offices or plants at different localities. They are also employed by the wire companies themselves for the transmission of company business and sometimes as an aid in handling toll telephone traffic.

There are two systems of simultaneous transmission in common use, the simplex and the composite systems. The simplex system secures the transmission of one telephone message and one telegraph message over one pair of wires. The composite system secures the transmission of one telephone message and two telegraph messages over one pair of wires. The former is virtually a phantom circuit scheme, but the latter is fundamentally a system of simultaneous transmission over the same wire without interference.

Theory. — In opening the discussion of the simplex system, it is considered expedient to show first a skeleton circuit illustrating the theory of the scheme or method. This circuit is shown in Fig. 86 and it will be observed readily that the principle taken advantage of is that of the wheatstone bridge principle. This circuit shows only the morse equipment, with the usual apparatus at each terminal. Such telegraph circuits, as will be noted, take the place of the battery in the wheatstone bridge, while coils X, Y, X' and Y' constitute the four arms of the bridge. Leads a and b are the line wires and since for all practical purposes the resistances of these wires can be kept so nearly alike as to prevent any perceptible unbalance, a galvanometer placed as shown will always indicate a balanced condition, *i.e.*, two points on the line wires equally distant from the office will be at equal potential and consequently no current will flow through the galvanometer. Therefore, when keys *K* and *K′* are closed, a current will flow from battery *B′* through the key contact and relay *R′* to *Z′*; at this point the current divides, half of it traversing the upper bridge arm and the other half the lower arm, to the point *Z*, at which junction the currents unite and flow through relay *R*, through the key to battery *B* and back through the earth to battery *B′*. The path of the current can be traced readily with the aid of the arrows in the figure.

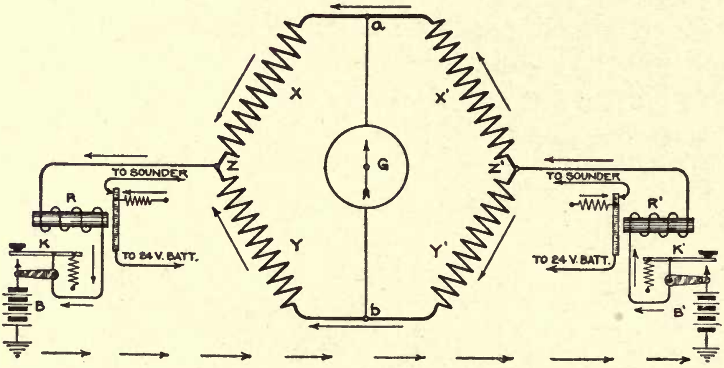


FIG. 86. — Theoretical Diagram of a Simplex Circuit.

Repeating Coil Method. — These conditions may be embodied in a telephone line as shown in Fig. 87, which represents a standard simplex system using the repeating coil method. It will be noted that either telephone jack is wired direct to one winding of a repeating coil, the opposite winding being carried to the line wires; consequently the telephone talking circuit is identical with that ordinarily used in toll work in connecting grounded lines to metallic lines. The telegraph circuit is connected to the middle points of windings 2 and 2′ of the repeating coils *A* and *A′*, respectively; and thereby the balanced wheatstone circuit is established. The toll circuit will therefore be balanced at all times as regards the telegraph current. It should be noted further that the additional resistance inserted into the telegraph circuit due to the windings of the repeating coils is quite immaterial, since the two line wires are connected in parallel and consequently the line resistance is cut in two. Furthermore, since the telegraph circuit is connected to the middle of either repeating coil winding, the current will divide equally and flow from the center toward each end; thus these halves of the coil will act non-inductively, since the mutual inductance neutralizes the self-inductance. It will be observed that each telegraph key is shunted with a condenser, the object of which is to take up the spark at the key contact. This naturally saves considerable wear and tear at the key contacts. It might be well to state that it is also the practice in some cases to shunt the relay, as well as the key contact, with this condenser. When this is done, however, it makes the relay action sluggish, although it reduces to a greater extent the inductive kick on the line, due to the magnetic energy stored in the telegraphic relay.

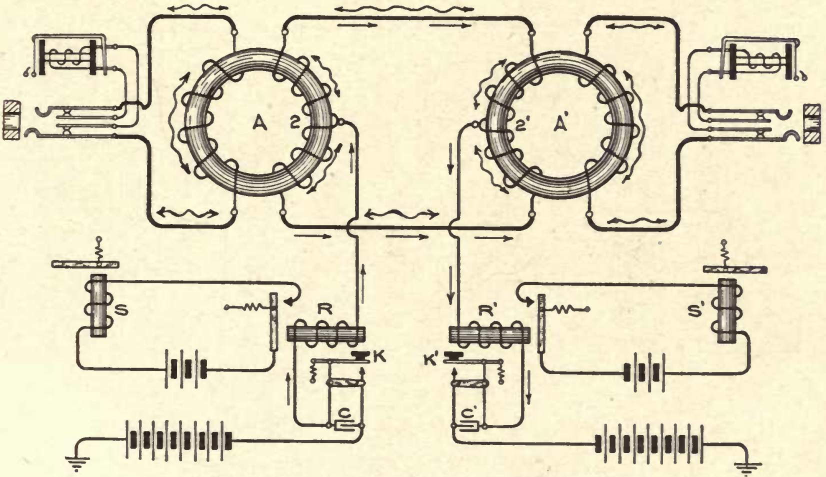


FIG. 87. — Simplex Circuit, Using a Repeating Coil.

The paths of the telephone and the telegraph currents can be followed easily in Fig. 87, by means of the arrows. The wavy arrows indicate the telephone current and the straight arrows the telegraph current.

Retardation Coil Method. — There is another method by which the same results can be obtained with the use of retardation coils in place of repeating coils. Fig. 88 shows a standard simplex circuit utilizing the retardation coil method. These coils usually contain two parallel windings upon a very heavy iron core. The core is made of soft iron wire which is either bent back from the ends of the coil so as to meet in the middle (on the outside), thereby making a closed magnetic circuit, or the wires may be formed into a ring. The latter coil is known as the toroidal type. A closed magnetic circuit is desirable in order to give a maximum impedance and a minimum shunting effect on telephonic transmission.

By referring to the figure it will be observed that the telegraph circuit is tapped from the middle of the winding of the retardation coil in the same manner that this circuit was attached to the winding of the repeating coil in the previous case; the coil is then bridged directly across the line. The telephone circuit is protected from the telegraph pulsations by the condensers placed in each side of the line. Since a fair rate of speed for hand sending is twenty-five words per minute, which would mean about five dots and spaces per second, the condenser impedance will be very high and will greatly diminish the impulses passing to the telephone circuit. However, since the average frequency of telephone currents amounts to about eight hundred cycles per second, these condensers will then offer a relatively low impedance. The retardation coil, on the other hand, offers a very great impedance to such a frequency and thus the efficiency of telephone transmission is but little impaired. The paths of the telephone and the telegraph currents in this circuit can be followed easily by the arrows, the notation of which in all cases will be the same as that used in the previous case, *i.e.*, the straight arrow for telegraph currents and the wavy arrow for telephone currents.

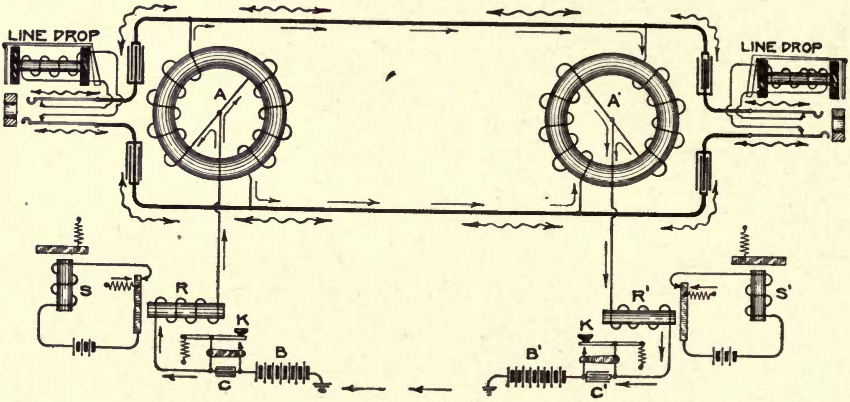


FIG. 88. — Simplex Circuit, Using Retardation Coils.

There are advantages to be claimed for either of the above systems and the most important of these may be enumerated as follows. In the first place, the retardation coil system is cheaper to install and the efficiency of the talking circuit is not reduced to the extent that it is in the repeating coil system, with the repeating coil losses. This is due to the fact that these repeating coils must be designed for transforming both voice currents and ringing currents, and consequently are not built to give a talking efficiency of the highest obtainable value. Therefore, when several of these repeating coils are placed in a long circuit, the voice transmission is very materially reduced. In the repeating coil system, however, no trouble is experienced in ringing with grounded generators, but such a generator used in connection with the retardation coil system will disturb all of the telegraph apparatus on the line. It might be said in general, that the repeating coil system is best adapted to short lines, while the retardation coil system may be used for lines of any length and is much superior for long lines with several intermediate telegraph stations.

It is frequently necessary to have an intermediate telegraph station where no telephone connection is needed, and *vice versa*. The simplex system is quite flexible in this respect and many combinations are easily arranged.

Fig. 89 shows an intermediate telegraph station in conjunction with a through telephone circuit; and several such stations can be worked in series on the same line. The general principles explained in connection with the circuit of Fig. 88, as regards the functions of capacity and inductance, are applicable in this case also and need not be repeated. The paths of the currents can be traced easily by means of

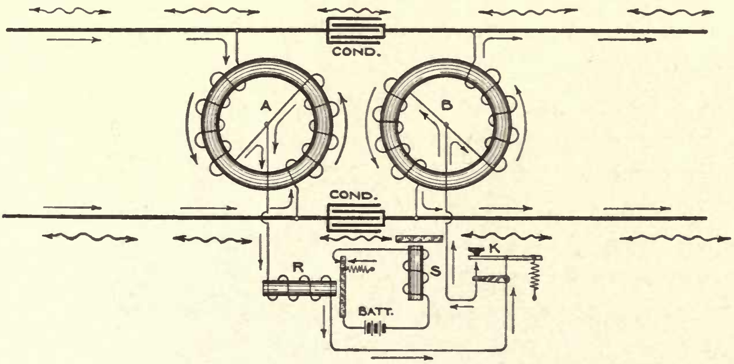


FIG. 89. — Diagram of an Intermediate Telegraph Station on a Simplex Line.

the arrows. Fig. 90 shows a through telephone circuit and two terminal telegraph stations; that is to say, each telegraph station operates independently of the other, while the telephone circuit is continuous. The principal difference between this and the circuit immediately preceding is that in Fig. 89 the operation of the telegraph key transmits the signals both ways, thereby actuating all the telegraph instruments on the line; while in Fig. 90 the operation of the telegraph key sends out an impulse in but one direction. This can be readily seen by following the arrows in the figure.

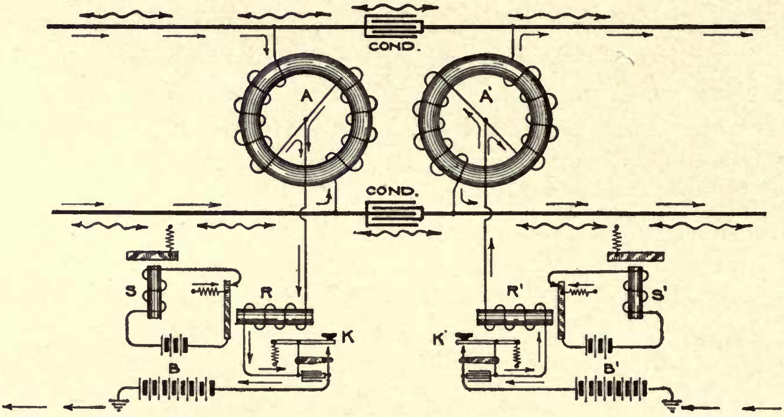


FIG. 90. — Diagram of a Terminal Telegraph Station on a Simplex Line.

In addition to the intermediate and terminal telegraph station there is the so-called telephone terminal station, which is illustrated in Fig. 91. This figure also shows the American Telephone and Telegraph Company's standard repeater circuit. This repeater circuit is used in long telegraph lines to boost the telegraph current, or rather to replace the distant battery by a new one at an intermediate station, thus working the long circuit in two or more parts, each part being energized by a distinctly separate set of batteries. A brief description of the operation of this repeater next follows.

It will be noted that the telephone connections in Fig. 91 are derived in the usual manner and that the telegraph circuit is looped through from the middle of repeating coil *B*, through the telegraph apparatus and thence to the middle of repeating coil *B'*. The flow of the currents may be traced by means of the arrows.

All the circuits in the repeater are normally closed as shown in the figure, but when the operator at the distant southern station opens his key, it will cause the release of relay *R′*, which in turn will de-energize coil *V′* of the telegraph transmitter. The two coils *H* and *H′* of the transmitter are normally short-circuited by the contacts *T* and *T′* of the transmitter armatures. Therefore, when coil *V′* of the transmitter is de-energized, it will cause the armature to fall back. This armature is pivoted at *X′* and is so arranged that in falling back the contact at *T′* is broken before the one at *Z′*. The breaking of the contact at *T′* removes the shunt around coil *H* and thus causes a flow of current through this coil by means of a circuit that can be traced from battery *A′*, through coil *N′*, thence by way of contact *T*, coil *H*, resistance *N*, battery *A* and finally to ground. Consequently the opening of the circuit containing relay *R*, at contact *Z′*, will not release the armature of the other transmitter. Thus each make and break of the key at the southern station will cause a corresponding make and break at *Z′*, and will thereby send out an impulse from the line battery at *B*, over the north end of the line.

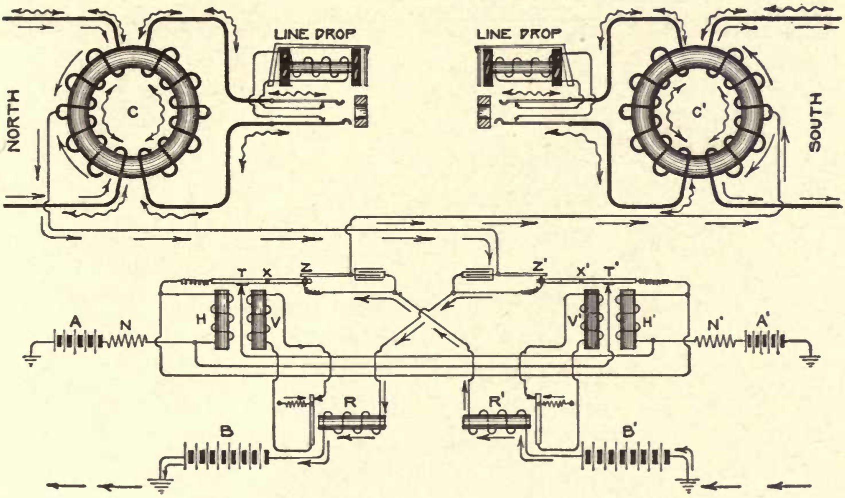


FIG. 91. — Terminal Telephone Station and Telegraph Repeater.

In case the operator at the northern station desires to signal the southern operator when the latter is sending, the former need only to open his key and then the following conditions will be established. As soon as the contact *Z′* closes, the short circuit on coil *H* will be re-established; but the circuit through relay *R* is open at the distant northern station, so that the armature of the transmitter will drop back and open the contact T. Thus coil H' is energized and will hold up its armature. The operator at the northern end is now in a position to communicate with the southern operator in a manner identical with that just described for sending messages in the opposite direction.

CHAPTER XIII

COMPOSITE SYSTEMS

By the method of simplexing it is possible to transmit a telephone and a telegraph message over one pair of wires simultaneously. The economy thus obtained is well worth having, but with the composite system it is possible to send simultaneously one telephone and two telegraph messages on the same pair of wires, the earth being used as a return for the telegraph circuits; or one telephone and one telegraph message if but one wire is used, in which case the earth is used as a return for both circuits. Thus it is possible, by the last method, to operate the very expensive toll lines at a telegraph efficiency which is 100 per cent higher than that obtained by simplexing; consequently if a telephone company can create a sufficient demand for telegraph service, there is an opportunity to largely increase the revenue per mile of wire. This arises from the fact that about 75 per cent of the total investment is in poles, cables, conduits and wires and, therefore, any additional expenditure on the terminal plant which will increase the earning power of the outside plant is a very profitable investment.

In the simplex circuit both of the telephone wires are operated in parallel for the telegraph or morse circuit, while in a composite system each line conductor constitutes a separate morse circuit. Consequently, with the composite system, mutual interferences between the telephone and the telegraph operation must be guarded against; and then there is the additional complication of possible interference between the two telegraph circuits, which is commonly known as "cross writing." There are several practical methods of compositing a telephone line, but the following method has been used with great success by the American Telephone and Telegraph Company. Fig. 92 shows an ordinary grounded telephone circuit composited for telegraphic service.

Grounded Composite System. — The retardation coils *A* and *A′* each consist of two windings whose total resistance is 50 ohms; they are wound on very heavy soft iron cores of the closed type. A coil of

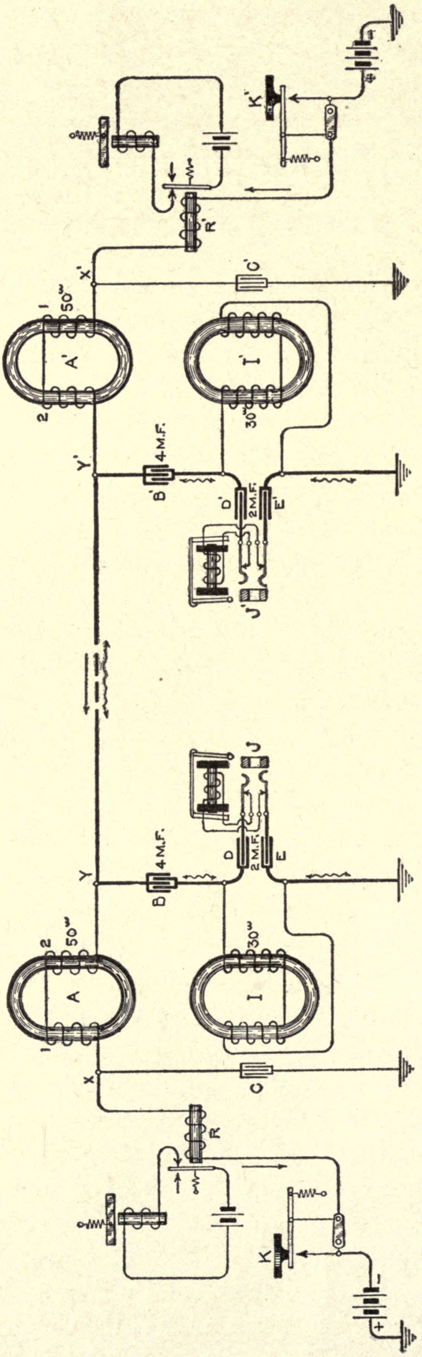


Fig. 92. — Grounded Line Composited for Telegraph Service.

this kind as used by the American Telephone and Telegraph Company is shown in Fig. 93. These windings are connected differentially, as shown in the circuit, and the action of such a coil is as follows: The direct or pulsating current of a low frequency, such as that produced by the manual operation of a telegraph key, the coil acts much like a non-inductive resistance, since the inductance set up in one-half of the coil is largely counteracted by that of the other half. However, with the high-frequency voice currents, the comparatively small inductance gives rise to a very large impedance, so that such currents scarcely penetrate the coils at all. This type of coil was developed experimentally and found to give satisfactory results, which seems to be the main reason for its use. There seems to be no satisfactory explanation from a theoretical standpoint for the adoption of this particular design. Coils *I* and *I'* are also composed of two windings and their total resistance is 30 ohms. These windings are likewise placed on a massive soft iron core of the closed type, but are connected in series, *i.e.* the windings magnetize the core in the same direction; and hence such a coil has a very large inductance. Since the remainder of the apparatus in the circuit is not of special design, we may now consider the operation of the circuit as a whole. In order that this description may be as simple as possible, the telegraph circuit will be traced first.

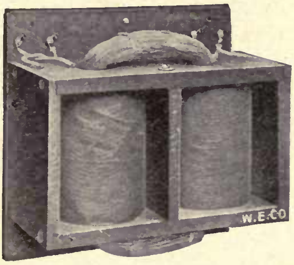


FIG. 93. — Retardation Coil Suitable for Composite Work.

The operation of writing at key *K* will send a pulsating current out on the line by way of relay *R* to the point *X*. At this junction, part of the current is required to charge the condenser *C* and the remainder traverses the coil *A* to the point *Y*. However, the joint action of condenser *C* and coil *A* on the telegraph current brings about very beneficial results, *i.e.* the otherwise abrupt changes in current and potential caused by the actuation of the telegraph key are made to take place more slowly. The current and potential here meant are those of the line, beyond the point *Y*. Fig. 94 shows the transformation of the rectangular wave of current when acted upon by capacity and inductances as explained. This action may be explained as follows: The depression of the key causes a heavy flow of current to the point *X*, where the coil *A* acts as a momentary barrier, and mean-while the condenser *C* will be charged; upon the opening of the key, the condenser *C* tends to discharge in the direction of the original current and to oppose the discharge from the line, thereby tending to maintain the flow of current and thus causing a more gradual decrease. Hence the combined action of the coil and the condenser prevents any very abrupt fluctuation of current in the line. The telegraph current has been traced to the point *Y* and from there it passes to the line. At the distant terminal it takes a similar path and actuates the relay *R′*. Should any of the telegraph current leak through condenser *B*, no material portion of it will reach the telephone, because the shunt path to ground through the coil *I* offers relatively much less impedance than the condensers *D* and *E*.

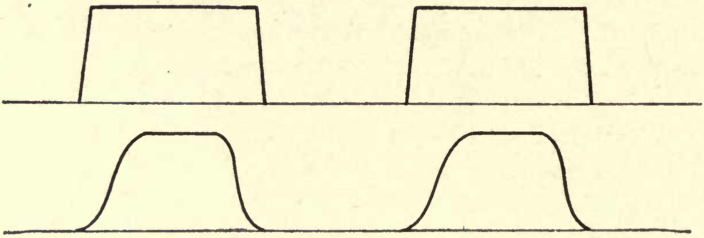


FIG. 94. — Wave Form of Telegraph Current in Composite Circuit.

Turning now to the telephone circuit, it is evident that the high-frequency voice currents will readily pass through the condensers *E*, *D* and *B*, and will be choked out of the telegraph circuit by means of the impedance coil *A*. The current will consequently flow over the line to *Y′*, where it is again choked out of the telegraph circuit by coil *A′* and will find a ready path through condensers *B′* and *D′*, the telephone instrument and condenser *E′* to ground. Thus the telephone current is kept out of the morse leg, and the telegraph current, in its turn, cannot interfere with the telephone circuit. The paths of the telephone and the telegraph currents can be readily traced by means of the arrows in the figure.

Metallic Composite System. — The principles made use of in compositing a grounded line, as explained above, are all applicable to the problem of compositing a metallic line, but in the latter case the possibility of cross writing must be carefully guarded against. The circuit of a composited metallic line is shown in Fig. 95. The arrangement of apparatus is very similar to that shown in Fig. 92. Since the apparatus, such as the retardation coils *A* and *I*, is identical with that

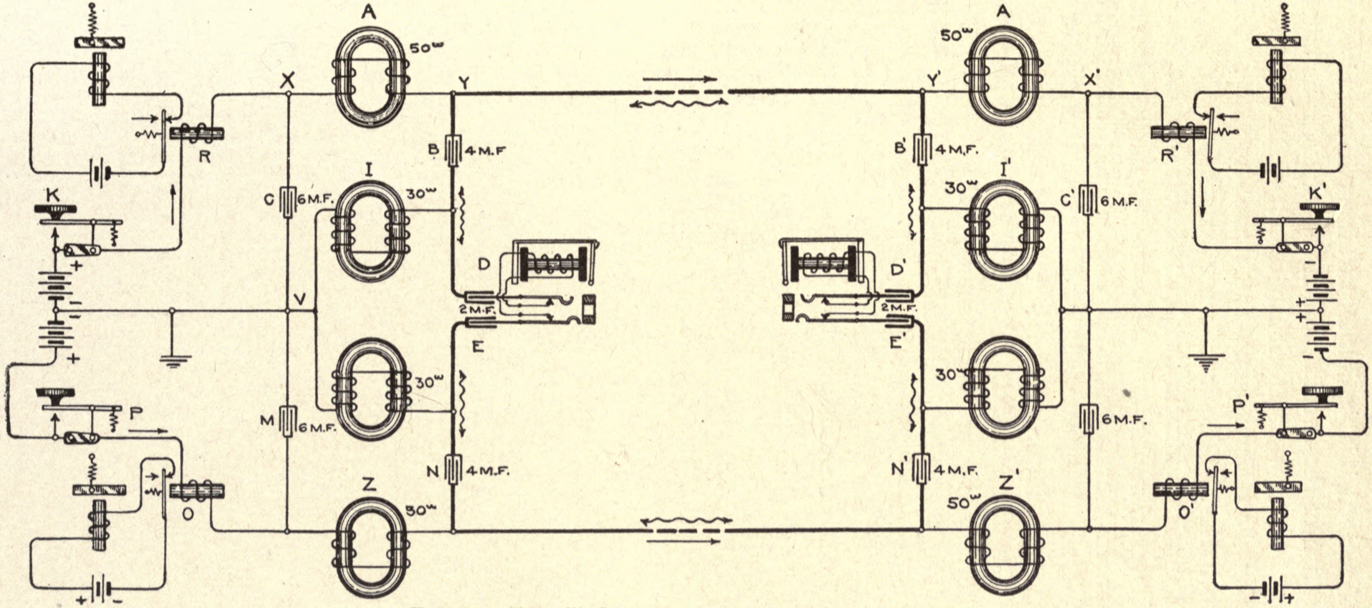


FIG. 95. — Metallic Line Composited for Telegraph Service.

previously described, it is possible to start immediately with a narrative of the operation of the circuit. When the key *K* is actuated, a pulsating current will flow, as previously described, through relay *R* and coil *A* out on the telegraph line, and thence by way of coil *A'* and relay *R'* to battery. The functions of condensers *C*, *B*, *D* and *E* and coils *A* and *I* are identical with those described for the grounded circuit. However, in this case there are two morse wires and these are interconnected through each telephone drop. In sending on either morse circuit, slight impulses will pass through the drop or the telephone to the opposite morse circuit unless means to prevent this are provided. The function of the coils *I* and *I'* is to minimize or prevent this cross writing, by providing shunt paths to ground for these impulses. The operation of the telephone circuit is practically the same as that described for the grounded system, the ground return being replaced by the second morse wire. In passing it might be well to add that for the most satisfactory operation of the telephone circuit, the condensers *B*, *B'*, *N* and *N'* should be limited in their capacity, four microfarads as indicated in the circuits shown in Figs. 92 and 95 giving very satisfactory results. Although it is a well-established fact that as the capacity of a condenser is increased, the efficiency with which it will transmit voice current is likewise enhanced, the limit to which the capacity of these condensers may be raised is soon reached. This is due to the fact that, as the potential of the telegraph line rises and falls with the make and break of the telegraph key, a very noticeable disturbance will be created in the telephone circuit by the greater charging currents in the condensers. There is a circuit in use giving very satisfactory results, in which the condensers *D* and *E* have been entirely omitted; in this case the capacity of *B* is reduced to two microfarads. The capacity of condenser *C* varies from six to twelve microfarads.

The most serious objection to the composite circuit arises from the fact that it contains so much capacity to ground. These condensers must be fully charged before the telegraph current on the line can attain its maximum value; and hence the telegraph relay will not respond instantly to the touch of the key. This condition is rather detrimental when very fast sending is being done, but for ordinary work the operation of the circuit is quite satisfactory.

Composite Ringer. — An apparent objection to this system arises from the fact that the ordinary telephone generator cannot be used

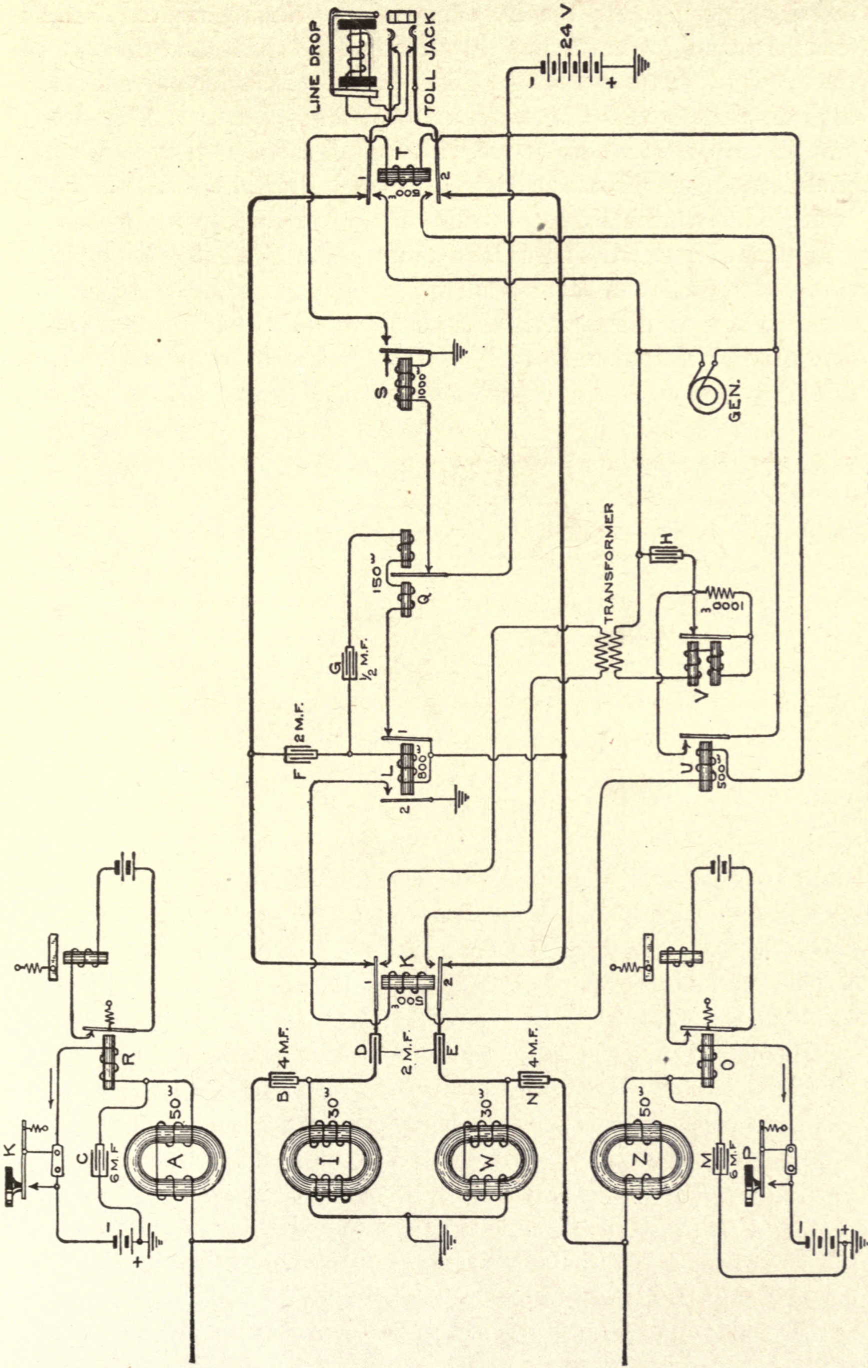


FIG. 96. — Method of Ringing on Composite Line.

for signaling, because the frequency of the ringing current is low enough to find a path through the coils A, A', Z and Z' and thus cause the telegraph relays to chatter. This difficulty is avoided by a special composite ringer which is shown in Fig. 96. In this circuit the telegraph apparatus for each morse wire and all the necessary telephone equipment is shown, but the description will be limited to the operation of the ringing mechanism. In this circuit there are several pieces of apparatus of special design which require description before the operation of the circuit can be understood.

Relay *L* is so designed that it will be actuated by an alternating current of low frequency such as that generated by the ordinary ringing dynamotor. The construction of this relay is shown in Fig. 97.

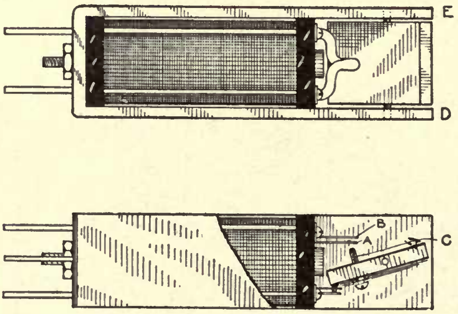


Fig. 97. — Low-frequency Alternating-current Relay.

This drawing shows the top and side views of the relay. It will be noted that the armature is very massive and heavy, and its inertia is sufficient to hold it in place when once attracted, even though the magnetizing current is alternating and of low frequency. The contact springs are long and very flexible, and although the armature has a tendency to vibrate slightly, the resiliency of the springs will prevent the opening of the local contacts. The break contact is held in place by the weight of the armature; a rubber bushing imbedded in the armature normally rests upon the upper spring of this pair of contacts. The make contact is actuated when the armature is drawn up, due to the fact that the insulated tip of set-screw *C* forces spring *A* into contact with *B*. The magnetic circuit of the relay can be traced from the core of the coil, through the armature and thence through the two metallic sides *D* and *E*, to the front of the core. Therefore, as soon as sufficient magnetic energy is set up in the core of the coil, the armature will be raised to a horizontal position, reducing the air gap to a minimum.

Another piece of ingenious apparatus is the high-frequency alternating-current relay *Q*, which is designed with a small inertia of the moving parts, so as to respond to comparatively weak alternating currents of high frequency. This relay is shown in Fig. 98. The design is a radical departure from ordinary methods, and the principle upon which it operates is similar to that of a polarized bell. The permanent magnet *A* energizes the cross piece *D*, thereby producing a pole of the same polarity as that of *A* in the cores of coils *B* and *B′*, by means of the paths through the supports *G* and *G′*. At the other end of the magnet *A* the reed *F* is magnetized through the support *H*, and hence the polarity of the reed at the coil end will be opposite to the induced polarity in the cores before mentioned. The reed is adjusted with a slight normal bias to give a firm closure of its local contacts. The coils *B* and *B′* are so connected that they produce magnetic poles of opposite polarity. It follows that an alternating current during a given half cycle will strengthen one pole while it weakens the other and during the next half cycle will reverse its effect. The resultant field will cause the reed to vibrate synchronously. This reed *F* is a stiff steel spring whose natural period of vibration is relatively high. Directly above this reed is another reed *C* of light non-magnetic material, which makes contact with reed *F* at point *Z*. The operation of the relay may now be explained as

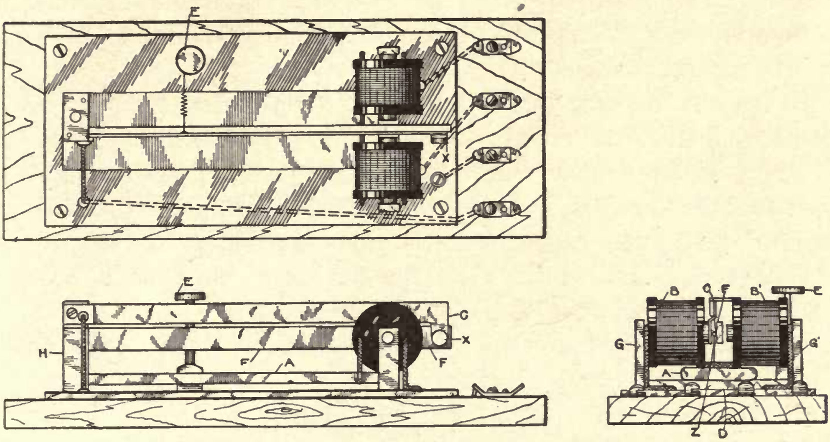


Fig. 98. — High-frequency Alternating-current Relay.

follows: When an alternating current of high frequency traverses the coils *B* and *B′*, the reed *F* is set into synchronous vibration; in its movement it will strike reed *C*, whose action is comparatively slow. The rate of vibration of reed *C* is retarded by the lead weight *X* which is placed at the contact end of the reed. Under these conditions the contact *Z* is closed but a very small fraction of the time and for all practical purposes is open. The adjustment of the relay is accomplished by means of thumbscrew *E* and the associated spring, which control reed *C*.

When the toll operator wishes to ring over the line her procedure is not different from ordinary ringing, which is already very familiar. The usual operation causes the low-frequency ringing current to flow out over the tip of the jack to the armature of relay *T* and thence by means of the break contact 1 to the tip of the line, condenser *F*, the coil of relay *L* and the ring of the line to the break contact 2 of relay *T* and back to the ring of the jack. No appreciable portion of this current will flow through the shunt path offered by condenser *G* and the high-frequency relay *Q*, since this condenser has a capacity of only one-half microfarad and therefore offers a very high impedance at the ringing frequency. Due to the completion of the circuit just outlined the slow-acting alternating-current relay *L* will be actuated. The attraction of armature 1 will open the shunt path around relay *L* through the high-frequency relay and, consequently, the small component which flows through the shunt circuit will exist only momentarily. The attraction of armature 2 of relay *L* will complete a circuit which may be traced as follows: from the ground on armature 2 of this relay, by way of the make contact, to the coil of relay *K* and thence through the coil of relay *U* to battery. Thus relays *K* and *U* will be energized. The attraction of the armature of relay *U* will close the following circuit: from the ringing dynamotor to the armature of the same relay and thence by way of the make contact to the make contact and the armature of the high-frequency vibrator *V*, through the coils of the latter and then by way of the primary of the transformer back to the generator. The completion of this circuit will energize the coils of the high-frequency vibrator, which is self interrupting.

It will be noted from the above description that the high-frequency vibrator is in fact nothing more or less than a buzzer-like contrivance for furnishing a current of such high frequency and small amplitude that it will not affect the telegraph instruments. It will be further observed that the armature and make contact of the vibrator are shunted by a noninductive resistance of 1000 ohms, the object of which is to reduce sparking at the contacts. This resistance is purposely made so high that the vibrator armature will release freely. The vibrator is designed to furnish about twenty interruptions or cycles for each cycle of the ordinary ringing current. Thus the frequency is in the vicinity of 300 cycles per second and will not interfere with the operation of the telegraph apparatus on a composited line. The function of the condenser *H* is to increase the amplitude of the secondary E.M.F., which it does by facilitating the discharge of the magnetic energy of the vibrator and the primary of the transformer. It will be obvious that as long as relay *U* is actuated, the vibrator will establish a pulsating current of high frequency, which traverses the primary winding of the transformer. Consequently there will be induced in the secondary an alternating current of a like frequency, which will find its way to the line by means of the following path: from the transformer to the make contact of armature 1 of relay *K*, which has been previously operated as stated above; and thence by way of this armature through condensers *D* and *B* to the tip of the line, returning by way of the ring of the line to condensers *N* and *E*, armature 2 and the make contact of relay *K* and then to the transformer. Since this current is of high frequency it will meet excessive impedance from coils *A* and *Z* or *I* and *W* and, consequently, will not interfere with the telegraph instruments.

An incoming high-frequency signal arriving over the tip side of the line will pass through condensers *B* and *D* to armature 1 and the break contact of relay *K*, thence by way of condensers *F* and *G* to the coils of the high-frequency relay *Q*, then to the break contact of relay *L* and thence by way of armature 2 of relay *K*, through condensers *E* and *N* and back to the ring side of the line. The current will pass mainly through the high-frequency relay on account of the relatively large impedance of the relay *L*, and the small component which traverses the latter will be insufficient to actuate it. The actuation of relay *Q* will open the circuit containing relay *S*, and hence the latter will be de-energized. Since relay *S* is slow-acting, any momentary closure of the contacts of the high-frequency relay will be without effect. The release of relay *S* will close a circuit from the ground on its armature to its break contact and thence to relay *T* and battery.

Thus relay *T* will be energized and will thereby complete the following circuit: from the ringing generator to the make contact of armature 1, then by way of the armature to the tip of the jack and its break contact, through the coil of the line drop, thence to the other break contact and the ring of the jack, to armature 2 and the make contact of relay *T* and back to the generator. Thus the regular ringing current will traverse the coil of the drop and actuate it in the usual manner. The line is cut off at the break contacts of relay *T* and hence the ringing current from the generator cannot affect the morse apparatus.

Railway Composite System. — The railway composite is a special development of the general system designed to meet the conditions on railway telegraph lines. It is now quite extensively employed by the railway systems over the country, particularly in the West.

Reference to the circuit in Fig. 99 shows that the telephone circuit terminates in a subscriber's set instead of a jack as in the systems previously explained. This set contains all the apparatus required for a telephone terminal, therefore the work of installing a telephone set in this type of line consists in merely stringing a lead from the line wire to the instrument. The simplicity of this installation is one of the advantages of the system and is often made use of for emergency service. The distance intervening between telegraph stations on the western railroad lines is often very great and, if a train were to be stalled or wrecked midway between two of these stations, it would therefore take some time for a man to walk to the nearest station to secure assistance. However, if the train is equipped with a portable emergency set, the message can be readily sent at once, since the train crew can tap the wire and report by means of the telephone; thus the loss of much valuable time and many serious delays may be avoided. These instruments when arranged for train service are provided with a pole, one end of which terminates in a metallic hook for engaging the line wire. The rails usually serve for the ground connection. The telephone instrument is nothing more than an ordinary local battery set equipped with a special induction coil, which is utilized both in speech transmission and in the generating of the signaling current. The set is not equipped with a ringer, this being replaced by a special signaling device *H*, as shown in the circuit in Fig. 99. The howler *H* used in this circuit is specially designed for the purpose, the diaphragm being made of

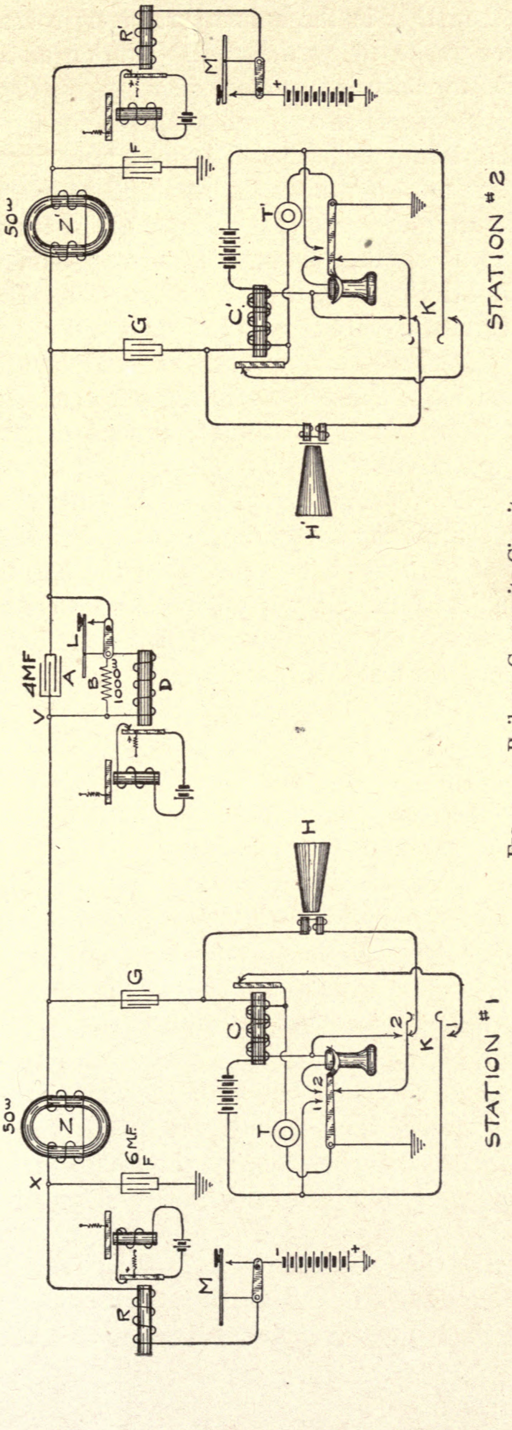


FIG. 99. — Railway Composite Circuit.

heavier stock than that in the ordinary receiver; consequently it is not distorted or weakened by the rapid vibration of comparatively large amplitude, to which it is subjected.

The combination of condenser *F* and coil *Z* will modify the telegraph impulses as described previously. The telegraph current will flow over the line wire until it reaches an intermediate telegraph station, such as that shown in the circuit; at this point it has three paths, one by way of relay *D*, another by way of the 1000-ohm noninductive resistance *B*, and the third by way of condenser *A*. However, since the telegraph current is pulsating in nature, it will not flow continuously through condenser *A*, but will rather select the paths offered by resistance *B* and relay *D*. Since the resistance coil *B* is wound to 1000 ohms and the morse relay *D* is but 150 ohms, the great majority of the current will traverse the coil of the relay and then pass out on the line again. The function of resistance *B* is to prevent response of the relay to the telephone ringing current. Condenser *A* retains the continuity of the telephone circuit when the telegraph operator at key *L* is sending. Any telegraphic line current consequently will operate the telegraph relay *D* and all other intermediate telegraph relays in the line, and will then pass through coil *Z′* and relay *R′* at the other end of the line and thence to battery and ground. The operation of any telegraph key consequently will actuate all the telegraph relays in the line and will not interfere with the telephone circuit because the telegraph current is kept out of the instruments by means of condensers *G* and *G′*.

It remains to be explained how the telephone talking and ringing currents are transmitted without interfering with the telegraph circuit. It will be noted that the telephone sets are wired in multiple from line to ground, and therefore when signaling current is sent out on the line, all the telephone instruments will respond. When there are three or more telephone stations a system of code ringing must be employed. Fig. 99 shows but two telephone stations and one intermediate telegraph station, but the number of intermediate stations may be several, depending on the length and character of the circuit. Ordinarily four or five telephone stations is the working limit.

The operation of the telephone circuit is as follows: When a trainman at station 1 desires to call another telephone station, he will actuate key *K* the required number of times to give the proper code ring, with the following results. In the first place a circuit is completed that is traceable as follows: from the battery to the primary of the induction coil, thence to the armature of the coil, through the break contact to contact 1 of key *K*, then to the lever spring of the key and back to the other side of the battery. This induction coil is similar to the standard coil in a subscriber's local battery set, with the extra feature of an armature and a break contact. Thus when the above circuit is completed the primary of the coil will be energized and will, therefore, attract the armature and subsequently break the circuit. This will release the armature and thus close the circuit again, thereby energizing the primary of the coil and causing the re-attraction of its armature, which will be repeated indefinitely. Thus the operation of this circuit is identical with that of an ordinary buzzer or vibrating bell. The making and breaking of the primary circuit generates an alternating E.M.F. in the secondary which is impressed on the line and establishes the signaling current. This alternating current will follow a path which can be traced from the ground on the switch hook to the break contact of the latter, then to the lever spring of key *K* and thence by means of contact 2 through the secondary of the induction coil and condenser *G* out on the line. Due to the large inductance of coil *Z* the current will pass almost wholly out on the line, to the point *V*. At this junction it will divide among the three parallel paths as offered by the relay *R*, the non-inductive resistance *B* and the condenser *A*. The condenser offers the least impedance of these three paths and therefore conducts a large fraction of the current. The portion which traverses the relay *D* is too small to affect its armature. The signaling current, upon leaving the intermediate telegraph station flows over the line to condenser *G′* and thence by way of the howler *H′*, the break contact of key *K*, its lever spring, and the break contact of the hook switch itself, to ground. Thus the howler will be energized and will consequently emit the code signal imparted to the key *K*.

The removal of the receiver from the hook will close the primary circuit, which can be traced from the battery through the primary of the induction coil and thence by way of the transmitter and the hook switch to contact 1 and the other side of the battery, while the secondary circuit can be traced from ground by way of the hook switch, the contact 2, the receiver, the secondary of the induction coil and the condenser *G* to the line. Since the circuit conditions in the other set are identical with those just described at station 1, it is plain that the talking circuit is complete; and since the frequencies of talking current are always high, the path followed is substantially the same as that given for the signaling current.

The telephone circuit employs a ground return and is naturally susceptible to the noises inherent in all grounded systems. The induction from parallel telegraph circuits is sometimes very severe, but all such disturbances are ordinarily overcome by reducing the sensitiveness of the receivers. On this account it is seldom possible to secure satisfactory operation over a circuit of more than one hundred miles. At the same time the transmitters must be made as powerful as possible and, consequently, the number of cells in the primary circuit is increased to seven or eight.

CHAPTER XIV

PHANTOM LINES

It was shown in the last chapter that the efficiency of a toll wire plant may be greatly increased by employing apparatus which permits simultaneous use of the same wires for telephony and telegraphy. The efficiency may be still further increased by the use of the phantom circuit principle. Fig. 100 shows how four retardation coils may be inserted in two metallic circuits so as to obtain an additional telephone circuit. In this case, the two standard telephone circuits *A* and *B* are called the physical circuits, while circuit *C* is termed the phantom circuit. The retardation coils are, as will be observed, bridged directly across the line and the taps for the phantom circuit are taken from the middle points of these coils. Thus the two line wires of each of the physical circuits are operated in parallel for the limbs of the

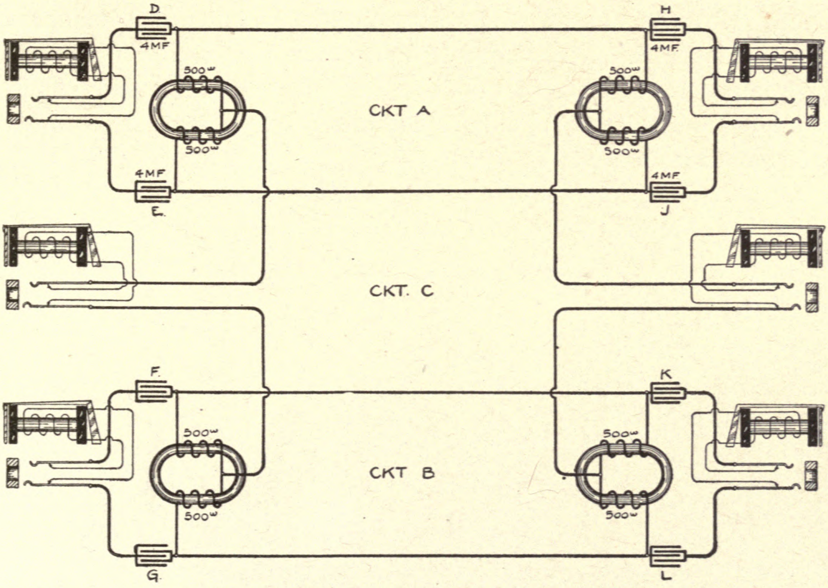


Fig. 100. — Retardation Coil Type of Phantom Circuit.

phantom circuit, whose line resistance is consequently but half as great as that of the physical circuits. The condensers *D*, *E*, *F*, *G*, etc., as will be observed, are inserted in the line on the switchboard side of the retardation coils and usually have a capacity of about four microfarads. These condensers are not necessary for the satisfactory operation of the phantom and are only used in this connection so that the physical circuits may be used for simplexing when phantom work is not desired. In this case they serve to keep the telegraph currents out of the switchboard circuit. The ringing and the talking currents from the phantom circuit pass readily through the retardation coils, since the telephone taps are taken from the centers; therefore the self-inductance of such a coil is neutralized by the mutual inductance, and the coil as a whole acts like a noninductive resistance. However, to an alternating current flowing in circuits *A* or *B*, these coils offer their full inductance and a correspondingly high impedance. Thus it is obvious that signaling or talking is permissible on the three circuits simultaneously, without any mutual interference.

In this connection it should be said, however, that for the successful operation of a phantom circuit the physical lines should be extremely well balanced. This is true not only of the resistance, but likewise of the inductance, the capacity and the leakage. The distribution of potential and current in a telephone circuit depends upon all four of these properties and hence they must all be considered in securing a perfect balance.

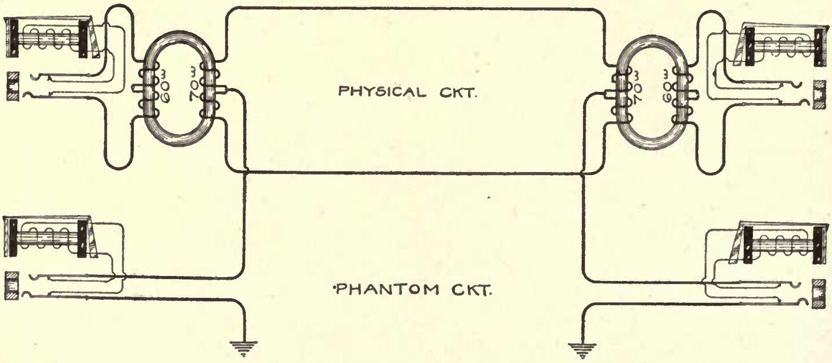


FIG. 101. — Repeating Coil Type of Grounded Phantom Circuit.

Fig. 101 shows a grounded phantom circuit employing repeating coils. This is not necessary, however, and retardation coils may be used as before, if desired. The ground is used as a return conductor for the phantom circuit, which is therefore likely to be noisy. The switchboard end of the physical circuit is inductively connected to the line by means of the repeating coil and the phantom tap is taken from the middle point of the line winding of this coil. This winding consequently acts as a noninductive resistance in the phantom circuit, as did the retardation coil in the circuit previously explained; and since the physical circuit makes use of the coil as a simple repeating coil, there will be no interference between the two circuits. The one objection to the repeating coil method is that these coils must be designed for transmitting both ringing and talking currents; hence the efficiency of speech transmission is somewhat impaired. Fig. 102 shows a very efficient type of repeating coil as used by the American Telephone and Telegraph Company. Fig. 103 shows a circuit phan-

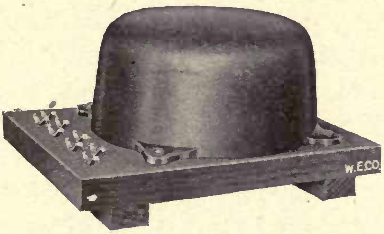


FIG. 102. — Repeating Coil Suitable for Phantom Use.

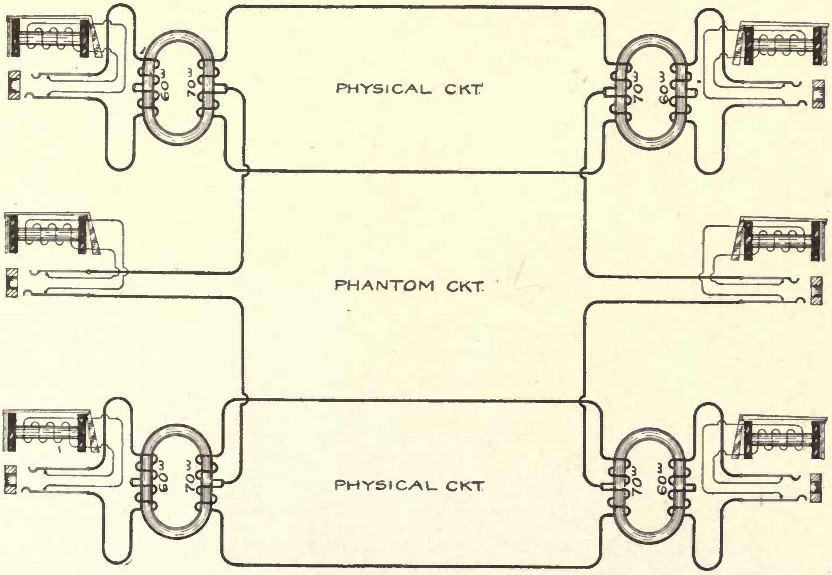


FIG. 103. — Repeating Coil Type of Phantom Circuit.

tomed by means of repeating coils, the operation of which will be clear from an inspection of the drawing.

Phantom circuits are also used as two-way order circuits between toll operators. In this case the passing of tickets and any other required exchange business can be handled over this circuit, and consequently the physical circuits are always available for regular service. This is quite an item to the telephone company, as the subscriber only pays for the time he is actually talking; and if the physical circuits are ordered up by means of the phantom, they will be revenue-producing a larger portion of the time. A two-way phantom order circuit is shown in Fig. 104, and since the general arrangement of the phantom is similar to those already described, only the special features will be explained. It will be noted that the middle points of the repeating coils *A* and *A′* are wired to the lever contacts of keys *K* and *K′*, and therefore when key *K* is actuated the two following circuits will be established. One is completed from ground, by way of relay *R*, to the make contacts of key *K* and battery. This will operate relay *R* and thus place the operator's telephone set in circuit with winding 2 of repeating coil *A*. The second circuit that is completed by the operation of key *K* may be traced from battery to the contact springs of key *K* and thence by means of the lever contacts of said key to the middle point of winding 1 of the repeating coil *A*. At this junction the current will divide, half of it flowing through the

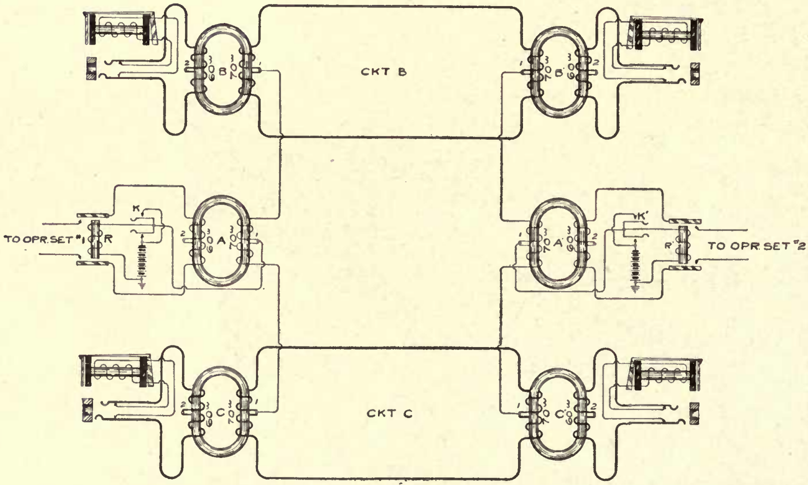


FIG. 104. — Phantom Circuit Used as an Order Wire.

upper portion of coil 1 to the middle point of coil 1 of the repeating coil *B*, thence over the line wires of circuit *B* to the middle point of coil 1 of repeating coil *B′*, from which point it may be traced to the middle point of coil 1 of repeating coil *A′*. At this terminal the current unites with the other portion which flowed through the lower half of winding 1 of repeating coil *A* and follows a path over telephone circuit *C*, similar to that outlined above for circuit *B*. The flow of current can now be traced through relay *R′* to ground. Consequently relay *R′* will be energized and thus the operators' sets will be connected directly to windings 2 of repeating coils *A* and *A′*; the operators then communicate over the phantom. The restoration of key *K* will release the relays and return the circuit to normal conditions. The operation in the opposite direction is similar.

Before leaving the subject of phantom operation, it seems appropriate to emphasize some of the precautions that should be taken. As previously stated, the lines must be well balanced as regards capacity, inductance, leakage and resistance. For this reason it is advisable to keep the carbons on phantom lines scrupulously clean, since the accumulation of dust at this place is very likely to cause an unbalance which will be noticeable. In order to obviate inductive disturbance an extensive system of transposition must be resorted to; in the first place, the individual wires of each physical circuit must be regularly transposed and, secondly, the two wires of one physical circuit (which compose one lead of the phantom) must be transposed with the wires of the other physical circuit (which constitutes the other conductor of the phantom).[1] If these provisions are not carefully observed, inductive disturbances are almost certain to manifest themselves. However, when the phantom is well balanced, the transmission is often slightly superior to that obtained over the physical circuits.

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[1] More will be said of this in Chapter XIX, which treats of transposition systems.

CHAPTER XV

TEST AND MORSE BOARDS

THE three preceding chapters describe the conventional circuits and give the general theory upon which the principles of composite, simplex and phantom work are based. This is but half the problem, however, and it is the purpose of this chapter to describe the methods of applying these principles to actual practice. The work of compositing or phantoming is seldom if ever resorted to at the toll board; and although in some of the smaller offices the wire chief's desk is provided with the necessary equipment for handling this type of service, the best practice is to have an entirely separate and distinct board termed the test and morse board. It should be borne in mind, in reading the following description, that the desired end in this work is flexibility, which is naturally essential in all switchboards, but especially for the board under discussion, due to the great variety of combinations that are necessary.

Test and morse boards may be readily grouped in two general classes, one in which cords and plugs are employed in making the various connections and the other, sometimes known as "cordless boards," requiring the use of plugs only to change the normal layout, the jack contacts being used for switching purposes except in emergencies. The first type is the more flexible of the two and is consequently better adapted for small equipments. Each of these systems is in general use and merits description, and since the cord and plug type was the first to be adopted, it will receive attention first.

The lines entering the ordinary test board are of three classes; namely, toll lines, local trunks and long distance or toll terminals, the latter embracing both telegraph and telephone subscribers' drops. The toll lines present the greatest degree of complication and will be treated at length.

Fig. 105 shows the ordinary toll-line circuit, which, after passing through the standard protection, is looped through six jacks. This wiring results in a very flexible layout, as by means of these jacks the wire chief is enabled to cut off the switchboard end of the circuit and remain bridged on the toll line and *vice versa.* The functions of this circuit will be readily appreciated as the description of the board progresses. The jacks are arranged in pairs, being numbered in the figure, 1, 2 and 3 respectively. It will be observed that if a twin plug be inserted in pair 3, the apparatus connected to the cord will be bridged across the toll line and the switchboard end of the circuit will be disconnected. If the plug is inserted in pair 1, however, the equipment connected to the cord will be in connection with the switchboard. Plugging into pair 2, in addition to operating the busy signal at the toll switchboard by means of the make contact in the jack, will connect the cord equipment to the toll line. Therefore this pair of jacks is ordinarily used for testing, so that the operators may know that the line is in use. The jacks as shown in the circuit are mounted in vertical panels in the face of the board and are consequently very accessible to the cord circuits.

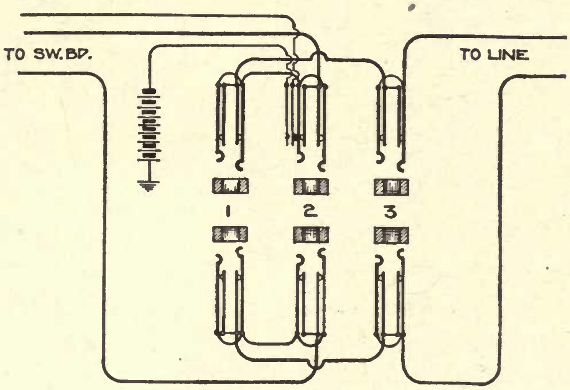


FIG. 105. — Toll-line Circuit at Test Board.

The first of the cord circuits that will be discussed is the regular composite circuit shown in Fig. 106. The apparatus shown in the diagram is the same as that described in Chapter XIV and a full description is unnecessary. It will be noted that the circuit shows two single and two twin plugs; the single plugs are the morse legs and the twin plugs are respectively the line and the drop sides. When it is desired to composite one of the regular toll lines, the wire chief will insert the twin plug marked "switchboard" in jacks 1 (Fig. 105) and the twin plug marked "line" in jacks 3. The two plugs marked "morse leg" are then inserted into the jacks which lead to the morse board or the morse subscribers' equipment. The operation of the circuit has already been explained in Chapter XIII. It will therefore be evident that by means of the circuit shown in Fig. 106, any toll line entering the test board can be composited with ease and rapidity.

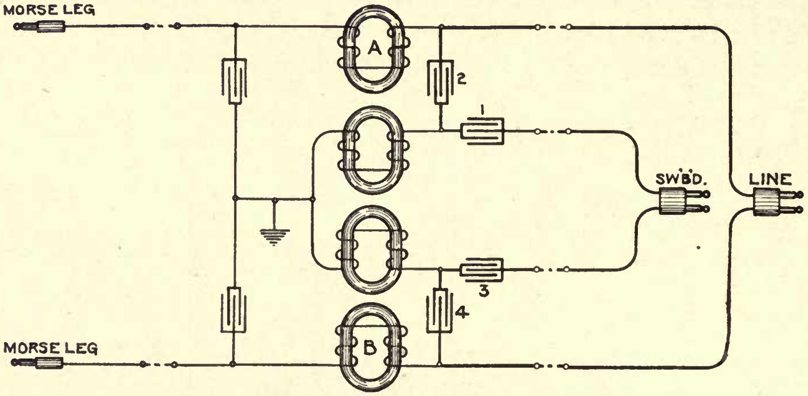


Fig. 106. — Composite Cord Circuit at the Test Board.

In case it is desired to simplex one of the regular toll lines, the circuit shown in Fig. 107 is utilized. The twin plugs are inserted in jacks 1 and 3 of the line circuit shown in Fig. 105 and the single plug is inserted in a jack which is wired to the morse equipment.

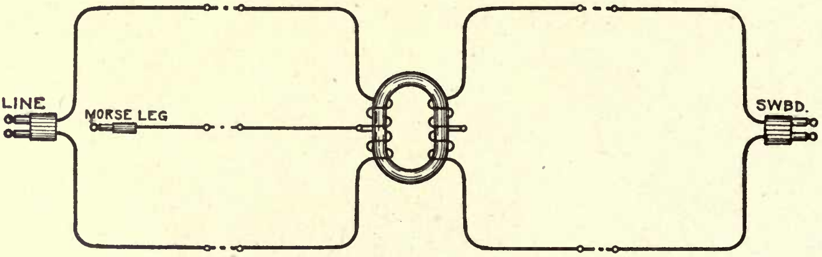


Fig. 107. — Simplex Cord Circuit at the Test Board.

The battery for the operation of these morse circuits is also carried to jacks that are located in the test or morse board. The method of wiring is shown in Fig. 108, from which it will be observed that the battery leads are looped through three jacks. These three jacks are mounted in a row straight across the battery panel; and the number of these jacks depends upon the size of the office and the extent of the morse service. Naturally, the principal function of this circuit is the feeding of battery, but it is also available for monitoring purposes. Thus it will be observed that by plugging into jack 1, battery will be fed out on the two strands of the cord; while if the plug is inserted in jack 2 the apparatus wired to the plug will be cut in series with the regular circuit. For example, suppose that the regular battery tap has been taken from jack 1, and that the wire chief has inserted another plug, to which is attached a standard morse set, in jack 2. This will establish a circuit from battery through jack 3 to the tip and ring springs of jack 2, where by virtue of the plug inserted, the battery will flow from the ring spring of the jack through the morse apparatus, and thence to the tip spring of the jack, being traced from there to the conductor springs of jack 1 and then to the morse circuit. Consequently the current used by this circuit must all flow through the monitoring apparatus attached to jack 2, and the wire chief or monitor is therefore enabled to obtain a rapid and accurate conception of the condition of the circuit. Jack 3 of the circuit is used for cutting off the battery entirely; this arrangement is not universally used but has been found very convenient.

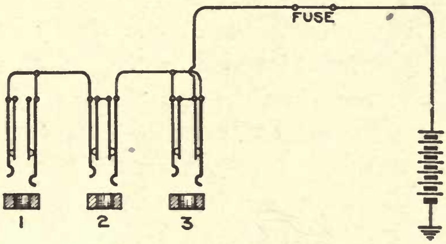


Fig. 108. — Battery Jacks at the Test Board.

Fig. 109. — Telegraph Monitoring and Test Circuit.

Attention is now called to the circuit shown in Fig. 109, which embodies the monitoring circuit above referred to as well as the usual morse testing circuit. Plug 2 is the monitoring plug, the insertion of which establishes conditions as described in the preceding paragraph, while the single conductor plugs 1 and 3 are used for testing purposes. Testing conditions are established by inserting one of these plugs in the jack of the morse circuit to be tested and the other plug in the battery jack. The telegraph relay will then be in series with the battery and the line, and the conditions for testing will be established.

The method of monitoring the morse circuits having been duly described, a description of the telephone circuit is next essential. This circuit cannot be used for monitoring, for the reason that it is not desirable to have the wire chief cut in on a telephone connection; the transmission on these circuits must be kept up to the highest point of efficiency and the bridging of an additional telephone across the line would cut down the transmission. The telephone circuit referred to is shown in Fig. 110, and is nothing more than an ordinary operator's telephone set equipped with the usual secondary cut-out. This circuit is used by the wire chief in talking to trouble-men out on the line, and also for ordering up composite and phantom sets at other offices.

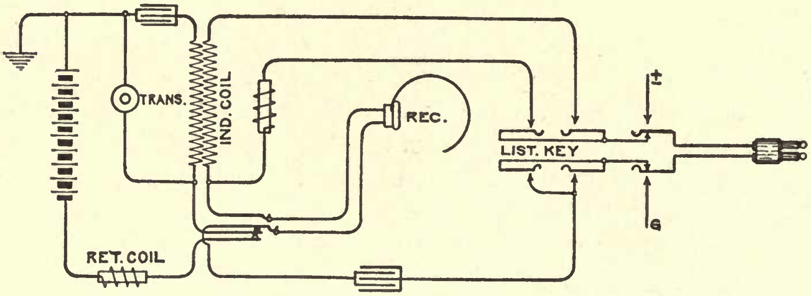


FIG. 110. — Wire Chief's Telephone Circuit at Test Board.

The successful operation of the circuits entering a test board depends to a great extent upon the maintenance of almost perfect electrical balance, and when it is appreciated that this balance is sensitive even to atmospheric conditions, the importance of having proper and efficient testing circuits is soon realized. Therefore, since these testing circuits are most essential, the more important ones will be shown in detail.

In Fig. 111 is shown the regular voltmeter or ammeter circuit with which every test board should be equipped, the wiring of which, though extremely simple, is very flexible. Thus by plugging into jack 2 the meter will be bridged across the circuit attached to the plug, while by the use of jacks 1 and 3, practically any combination is possible. For instance, if it is desired to determine whether or not a line is grounded, it becomes possible, by means of two single-conductor cords and plugs, to readily set up a circuit which would immediately give the desired information. Thus if the regular battery jack were connected to jack 3, and jack 1 to the line under test, a full deflection of the voltmeter would be obtained in case the line were grounded. The presence of foreign potentials can be readily ascertained by inserting the cord from jack 3 in one of the ground jacks, or by inserting one of the ground plugs directly in the jack. This circuit, as previously stated, is most essential and in the hands of an experienced wire chief can be used for making almost every conceivable sort of test.

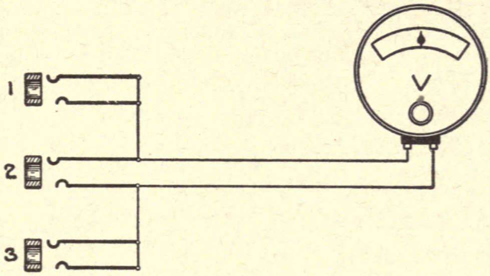


FIG. 111. — Voltmeter and Ammeter Circuit at Morse Board.

Another test circuit which is used very extensively is the "bridge circuit" shown in Fig. 112. The two plugs shown in the diagram are inserted in either end of the circuit that is to be measured, thereby supplying the fourth or unknown arm of the bridge. The circuit is self-explanatory and will be passed without further comment.

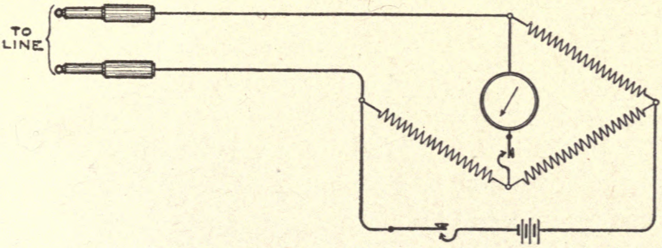


FIG. 112. — Bridge Circuit at Test Board.

There is one more test circuit which is sometimes used in the operation of a test board, namely, the galvanometer circuit shown in Fig. 113. This circuit is so wired that galvanometer measurements can be made on any line, direct. In case the instrument is wired as shown in the figure, the operation of setting up the circuit is extremely simple. All that is necessary is to insert the battery plugs in the proper battery jacks and the line plugs into the jacks of the line under test. Under these conditions the galvanometer, battery and line will be in series, and consequently the apparatus is connected in the desired relation. Furthermore, if it is desired to use the galvanometer in connection with other apparatus the method of wiring shown is adaptable to almost any condition.

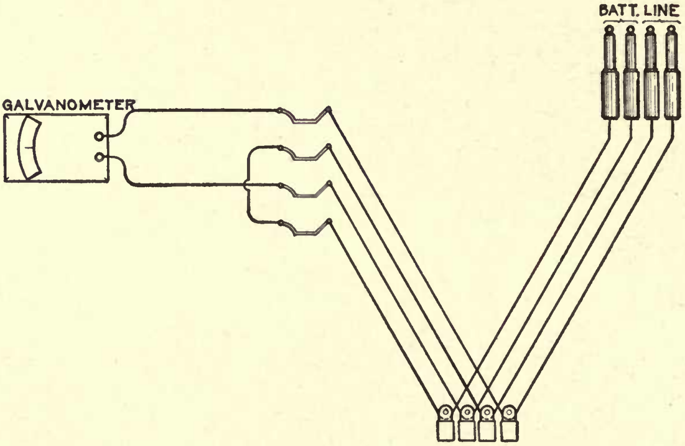


FIG. 113. — Galvanometer Circuit at Test Board.

This completes the description of the wiring of the principal circuits that are found at a board of this character, and it now becomes necessary to show how these circuits are installed and distributed in the board itself. For this purpose reference will be made to Fig. 114, which shows the face equipment of a standard test board in which the different circuits will be designated. The board is called a through test board to distinguish it from the so-called terminal board. The terminal station, as the name implies, is the terminus of the line, *i.e.* it is not intermediate between long-distance offices. Hence, in the terminal station we find a large number of leased lines, usually occupying one or two panels, whereas the function of the through station consists mainly of interconnecting two or more long-distance offices.

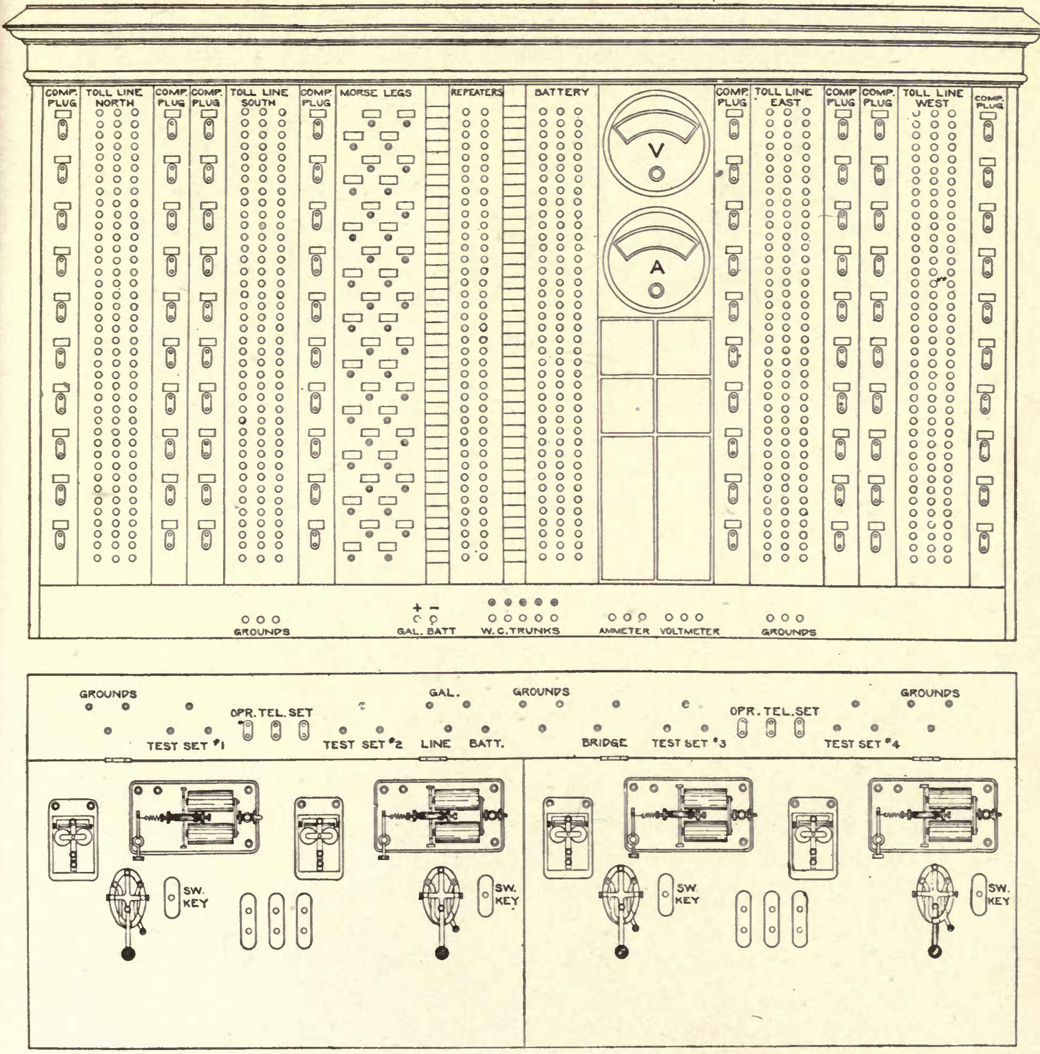


FIG. 114. — Jack and Key Equipment of a Standard Test and Morse Board.

However, it will be obvious from what has just been said that the through station shown can be easily converted into the terminal type by the addition of panels for leased lines.

The apparatus used in the various circuits is all properly designated on the drawing, to facilitate description. Attention should first be given to the four panels labeled "toll lines," each consisting of three complete vertical rows of jacks. These jacks correspond to the ones shown in Fig. 105, from which it will be noted that they are arranged in pairs, the first two horizontal rows of jacks in each panel constituting one metallic line, the next two another line, etc. As will be observed, these panels are labeled "north," "south," "east" and "west," respectively, which indicates that the lines from the north terminate in the north panel, those from the south in the south panel, etc. On either side of these line panels are the panels in which are installed the composite and phantom sets terminating in plugs. Above each of the plugs is placed a designation card, so as to render the location of a particular circuit an easy matter. The single-conductor morse legs of these composite circuits are located in the panel marked "morse legs," and these plugs, like the line and switchboard plugs, are provided with designation strips to facilitate location. In the panel marked "battery" are placed the regular battery jacks, the wiring of which is shown in Fig. 108. The panel marked "repeater" contains the jacks in which the circuits of the telegraph repeaters terminate. It might also be well to state in passing that it is feasible and sometimes the practice to multiple the composite plugs in several panels, so as to reduce the amount of equipment and still have the apparatus convenient for connection with any line.

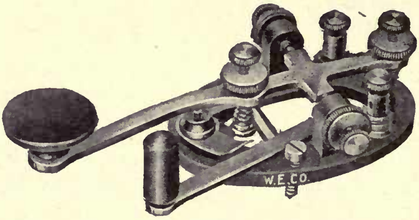


FIG. 115. — Legless Telegraph Key.

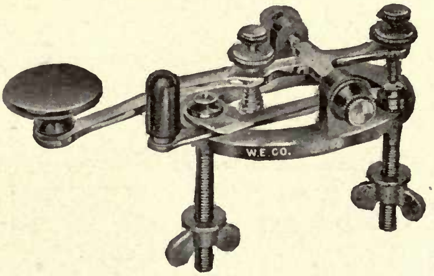


FIG. 116. — Leg-type Telegraph Key.

The manner in which the equipment is installed in the face of the board being understood, it seems well to call attention to the simplicity of the operation which this arrangement affords. Thus suppose it is desired to composite a line. This is accomplished by inserting the composite plugs on either side of the line panel in the proper line jacks, and the morse legs into the desired leased lines, or repeater jacks, and the operation is completed. Any other circuits that are customarily set up at this board can be established, by reason of the general arrangement of the apparatus, with equal dispatch.

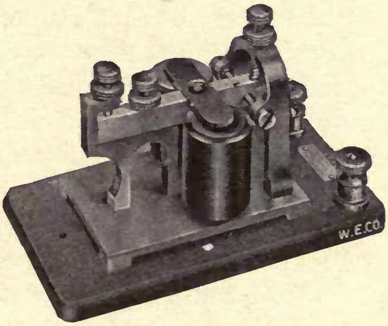


Fig. 117. — Telegraph Sounder.

The regular line jacks are only one part of the equipment necessary and attention will now be directed briefly to the testing and miscellaneous circuits. The apparatus for these is all properly designated on the drawing and therefore a very brief reference to a few of them is all that is necessary. Thus, beneath the regular panel equipment, in the face of the board, are found the ground jacks often needed in testing, and the voltmeter and ammeter jacks, which are wired from the instruments shown above as indicated in Fig. 111. There may also be seen the office trunk jacks used for intercommunication between this board and the toll board and the various desks in the office. On the key and plug shelf are shown the equipment for the regular test circuit of Fig. 109, the operator's telephone circuit of Fig. 110, the bridge circuit of Fig. 112, and the galvanometer circuit of Fig. 113. The location of this equipment needs no special explanation.

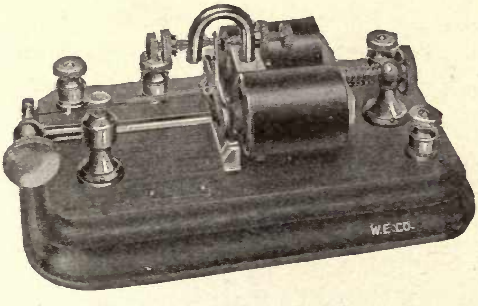


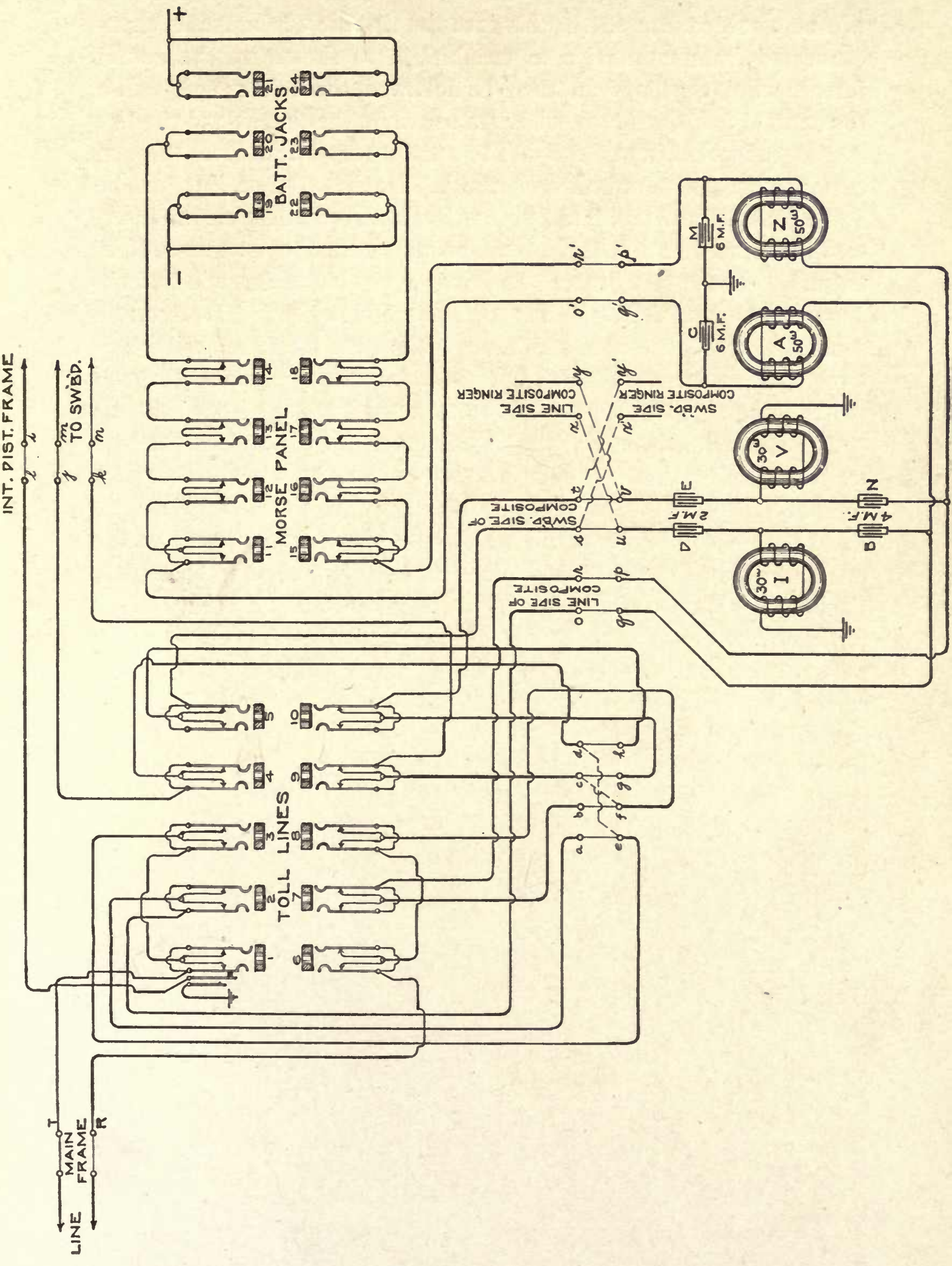
Fig. 118. — Telegraph Relay.

While in the equipment just shown the plugs used in connection with the simplex and composite circuits are all in the face of the board, it is sometimes the practice to have all these plugs on the shelf. The objections to the last arrangement are, first, the resulting tangle of cords across the face of the board when a number of connections are up and, second, the space on the shelf utilized by this equipment is needed for the testing apparatus. However, notwithstanding these objections, experience has shown that for small equipments this type of board gives excellent satisfaction and is to be recommended in preference to any other arrangement.

As already stated, test and morse boards can be divided into two general groups: the first, in which cords and plugs are employed in making the various connections, — the description of which has just been completed, — and the second, sometimes known as the cordless board, to which the remainder of this chapter will be devoted. The cordless board eliminates, to a considerable extent, the weakest part of a switchboard equipment, and in that respect it is beneficial, as it necessarily avoids the annoying cord troubles and reduces the cost of maintenance. Furthermore, the face of the panel is not obstructed by the many intersecting cords, and the location of the equipment in the board is, therefore, greatly facilitated. The above statement may raise the question as to why the cord equipment continues to be in demand. It will be understood upon a more thorough investigation, however, that each type of equipment meets particular conditions. For small equipments, in which the amount of apparatus necessary for composite, simplex and phantom work is limited, a cord equipment is preferable. This follows directly from the fact that cords permit greater flexibility than the other type, which is very essential in small offices. For a large equipment, however, it has been proved good practice to wire a composite set permanently in each of the toll lines entering the office. In this case the cordless equipment is a distinct advantage because the cord complication is entirely eliminated in normal operation.

Fig. 119 shows a standard toll line wired through the test board. As shown, the line upon entering the office is first wired through the regular protection at the main frame. From the frame the tip side of the line can be traced through the cut-off jacks 1 and 3 to terminal *e* on the composite distributing frame, while the ring side of the line is wired through cut-off jacks 6 and 8 to terminal *f* on this frame. At the frame the line can be cross-connected for a direct telephone circuit without morse service, or it may be associated with a standard composite set.

Since the former of these two involves the simpler construction it


INT. DIST. FRAME
TO SWBD.
LINE
MAIN FRAME
T
R
TOLL LINES
MORSE PANEL
BATT. JACKS
LINE SIDE COMPOSITE RINGER
SWBD. SIDE COMPOSITE RINGER
SWBD. SIDE OF COMPOSITE
LINE SIDE OF COMPOSITE
M 6 M.F.
C 6 M.F.
Z 50ω
A 50ω
V 30ω
I 30ω
E 2 M.F.
D
N
B 4 M.F.
+
−

will be considered first. In this case the tip side of the line is cross-connected from terminal *e* to terminal *d*, as shown by the dotted jumper wire; the line can then be followed through cut-off jack 4 to terminal *j* on the intermediate frame, while the ring side of the line is cross-connected from terminal *f* to *c* and is wired from there through cut-off jack 9 to terminal *k* on the intermediate frame. It will be noted that a third terminal *l* is associated with the line on the intermediate frame and that this terminal is wired direct to a make-contact on jack 1 at the test panel. The reason for this wiring will become apparent in what follows. The three terminals *l*, *j* and *k* are cross-connected at the intermediate frame to terminals *i*, *m* and *n*, respectively. The latter terminals are those wired to the position of the toll switchboard at which this line is to terminate.

The above description illustrates the method of wiring for a straight telephone circuit and it is next essential to show how the line may be composited. For this purpose one must return to the line terminals *e* and *f* at the composite distributing frame, to which points the circuit can be traced in the outline above. When it is desired to composite the line, the jumper wires *ed* and *fc* are removed and a new set of four jumpers replaces them. Thus terminal *e* is cross-connected to terminal *a*, from which point the tip side of the line can be traced through cut-off jack 2 and then to terminal *o* on the composite distributing frame, while terminal *f* on this frame is cross-connected to *b* and can be traced from there through cut-off jack 7 to terminal *r* on the composite frame. The tip side of this line is then cross-connected to terminal *q*, from which point the telephone circuit can be traced through condensers *B* and *D* to terminal *u* on the composite frame and thence to terminal *x*, through the line side of the composite ringer and terminal *x′* on the switchboard side of the ringer; from there it can be followed to cut-off jack 5 and terminal *h* on the composite frame, then by means of jumper *hd* to cut-off jack 4 and thence to the tip side of the intermediate distributing frame. The ring side of the line follows a similar path, which can be traced from terminal *r* on the composite frame by means of the jumper to terminal *p*; through condensers *N* and *E* to terminal *v*; then by means of jumper *vy* it can be followed to the line side of the composite ringer and thence from *y′* on the switchboard side of the ringer, by means of jumper *y′T*, to cut-off jack 10 and terminal *g* on the composite frame. The lead is then cross-connected to terminal *c* and can be traced by means of cut-off jack 9 to the ring side of the intermediate frame. When the composite ringer is wired in the circuit, the solid-line jumpers *us* and *vt* are omitted. However, when the line is normally looped through the office for through service, the solid jumpers just referred to are used, and the dotted jumpers to the composite ringers are omitted.

Having traced the regular telephone wiring for composite operation, it remains to follow the path of the telegraph circuit. The telegraph jacks are cabled from the morse panel to terminals on the composite frame, as shown in Fig. 119. The morse taps shown in the circuit terminate at *o′* and *r′* on the composite frame. The telegraph circuit on the tip side of the line can be traced as follows: from terminal *o′*, by means of jumper *o′q′*, through impedance coil *A*, to terminal *q* and thence by means of jumper *qo* to cut-off jack 2; from here it can be traced to terminal *a* on the composite frame and then by means of jumper *ae* to cut-off jacks 3 and 1 to the line. The ring side of the line is traceable from terminal *r′*, by means of jumper *r′p′*, through impedance coil *Z*, to terminal *p*, and then by way of jumper *pr* to cut-off jack 7. From here the circuit can be followed to terminal *b*, through jumper *bf*, and cut-off jacks 8 and 6 to the ring side of the line.

It naturally follows that by cross-connecting composite frame terminals *a*, *b*, *c* and *d* to terminals *e*, *f*, *g* and *h* respectively, the toll line will be equipped for composite service; and it also follows that if jumpers *fc* and *ed* are included, while the others are omitted, the line is free from the composite apparatus and can be used for straight telephone service only. In some equipments the terminals *a*, *b*, *c*, *d*, *e*, *f*, *g* and *h* are located on a connecting rack in the rear of the test panel instead of on a separate frame. In the latter case they may form an entirely separate frame or be located on a part of the intermediate frame. Of these two methods the one using the separate frame is the better, since large connecting racks, containing many clips, should be avoided as much as possible in switchboard designs because they increase the probability of office trouble. The connecting rack is inferior, in general, to the standard frame.

The purposes of the different cut-off jacks in Fig. 119 will now be considered. These jacks are installed to afford, first, a ready means of testing. Thus when plugs are inserted in jacks 1 and 6, the line may be tested out through the main distributing frame, the switchboard portion of the line being cut off. In addition to this, the act of inserting the plug in jack 1 will close the make contact, which will ground the lead wired to the terminal *l* of the intermediate distributing frame and actuate all the busy signals associated with this line. If the plugs are inserted in jacks 3 and 8 the line can also be tested out through the main frame, but in this case no busy signal is displayed at the board. The composite set can be cut out by inserting twin plugs horizontally so as to connect the springs of jacks 3 and 4, and 8 and 9. By inserting a twin plug vertically in jacks 2 and 7, the toll line is opened and a test may be made through the composite apparatus to the toll switchboard. By inserting plugs in jacks 4 and 9, a test can be made direct to the switchboard. A twin plug inserted in jacks 3 and 8 will cross the line wires, *i.e.*, the line will enter the office by means of jacks 1 and 3 and will be carried out direct by means of the twin plug and jacks 8 and 6. The use of the battery and loop jacks in the morse panel will be explained in what follows, in connection with the face equipment.

The description of the standard circuit used for composite operation in connection with a cordless equipment being now completed, it becomes essential to show the circuit used for simplex and phantom work; and in this connection reference will be made to Fig. 120. It must be borne in mind that in simplex work the two line leads of the telephone circuit are operated in parallel for morse purposes, in place of using each lead of the telephone line for a telegraph circuit as in composite work. For phantom operation, furthermore, two telephone circuits are required, the two leads of each individual circuit being operated in parallel as one of the telephone leads for the phantom circuit. Fig. 120 shows two toll lines entering an office, each of which may be used for a simplex circuit; or by using the two in conjunction a phantom telephone circuit may be derived.

Since the wiring of line 1 is identical with line 2 in the composite panel, a description of line 1 will suffice. The tip side of the line, after passing through the protection at the main frame, is looped through cut-off jacks 1, 3 and 2 respectively; and from there is wired through winding 1 of coil *A*, through jacks 7, 8 and 6 and thence back to the ring side of the line. From the middle point of winding 1 of coil *A*, the morse tap is wired to jack 11 in the morse panel. The tip side of the switchboard end of this circuit is looped through cut-off jacks 4 and 5, and is then wired through winding 2 of coil *A* to jacks 10 and 9 respectively, and back to the ring side of the switchboard end of the line. Therefore when it is desired to simplex the above circuit, a plug is inserted in jack 11. This plug is attached to a cord, which is equipped with a similar plug at the other end, and the latter is inserted in a jack which leads either to the proper telegraph apparatus or the morse subscriber.

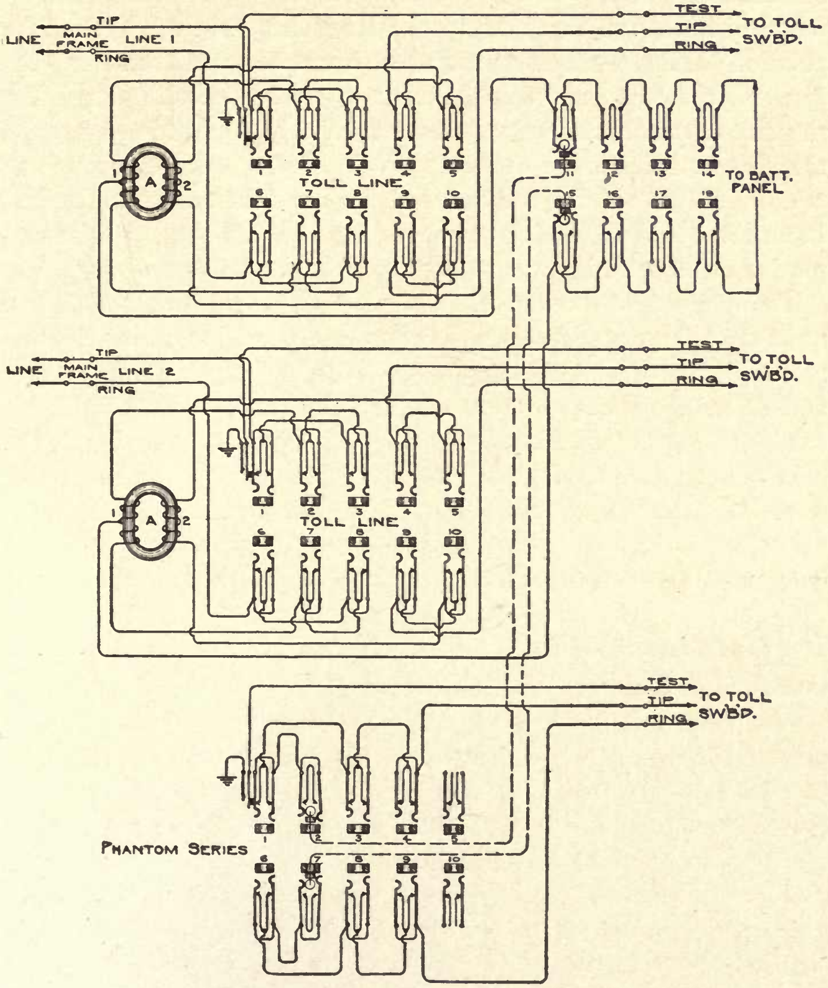


FIG. 120. — Simplex and Phantom Connection at a Cordless Test Board.

If a phantom circuit is to be established, however, the plug inserted in the morse jack, referred to above, is plugged in jack 2 of the series of phantom jacks, and a similar connection is made between jack 15 of the morse panel and jack 7 of the phantom-jack series. This connection is shown in the figure by means of broken lines. The tip side of the phantom circuit may then be traced from the toll switchboard through jacks 4, 3, 1 and 2 respectively, of the phantom-jack series, to jack 11 of the morse panel and thence to the middle point of winding 1 of coil *A*; from here it can be traced through jacks 2, 3 and 1, and 7, 8 and 6 out onto the two wires of toll line 1. The ring side of the phantom circuit can be similarly traced to and through the phantom-jack series to jack 15 of the morse panel, thence to the middle point of winding 1 of coil *A* of line 2 and then out onto the line. From what has preceded, it can be readily seen that the matter of simplexing or phantoming at the morse panel is a simple operation.

The function of the different cut-off jacks on the toll line, as well as in the phantom series, is for the purpose of testing, as in the composite circuit previously explained. Thus by plugging into jacks 1 and 6 a test may be made out on the line, the necessary busy test being displayed at the toll board while the switchboard equipment is cut off from the circuit. By plugging into jacks 3 and 8 the line is free from the switchboard equipment, but in this case no busy signal is displayed at the board; while plugging into jacks 2 and 7 cuts off the line and a test can be obtained through coil *A* to the switchboard. Plugging into jacks 4 and 9 makes possible a direct test to the switchboard. In fact the jacks in this circuit serve the identical purpose of those shown and described for the composite circuit.

The manner in which the jacks are mounted in the board is interesting; Fig. 121 shows a section of the test panel. As shown in the diagram, the first panel of jacks takes the toll lines, each line requiring five pairs of jacks straight across the panel. These jacks are wired as per the jack series numbered 1 to 10, shown in the composite circuit in Fig. 119 and in the simplex and phantom circuit in Fig. 120. The two upper rows of jacks on the face equipment drawing have been numbered to facilitate the explanation. To distinguish whether a certain set of jacks is wired for composite, simplex or phantom work, the panel is equipped with designation cards directly to the right of each set of jacks. It might be well to add here that the two extra jacks in the phantom series of the circuit in Fig. 120, which are not wired, are simply placed in the toll-line panel to make it uniform. In the next panel is located the jack series numbered 11 to 18 in the above-mentioned circuits. This panel is termed the morse panel, since all telegraph and phantom connections are put up by means of these jacks. In the next panel to the right are located the morse subscribers' jacks, to which are wired the leased lines as shown

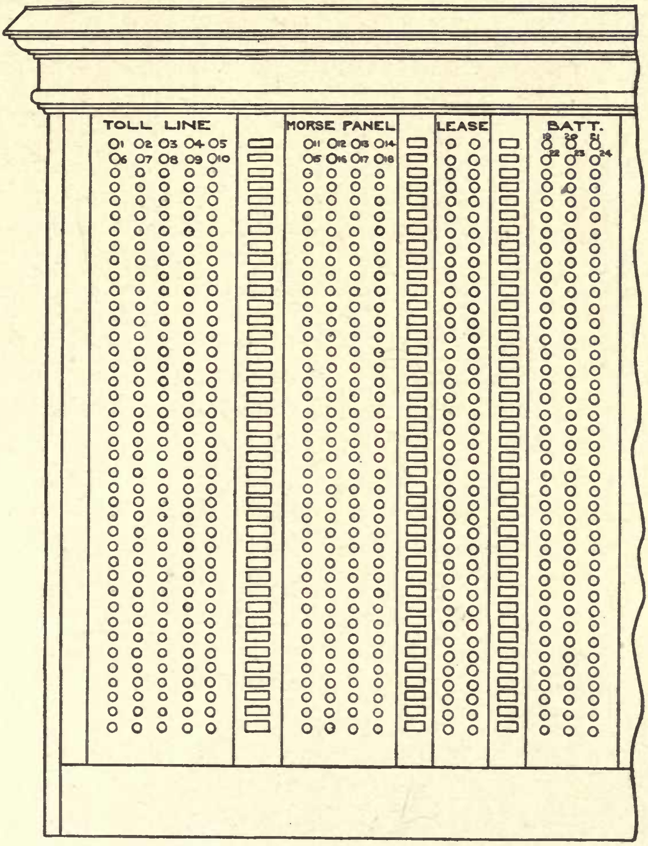


FIG. 121. — Face Equipment of a Cordless Test and Morse Board.

in Fig. 122. These jacks are either wired direct to the telegraph apparatus at the morse subscriber's station or to four-point switches as shown in the sketch.

The advantage of the arrangement shown consists in providing a means by which the morse subscriber can readily call the toll office when not plugged up for telegraph service. Thus suppose a subscriber desires telegraph service on some special occasion outside of the regular scheduled hours. If his line were wired direct to the telegraph instrument, he would have no direct means of calling, and would consequently have to call up from a local telephone. With the circuit as shown in Fig. 122, however, it is merely necessary to throw the switch to the telephone apparatus, when the toll operator can be called; the latter will switch the morse subscriber to the wire chief, who will then attend to his needs. Then when the plug for morse service is inserted in jack 1, the toll switchboard will be cut off by means of the break contacts in the jack, and the telegraph apparatus at the subscriber's premises can be placed in circuit by throwing the switch to normal.

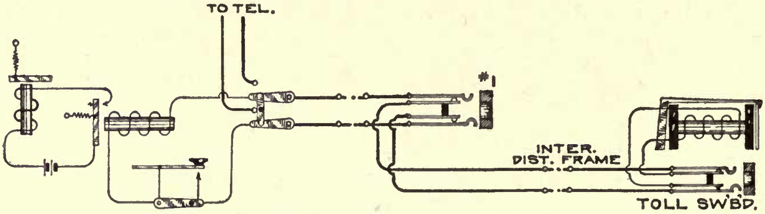


FIG. 122. — Leased Line Circuit.

The method of handling the telephone layout for simplex, composite and phantom operation has been fully discussed, but very little has been said regarding the operation of the battery panel. By referring to Fig. 119, it will be noted that a short-circuited twin plug inserted in jacks 19 and 20 and one inserted in jacks 23 and 24 will place negative and positive battery on the springs of jacks 14 and 18 respectively. Therefore, if a plug with a morse set attached is inserted in either of the jacks numbered 12, 13, 14, 16, 17 or 18, supervision or service can be directly obtained. The loop jacks are wired in each side of the line for flexibility and convenience. Jacks 11 and 15 in the morse panel are used for putting up leased lines or phantom connections; and they are therefore so wired that by plugging into them the remainder of the morse circuit is cut off by the break contacts. In case it is desired to place a telegraph repeater in the circuit, it can be plugged into jack 11 or 15 of the incoming line while the opposite tap is plugged into jack 11 or 15 of the outgoing line.

The general construction of a test board is identical with that employed for local boards. The framework of the section, which bears the weight of the apparatus and the mechanical strains, is made of angle iron. This frame is reinforced and covered by a wooden cabinet of proper design to give it a pleasing appearance.

The face of the board on which the various jacks are mounted is

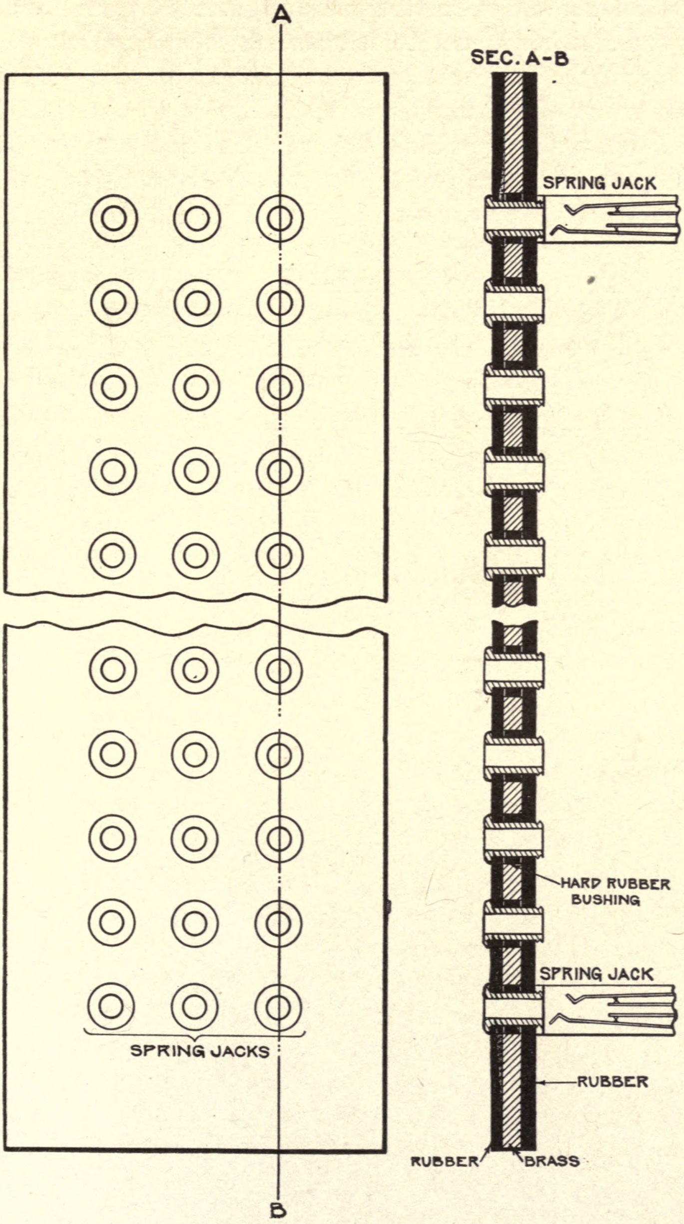


FIG. 123. — Construction of Jack Panels for Test and Morse Boards.

built of either solid hard rubber panels, or it may be made of sheet brass on either face of which is mounted a sheet of hard rubber. The former construction is used mostly for small equipments, while the latter is used for large equipments almost exclusively. The panel construction for large boards is shown in Fig. 123, from which it will be noted that the body of the panel is made of solid brass, which carries the mechanical strain of the equipment, the rubber sheet being used for insulation purposes only. In addition to the hard rubber which is fastened to each side of the brass strip, each jack hole is equipped with a rubber bushing to insulate the sleeve of the line jacks from the brass strip. The panel construction shown in Fig. 123 has been found practical, since brass is not affected materially by heat, and consequently the jacks mounted on a panel of this type are not thrown out of alignment due to the ordinary temperature variations. This is of vital importance, since a very slight contraction or expansion of the material upon which the jacks are mounted would make the use of twin plugs practically impossible. The brass sheet also acts as a reinforcement for the hard rubber, in that it keeps the rubber panel from either warping or buckling, since the same is rigidly attached to the sheet brass. This type of panel construction has met with great success in practice.

CHAPTER XVI

SMALL TEST PANELS

THE test and morse boards described in the last chapter are designed for offices of considerable size and are rather elaborate and expensive for the smaller toll systems. An efficient type of test board is just as essential in the small systems, however, as in those previously described. This fact has received somewhat tardy recognition, but such equipments have recently been standardized and merit special attention because of their extensive field of use. The smaller companies are commencing to realize that a test board, or panel, is of great benefit in handling toll lines, particularly in relation to phantom circuits and derived telegraph circuits.

Small toll stations very seldom have any use for simplex or composite equipment, since the demand for leased telegraph circuits is generally restricted to large business centers. While this is a fact it is nevertheless true that the telegraph can often be used economically for ordering up telephone connections on busy toll circuits. This reserves the circuits for revenue production exclusively, since their use by the operator in establishing connections is thus eliminated.

There are several ways in which the apparatus required for phantom operation may be installed. In some cases, the coils used to create a phantom circuit are permanently wired in the circuit. This practice would seem satisfactory if the lines are to be continually operated on a phantom basis. But as this is frequently not the case, it is better practice to insert the coils in the circuits in such a manner that they can be readily removed, making it possible to obtain a clear circuit for testing purposes, which is always essential.

In order that the equipment shall possess this desired flexibility, means must be provided for switching the various coils in and out of the line with the least amount of trouble, the continuity of the line being maintained, while this is accomplished. The amount of apparatus that is cut into the circuit for this purpose should be reduced to a minimum, so as to prevent the increase of office troubles. However, the possibility of additional trouble with apparatus which has been properly designed and correctly installed is very small.

The types of test panels used for this purpose should therefore be substantially built, of simple design and, above all, of moderate cost. Two views of a test panel which possesses these essential characteristics are shown in Fig. 124. This panel is typical of the Kellogg Switchboard and Supply Company's manufacture. It is designed for an ultimate capacity of forty wires, or twenty metallic circuits, and six pairs of phantom connecting cords; the equipment

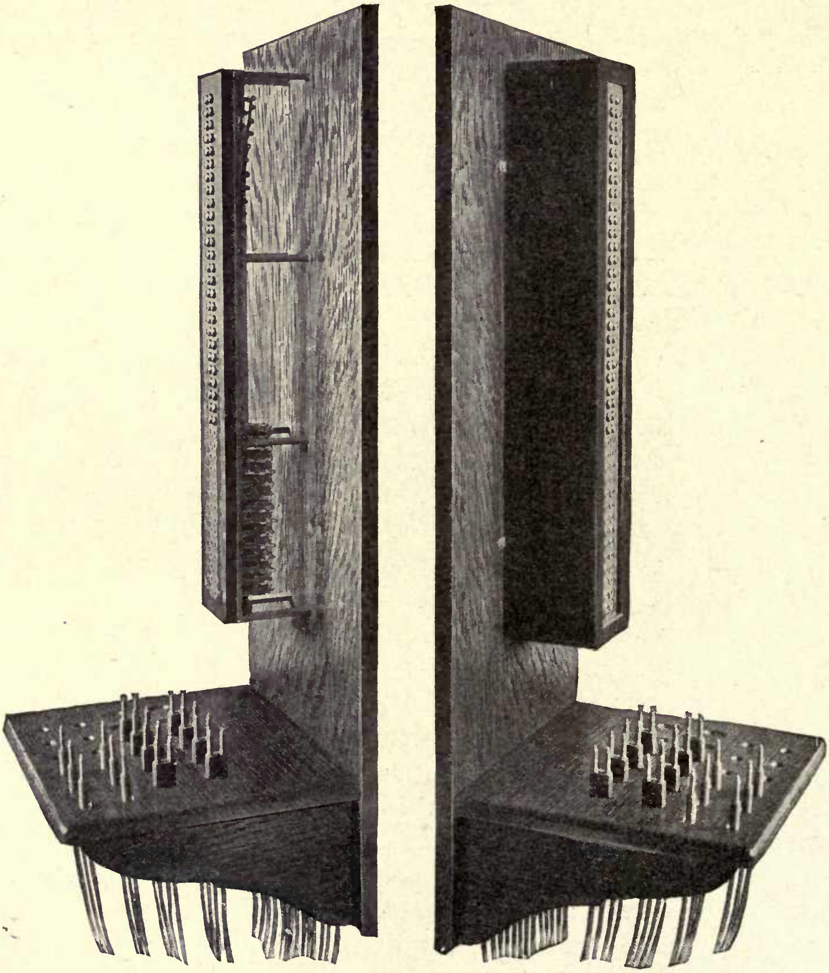


FIG. 124. — Forty-wire Test Panel.

shown in the figure consists of jacks for seven metallic lines and four cord circuits. The provision of space for additional equipment is generally advisable, since the increased cost of the larger cabinet is merely nominal and the future growth of the equipment can rarely be predetermined with great accuracy. The view to the left, in Fig. 124, shows the panel with the cover removed and displays the ease with which soldered connections on the jacks may be examined, as well as the simplicity with which additional equipment may be installed.

Fig. 125 shows a panel of different design, which is arranged for an ultimate of twenty wires or ten metallic circuits. Panels of this type can be made for any desired number of lines, but it is found convenient to divide the equipment into two or more panels when more than forty wires are to be accommodated. This is due to the

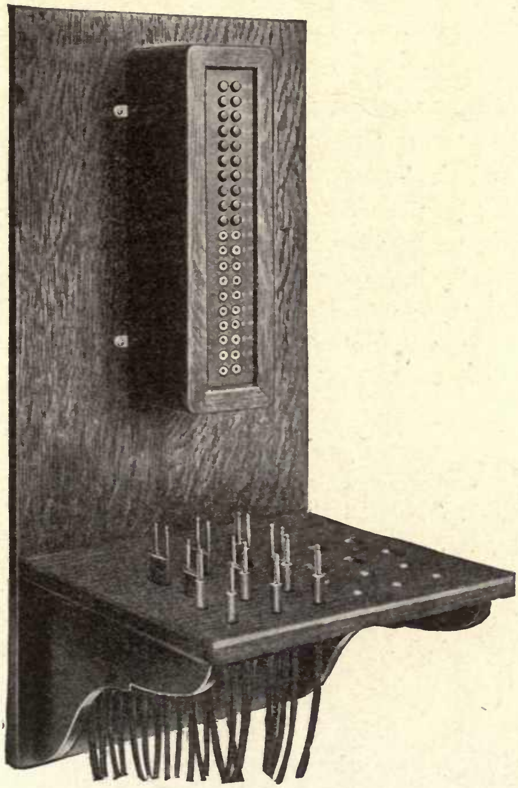


FIG. 125. — Twenty-wire Test Panel.

fact that it is hardly good practice to mount more than two rows of jacks on the same panel, because of the difficulty which would be encountered in inspecting the jack contacts. In case several rows of jacks are desired, this difficulty could be avoided by hinging the panel so that it might be swung away from the back board, thus making the jacks accessible. This type of construction can hardly be recommended, however, since it complicates the wiring in the respect that provisions have to be made for the necessary movement of the panel. Two or more panels similar to those shown are sometimes mounted on one back board, each panel having a separate cover or case; this is by far the better construction, when a larger capacity becomes necessary.

The two types of toll test panels just shown are provided only with line jacks, and phantom, composite and simplex cord equipment. However, these panels are often equipped with a telephone set and associated cords, to provide for talking and ringing on the lines at the panel. A panel of the Western Electric Co.'s type having a capacity of twenty-one wires is illustrated in Fig. 126.

FIG. 126.—Western Electric Company's Twenty-one Wire Toll Test Panel.

The jack panels or mounting strips used for these smaller equipments should be of the same rigid design as that described for the large boards in Chapter XV. As must be evident from the illustrations, this type of panel is designed to mount on the wall or some other convenient support; hence the coils required for phantom operation are not mounted in the cabinet, but placed at some convenient location near by and connected to the panel by means of a suitable cable. This practice of locating the coils outside of the cabinet greatly reduces the weight and the strain on the supports; it also permits of the use of a much smaller and less expensive cabinet.

The usual method of wiring panels of this type is shown in Fig. 127, which requires four jacks for each metallic line. As shown in the circuit, the line wires after passing through the standard protection of fuse and lightning arresters are connected to the single-conductor jacks on one side of the test panel. From this point the circuit can be traced through the single-conductor jack contacts to the jacks on the other side of the panel, from which they are wired direct to the switchboard. The panels are often equipped with two double-conductor jacks instead of four single-conductor jacks per line, for the purpose of reducing the jack panel space and the initial cost of the equipment. However, this practice sacrifices part of the flexibility and in a measure increases the possibility of poor contacts at the jacks, since a single-spring contact is depended upon in place of the double-spring. For these reasons, the use of two double-conductor jacks per circuit seems to be false economy.

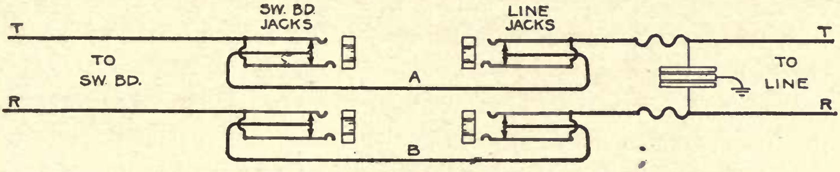


FIG. 127. — Wiring of Line Circuit for Small Test Panel.

The common method of arranging the jacks in the panel is shown in Fig. 128. The line jacks are grouped on one side of the panel and the switchboard jacks on the other. There are two general methods of designating the different jacks, so that they may be readily associated with the circuits to which they belong. One method is to stamp the number of the jack in the rubber panel, as shown in Fig. 128, while in the other method small card holders or designation strips are mounted at the right of the line jacks and the left of the switchboard jacks, as indicated in Fig. 126. The latter method is undoubtedly the better practice, since the cards used in connection with the designation strip may contain, in addition to the number of the circuit, the destination.

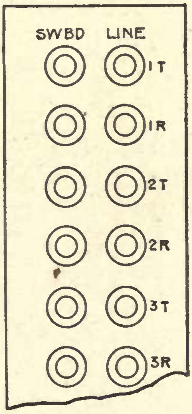


FIG. 128. — Jack Arrangement in Small Test Panel.

The directions which follow regarding the method of cabling and the size of the wire best suited for these small equipments seem appropriate, because this part of the installation is very frequently executed in a haphazard and unworkmanlike manner, which is conducive to much trouble. It is best to run a factory-made cable direct from the line jacks at the toll board to the switchboard jacks at the test panel, and from the corresponding jacks on the line side of the panel another factory-made cable should be used to carry the lines to the arresters. All the cable used in this connection should be composed of No. 14 or 16 B. & S. twisted pair wires, each wire having an insulation of two wrappings of silk and one of cotton. The wires marked *A* and *B* in Fig. 127 are usually No. 18 B. & S. bare, tinned, copper wire straps, this kind of wire being used for all the local wiring in the jacks.

For larger offices, it is often convenient to be able to cross-connect the lines so as to distribute the load between the various operators. The wiring which should then be used is shown in Fig. 129. The leads *A* and *B* from the back contacts of the jacks on the switchboard side of the panel, and *C* and *D* from the line jacks, are wired to a cross-connecting rack, where they may be interconnected as desired. A convenient and simple arrangement for such an equipment is shown in Fig. 130, which is sufficiently clear to make a further description unnecessary.

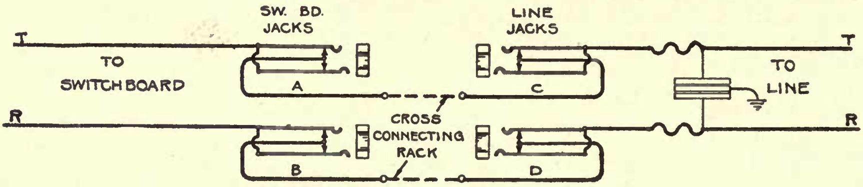


FIG. 129. — Line Wiring of Small Test Panel, Arranged for Cross-Connection.

This panel is typical of the class commonly known as toll test board extensions, in which no plug shelf or cord equipment is provided, and in which the coils used in the phantom and simplex connections terminate at the panel in jacks, in place of cords. A forty-one wire extension, as manufactured by the Western Electric Company, is illustrated in Fig. 131; no provision is made for cross-connection. The method of connecting the coils into the circuit with this class of equipment is indicated in Fig. 132; the line jacks being connected by patching cords to the jacks that are wired to the coils. The figure shows a line circuit connected as one side of a phantom, according to the retardation coil method; the middle point of the coil is connected to a phantom jack at the panel. Then, if two physical lines are thus connected, and the two phantom jacks are connected by means of patching cords to two switchboard jacks, the phantom line thus obtained will appear at the toll switchboard like any other

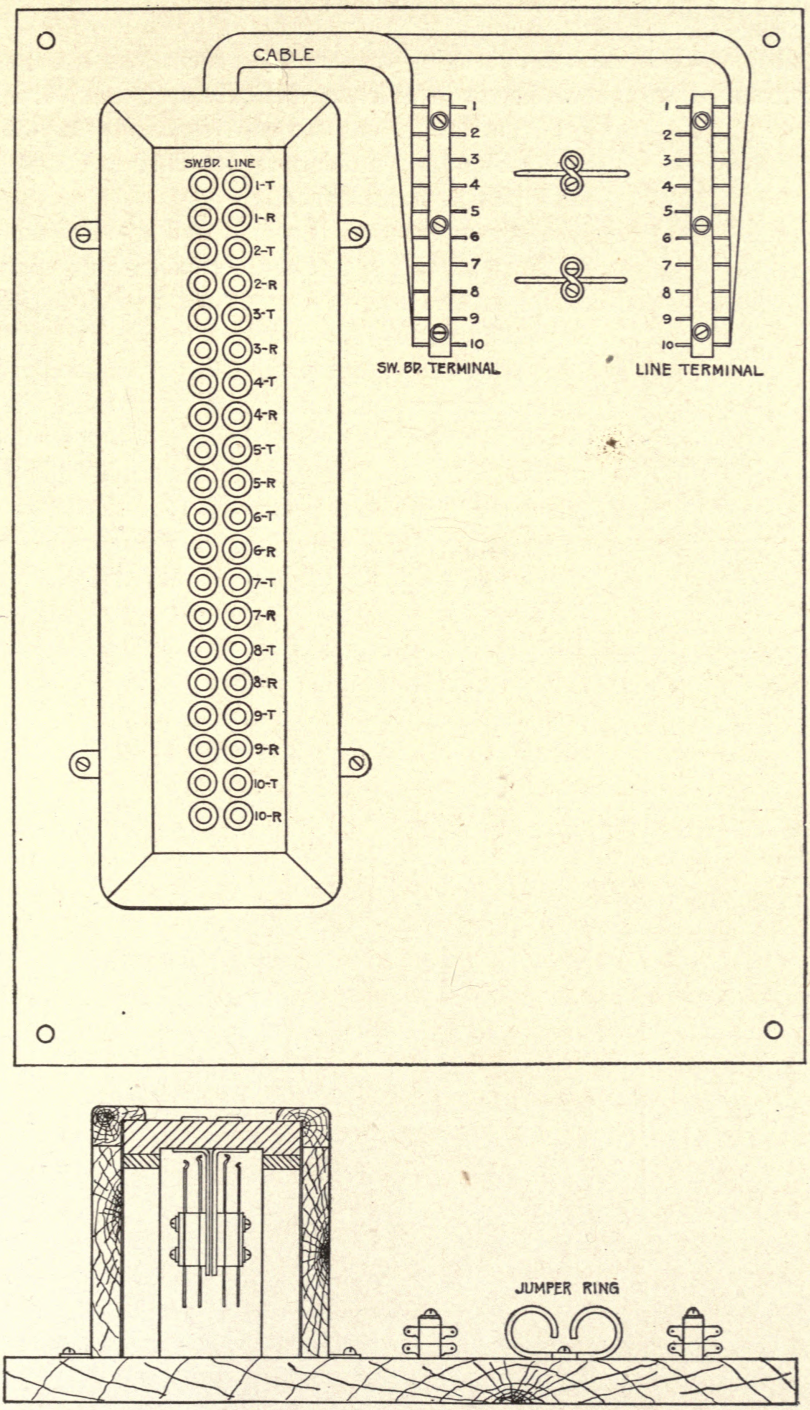


FIG. 130. — General Arrangement of Apparatus for a Small Test Panel.

toll line. This method of putting up phantom connections is not as convenient or rapid as the one in which cord circuits are used. These test board extensions are used especially for toll-line testing and patching, as described in Chapter XXI, on line maintenance.

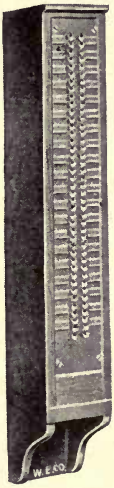


Fig. 131. — Western Electric Company's Forty-one Wire Toll Test Panel Extension.

In this connection it seems well to emphasize the fact that all toll stations, no matter how small, should be provided with some means for making simple line tests. This does not imply that every station should be provided with expensive testing instruments, but the simple preliminary tests should be possible at any station where line trouble manifests itself. For careful measurements to locate the trouble, the wire chief at the nearest large testing office should be called upon. The method of making these tests is fully described in Chapter XX.

To facilitate testing, two or more of the jacks may be wired to binding posts suitably located for this purpose. The desired connection with the test circuit can then be made by means of patching cords.

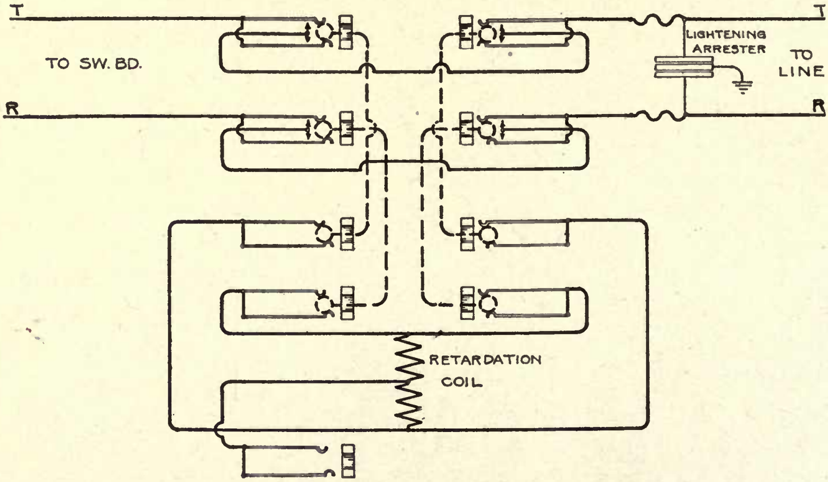


Fig. 132. — Simplex Wiring for Small Toll Test Panel.

A very convenient arrangement is a shelf or table just below the panel, on which the testing instruments and patching cords may be placed.

CHAPTER XVII

LINE CONSTRUCTION

Introduction. — In a toll system the outside plant usually represents three-quarters of the total investment, at least, and its correct design from an engineering standpoint is correspondingly important. There are few more intricate problems than those which arise here, involving the determination of correct proportions electrically and mechanically and an economical layout of routes. The quality of service depends not only upon correct design and good construction, but it is affected afterwards by the maintenance. Low costs in the last respect depend in turn upon the essentials for good service at the outset.

Construction standards have been advancing year by year, as a whole, and the present tendency is happily toward the policy that the best is none too good. The great need of stoutly built lines throughout those parts of the country subject to sleet storms has been learned from experience. Reliability is one of the well recognized elements of good service and should be taken into due account in mechanical design.

Toll-line construction at the present time falls in one of two general classes or types, aërial open-wire and underground cable. The former meets the requirements of long lines with a limited number of circuits, from an economic standpoint. It is greatly desirable to adopt the second, or underground type, however, when it does not produce excessive circuit charges, for the obvious advantage of greater reliability. Short toll lines connecting a city with its suburbs, or two adjacent cities, are usually underground as a matter of course. In these cases the ducts employed are usually part of a general underground system.

The cost of underground construction is prohibitive for toll lines carrying few circuits, especially the circuits for very long haul business. It was prohibitive in any case for circuits even of moderate length before the art of loading was developed. But since that event it has been found economical to place a few of the very large trunk lines in underground loaded cables. Such lines now connect New York and Philadelphia, New York and New Haven, and Chicago and Milwaukee. It is planned to extend the Philadelphia line to Baltimore and Washington and the New Haven line to Providence and Boston. In each instance these cables contain more circuits than could be sustained by a single pole line.

Except in rural districts toll lines are always metallic and the maximum capacity of the standard pole line of forty wires is therefore twenty circuits. Such lines have sometimes been overloaded and their capacity increased 25 per cent, or at the most 50 per cent, but this is attended with disadvantage from the standpoint of uninterrupted service.

The choice of pole-line routes is a most important matter and should receive careful study. The large telegraph companies have adopted rights-of-way on steam railroads to a great extent, partly for commercial reasons. The long-distance telephone companies have generally followed the policy of selecting country highways, one of the prominent reasons for which is the higher insulation which can be maintained.

In choosing a highway route between two given points it is usually possible to find a number of alternate routes which are feasible. The shortest route is generally the most economical one, but this cannot be settled finally until the total cost, including right-of-way, is estimated for each of the feasible routes. Preliminary to choosing a route, the country is driven over by an experienced locator, with a right-of-way agent, and the general conditions are carefully observed. Then the feasible routes are laid out accurately on a map and the cost of each route is determined as nearly as possible.

Private right-of-way is usually undesirable, because it is more expensive to distribute material, and more expensive afterwards to maintain the line. At the same time, where such routes will save long detours by highway, or avoid difficult obstacles, they may be the better choice.

The legal title to a right-of-way should always be made secure by obtaining the proper consents from the authorities and the property owners. This will save much future expense from changes in location and damage suits, and perhaps from the attempts of other companies to overbuild or underbuild along the same route. At the same time the necessary trimming rights should be secured, not only to clear the line of foliage when built, but to keep it clear afterward as a matter of maintenance.

The Line. — The properties of telephone lines have been extensively treated in another chapter, but it is essential to keep certain features in mind from a construction standpoint. High efficiency of transmission with uniform (unloaded) lines of open wire depends on low resistance, low capacity and high insulation; it depends also on a practically perfect balance between the two sides of a metallic circuit, which should be alike in resistance, capacity and insulation.

These facts should be kept clearly in mind in line building. Metallic pairs should always consist of the same size and kind of wire and the joints should be looked after with the utmost care. The insulation should be attended to with the same care and only perfectly whole insulators should ever be used. The trimming should be followed up carefully and all guys should clear the line wires by a safe distance.

Transpositions are usually cut in after the wires are strung, pulled up and tied in. They should never be cut in, however, until the line has been carefully measured and the transposition poles accurately located and marked.

When stringing additional circuits the transpositions can sometimes be cut in conveniently as the wire is strung, thus avoiding extra cuts and joints. But as a rule it is best to proceed with only one operation at a time.

As fast as the line is completed it ought to be carefully inspected for faults of every kind, before the crew is too far away to make alterations economically. The matter of inspection is most important and pays for itself in many ways, especially when the crews are under pressure to hold the unit costs down to a minimum.

There is little more to be said from an electrical standpoint as it concerns construction, aside from what follows in relation to the properties of line wire. The mechanical features of line construction are fully taken up in the succeeding portions of the present chapter.

Line Wire. — The only wire that should be used in the construction of toll lines, especially the long lines, is hard-drawn copper. It is true, of course, that for short branches and sometimes for a main line of medium length, say one hundred fifty miles, Extra Best Best iron wire can be used. However, due to the intrinsic value of copper and its property of resisting corrosion, it should always be used unless special conditions make iron more economical.

The intrinsic value of copper remains the same, on the average, even after it has been in use for years. During the past few years when the price was continually fluctuating, it frequently happened that a telephone company, by closely following the market and purchasing at greatest advantage, could buy line wire and after six months' or a year's use find its value enhanced considerably — perhaps 20 per cent or more.

It hardly seems necessary to add that the inferior grades of iron wire, such as Best Best and steel, should never be used except for very short distances where an extremely long span is unavoidable, where conductivity must be sacrificed for tensile strength. By tensile strength is meant the ability to resist a direct pulling stress and this is usually stated as the ultimate strength or the pulling stress in pounds required to break the wire. Good hard-drawn copper wire has a tensile strength equal at least to three times its own weight in pounds per mile; and in drawing specifications for such wire a clause stipulating this degree of strength is usually inserted. Of course the most important electrical property of a conductor is its conductivity or conductance. A conductor whose resistance is r ohms has a conductance equal to $\frac{1}{r}$, *i.e.*, the conductance varies inversely with the resistance; and since the resistance varies directly with the cross section of the conductor, the conductance must vary inversely with the cross section. Thus an iron wire having about six times the cross sectional area of a given copper wire would equal the latter in resistance; but the additional cross section of the iron wire would increase the distributed capacity of the line and impair its efficiency. Besides this, the additional weight of the iron wire would so increase the strain on pins, cross-arms and poles, as to call for much heavier construction throughout, at greatly increased cost.

A most convenient method of comparing the conductivity of wires, regardless of their size, is the mile-ohm, or more properly, the weight per mile-ohm. The weight per mile-ohm, as the words clearly indicate, is the weight of a circular wire one mile long and of such a cross section as to have a resistance of one ohm. Naturally the value of the mile-ohm will decrease as the conductivity of the metal increases; or in other words, the conductivity varies inversely with the weight per mile-ohm. Obviously the mile-ohm equals the weight per mile multiplied by the resistance per mile. The conductivities of two metals can be readily compared if the weight per mile-ohm of each is known. Thus if the weight per mile-ohm of pure annealed copper is 859 and that of a sample is 900, the percentage of conductivity X of the sample, taking pure copper as a standard, is then determined from the proportion

$$X : 100 :: 859 : 900.$$

$$X = \frac{100 \times 859}{900} = 95.44\%.$$

From the formula that the mile-ohm equals weight per mile times resistance per mile, we can obtain any one of the three quantities if the other two are known. Thus the resistance per mile equals the mile-ohm divided by weight per mile, and the weight per mile equals the mile-ohm divided by resistance per mile.

As previously stated, copper is the best conductor for long toll lines, because no other material gives so good a combination of tensile strength and conductivity. The tensile strength of annealed copper is about 34,000 pounds per square inch, and this figure is raised by hard drawing to 60,000 or even 70,000 pounds per square inch, with a corresponding increase in the resistance of only 2 per cent to 4 per cent. The copper line wire should be free from flaws, seams, scale and all other mechanical imperfections, and should be cylindrical in form and within one and one-half mils of the nominal gauge. The following are specifications submitted to the manufacturers who furnish copper wire for the largest toll-line companies in the United States.

> "**Specification for Line Wire.** — The standard line wire shall be of hard-drawn copper and shall conform to the following specifications:
>
> "The quality of copper used, the method of manufacture, and the method of handling and shipment of the wire shall be such as to insure for the wire the mechanical and electrical properties and the finish called for in these specifications. The quality of the copper used, the electrical and mechanical properties and the finish of the wire must be determined by the manufacturer before the wire is delivered. The telephone company is to have the right to make such tests as it may desire of the quality of the copper used, of the electrical and mechanical properties and finish of the wire at any time, before, during, or after the process of manufacture, and to have an inspector of its own witness the whole or any portion of the manufacture, handling, or shipment of the wire. The inspector of the telephone company is to have the power to reject any of the material or finished wire which the herein required tests

show to be defective in any way. The inspection of the copper used, and of the process of manufacture shall, however, not relieve the manufacturer from the obligation of furnishing perfect material, and sound and reliable work; and any imperfect material, or unfaithful work, that may be discovered before the final acceptance of the wire shall be corrected immediately upon the requirement of the telephone company, notwithstanding that it may have been overlooked by the inspector. If upon test it be found by the telephone company that the requirements for the wire, or for the finish, are not fulfilled when the wire is offered for final acceptance, the expense of all tests made by the telephone company on such defective wire shall be borne by the manufacturer.

" **Manufacture.** — The copper bars before rolling shall be entirely free from defects. Each coil shall be drawn in one continuous length and shall be free from factory joints.

" **Finish.** — The wire shall be uniformly cylindrical in form and free from scales, inequalities, flaws, splints and all other imperfections.

Mechanical and Electrical Requirements

" The weight in pounds per mile is found by multiplying the square of the diameter of the wire in inches by the constant number 16,030.

" **Coils.** — Unless otherwise specified by the telephone company, the weights of the coils shall lie within the limits given in Table 1.

" The diameter of the eye of the coil shall, in every case, be not less than 20 inches nor more than 22 inches.

" **Packing for Shipment.** — Each coil shall be securely bound with at least four separate pieces of strong twine, and shall be so protected by wrappings of burlap, that there will be no danger of mechanical injury to the coil during transportation. These wrappings of burlap must be placed upon the coil after it has been secured, as specified above, by the twine. Each coil shall have its weight and length of wire plainly and indelibly marked on two strong tags. One of these tags shall be attached to the coil outside of the burlap.

" **Testing Apparatus.** — All tests must be made with apparatus satisfactory to the telephone company."

In this connection it might be well to add a few remarks regarding standard sizes in which wire is drawn. The Birmingham Wire Gauge, abbreviated B. W. G., is more commonly used for iron wire, while the Brown and Sharpe Gauge, abbreviated B. & S. and the New British Standard Gauge, N. B. S. G., are most frequently used for copper wire. A few well-known relations between the wire sizes in the B. & S. gauge will be appended, as they afford a ready means of remembering the entire table. The diameter of the wire is expressed

TABLE I

PROPERTIES OF HARD-DRAWN COPPER WIRE

Number and Gauge.	Diameter in Mils.			Weights per Mile.			Breaking Weight.		Weight of Coils.		Conductivity.		Twists in 6 Inches.	Per Cent Elongation in 5 Feet.
	Required.	Maximum.	Minimum.	Required.	Maximum.	Minimum.	Actual Required.	Per Square Inch.	Maximum.	Minimum.	Required.	Minimum.		
8 B.W.G......	165.0	166.0	164.0	436.4	441.7	431.1	1328	62,108	218	152	97	96	30	1.14
10 B.W.G......	134.0	134.9	133.1	287.8	291.7	284.0	894	63,400	......	......	97	96	....	1.07
10 N.B.S.......	128.0	128.8	127.2	162.6	265.9	259.4	820	63,700	......	......	97	96	....	1.06
8 B. & S......	128.0	129.0	127.0	262.0	265.0	260.0	....	....	218	152	97	96	35	1.05
12 N.B.S.......	104.0	104.7	103.3	173.4	175.7	171.1	549	64,600	219	151	97	96	40	1.00
10 B. & S......	101.9	102.8	101.0	165.0	168.0	162.0	540	64,800	218	152	97	96	40	.99
13 N.B.S.......	92.0	92.6	91.4	135.7	137.5	133.9	433	65,100	......	......	97	96	....	.97
12 B. & S......	80.8	81.3	80.3	104.7	106.0	103.4	336	65,500	72	52	97	96	44	.95
14 N.B.S.......	80.0	80.5	79.5	102.6	103.9	101.3	330	65,600	72	53	97	96	44	.94
16 B.W.G......	65.0	65.5	64.5	67.7	68.8	66.7	220	66,200	......	......	97	96	....	.91
14 B. & S......	64.0	65.0	63.0	65.0	67.5	63.0	220	68,200	......	......	97	96	47	.91

in mils, or one-thousandths of an inch, and the area of the cross section is expressed in circular mils, which for any given size of wire is the square of the diameter. The area may also be expressed in square mils, which gives the true area in thousandths of a square inch and equal the square of the diameter in mils, times 0.7854. It may be well to bear in mind that the circular mil is to the square mil as the circle is to the square in which it is inscribed; and, consequently, the number of circular mils in a given area is always greater than the number of square mils.

Regarding the relation between the different sizes of wire in the B. & S. table, it may be noted that a wire which is three sizes larger than another will have twice the weight and one-half the resistance, and a wire which is ten sizes larger than another will be ten times as heavy and have one-tenth the resistance. Then by knowing the above relation and remembering that No. 10 B. & S. wire is approximately one-tenth of an inch in diameter and has a resistance of one ohm and a weight of thirty-two pounds per thousand feet, the whole table can be constructed mentally with sufficient accuracy for practical purposes. An additional relation which should be remembered is that the number of feet per ohm can be ascertained by dropping one cipher from the number expressing the circular mils in the conductor;

TABLE 2

BROWN AND SHARPE WIRE GAUGE

B. & S. Gauge.	Diameter in Mils.	Area in Circular Mils.	Weight in Pounds per 1000 Feet.	Tensile Strength.		Feet per Pound of Copper.	Ohms per 1000 Feet at 68° F. Hard-drawn.
				Hard-drawn.	Annealed.		
0	325	105,534	319.4	4973	2819	3.13	.10033
1	289	83,694	253.3	3943	2234	3.95	.12649
2	258	66,373	200.9	3127	1772	4.99	.15953
3	229	52,634	159.3	2480	1405	6.29	.20114
4	204	41,743	126.3	1967	1114	7.93	.25361
5	182	33,102	100.2	1560	884	10.00	.31987
6	162	26,250	79.4	1237	700	12.61	.40332
7	144	20,820	63.01	980	555	15.90	.50854
8	128	16,510	49.97	778	440	20.05	.64127
9	114	13,092	39.64	617	349	25.28	.80876
10	102	10,384	31.42	489	277	31.38	1.0199
11	90.7	8,234	24.92	388	219	40.20	1.2854
12	80.8	6,530	19.8	307	174	50.69	1.6218
13	72.0	5,178	15.7	244	138	63.91	2.0443
14	64.1	4,107	12.4	193	109	80.59	2.5779

also that the weight may be ascertained by dropping four ciphers from the number of circular mils and multiplying by the weight of No. 10 B. & S. wire.[1]

Table 2 gives the number, the area in circular mils, the weight in pounds, the tensile strength and the resistance in ohms per thousand feet in the B. & S. gauge.

Spans. — As already stated, copper wire when hard-drawn has a tensile strength of about 60,000 pounds per square inch and an elastic limit of about 30,000 pounds. These values represent the ultimate and should never be used in determining the proportions of a line. The actual strength of any size of wire, as given in Table 2, should always be divided by a proper factor of safety.

The several factors which determine the stresses in wire spans are the length of span, initial sag at the center of the span, changes of temperature, weight of the conductor and external loads of wind, sleet and snow. The stresses caused by external loads are often very formidable and frequently cause great trouble, due to the fact that they are not sufficiently considered in the design of the line.

It is a fundamental principle of mechanics that a uniform wire which is freely suspended between two supports, will assume a curve technically known as the catenary, when equilibrium is established. However, the exact determination of the stresses by means of this curve is not convenient; but in the case under consideration, the parabola, a much simpler curve, closely approximates the catenary, and will be used in the following deductions. The parabola is the curve that is assumed by a cord of no weight, under equilibrium, when loaded with an infinite number of infinitely small equal weights, which are uniformly distributed horizontally. Then, referring to Fig. 133, if a wire is suspended between the points *A* and *C*, it will take the curve *ABC*. What must now be determined is the relation

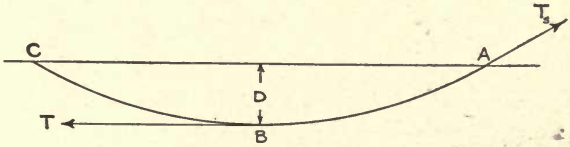


FIG. 133

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[1] "How To Remember the Wire Table," by Chas. F. Scott, in the Electric Journal, April, 1905.

between AC, or the length of the span which we shall call L, the vertical deflection d at the middle point of the span, the horizontal tension on the wire at the center of the span and the weight of the wire per foot. This relation can be expressed as follows:

$$T = \frac{L^2 w}{8d}, \quad \ldots \ldots \ldots \quad (1)$$

or

$$d = \frac{L^2 w}{8T}, \quad \ldots \ldots \ldots \quad (2)$$

in which L is the length of the span in feet, d is the central deflection in feet, T is the tension on the wire at the center of the span in pounds, and w the weight of the wire in pounds per foot.

The stress at any other point than the center of the span equals the stress at the center plus the weight of a length of wire equal to the perpendicular distance from that point to the lowest point of the wire in the span. Thus the stress at the supports A and C equals a $T_s = T + dw$. The quantity dw for ordinary spans is negligible and, consequently, has been disregarded because of the complication it would introduce in the formula.

From equations (1) and (2) it will be noted that for a given wire and span the tension varies inversely as the deflection, and that for a given tension and wire, the deflection varies directly with the square of the span; hence the strain on the wire can be reduced either by shortening the span or by increasing the deflection. To give a concrete example, we shall consider the case of a No. 8 B. & S. copper line on poles that are spaced at 130 feet, or approximately forty to the mile. Then what must be the deflection, assuming a factor of safety of four? This means that the tension T in the above formula should not exceed one-quarter of the breaking strain of the wire, which from the table gives a maximum value of 194 pounds. Using this value of T as a basis, we shall now determine from formula (2) what the minimum deflection at the center of the span should be. Then, proceeding upon the assumption that the wire has been given the calculated deflection, we shall further assume a most severe temperature variation in combination with external forces which are but seldom met, but which, nevertheless, are a possibility, especially in northern climates. This calculation is given in order to show the great necessity of a proper consideration of the natural forces, such as wind and sleet, in the design of toll lines, if they are to be proof against the ravages of a severe winter. Having assumed our value of T we now find the weight of the wire, from the table, to equal .049 pound per foot. Then if we substitute these values in equation (2), we have

$$d = \frac{130^2 \times .049}{8 \times 194} = 0.534 \text{ foot} = 6.41 \text{ inches.}$$

This minimum deflection should never be exceeded and, consequently, must correspond to the lowest temperature which can be expected. The deflection given to a line at a stated temperature must be so great that when the wire contracts in cold weather, the resultant deflection will not be less than the minimum. To ascertain the deflection required at some given temperature, within specified temperature limits, we must determine the length of the wire in the span at the time of erection and also for the lowest probable temperature. The total length of the wire in the span is approximately

$$L' = L + \frac{8\,d^2}{3\,L}, \quad \dots\dots\dots \quad (3)$$

from which the value of

$$d = \sqrt{\frac{3\,L\,(L' - L)}{8}}, \quad \dots\dots\dots \quad (4)$$

in which L' is the actual length of the wire and L the length of the span. Then if we take the coefficient of expansion of copper, per degree F., as 0.000,009,3 of its length we can readily determine the actual length of the wire in a span at any temperature.

If we assume in the previous example that the wire was erected at 90° and that the minimum temperature to which it will be exposed is $-10°$ F., then a sufficient deflection must be allowed at 90° to bring the deflection at $-10°$ to the minimum value just obtained. The length of the wire at $-10°$ F. is obtained from equation (3).

$$L' = 130 + \frac{8 \times (0.534)^2}{390} = 130.0.$$

This would be increased at 90° F., or for a temperature variation of 100° F., to 130.0 × .000,009,3 × 100, this giving a length at the higher temperature of 130.0 + (130.0 × .000,009,3 × 100) or 130.121 feet. The required deflection for this length can now be determined by equation (4), or

$$d = \sqrt{\frac{390 \times (130.121 - 130)}{8}} = 2.43 \text{ feet} = 29.2 \text{ inches.}$$

The comparison of the deflection just calculated with the previous deflection of 6.41 inches shows that a large temperature allowance should be made. However, in practice, the changes in deflection due to temperature changes are found not to correspond exactly with the law of expansion, because of elastic stretching under tension. This partly offsets the changes in length due to temperature, thereby lessening the changes in deflection. The actual behavior of copper wire, when erected under various tensions, has never been exhaustively determined; but it is safe to assume that the effective coefficient of expansion is subject to considerable variation, and a value of 0.000,004 instead of 0.000,009,3 is probably a fair approximation. In Table 3 are the temperature effects in spans as given in Roebling's handbook.

TABLE 3

TEMPERATURE EFFECTS IN SPANS OF HARD-DRAWN COPPER WIRE

Spans in Feet.	Deflections in Inches for Different Temperatures — Fahrenheit.								
	−10°	30°	40°	50°	60°	70°	80°	90°	100°
50	.5	6	8	9	9	10	11	11	12
60	.7	8	10	11	11	12	13	13	14
70	1.0	10	11	12	13	14	15	15	17
80	1.2	11	13	14	15	16	17	18	19
90	1.6	13	14	16	17	18	19	20	21
100	1.9	14	16	17	19	20	21	23	24
110	2.3	16	18	19	21	22	24	25	26
120	2.8	17	19	21	22	24	26	27	28
130	3.2	19	21	23	25	26	28	29	31
140	3.7	20	23	25	27	28	30	32	33
150	4.3	22	24	26	28	30	32	34	36
160	4.9	23	26	28	30	32	34	36	38
170	5.5	25	28	30	32	35	37	38	40
180	6.2	26	29	32	34	37	39	41	43
190	7.0	28	31	34	36	39	41	43	45
200	7.7	31	33	36	38	41	43	45	48

It will be noted that the deflections at −10° F., in this table, are based on a stress of 30,000 pounds per square inch, thus utilizing a factor of safety of two; and as the safety factor used in our calculation is four, the calculated deflection at −10° is approximately twice as great as that given in the table.

In our calculation thus far we have taken care of the weight of the wire itself, but we have not considered any of the external forces to which it is exposed. These manifest themselves in additional weight caused by a coating of sleet on the wire, and in wind pressure on the bare or ice-covered surface of the wire.

We shall consequently assume that our line has become coated with ice to a thickness of three-eighths of an inch, which is quite common during severe weather in many localities. Fig. 134 is a photograph of a piece of ice-coated wire taken from a line near Winona, Minnesota. This line was exposed to a sleet storm on Jan. 28, 1909, which resulted in the sleet formation shown; this measured $2\frac{1}{4}$ by $4\frac{1}{4}$ inches. This shows the possibilities of sleet formation and indicates that a three-eighths inch formation is not an abnormal condition. A layer of ice three-eighths of an inch in thickness would weigh 0.237 pound per linear foot, which is approximately five times the weight of the wire itself, and would increase the stresses severely. Assuming this load at the minimum temperature of $-10°$, for which the calculated deflection is 0.534 foot, we can obtain the tension at the center of the span from equation (1), or

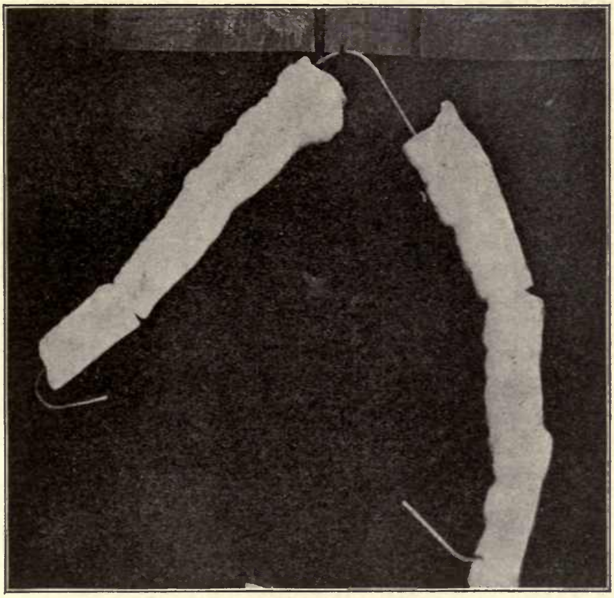

FIG. 134. — Illustration of Ice-coated Wire.

$$T = \frac{(130)^2 \times (0.237 + 0.049)}{8 \times 0.534} = 1130 \text{ pounds}.$$

This stress is 354 pounds greater than the ultimate tensile strength of the wire as given in the table and the wire would consequently stretch or break. Due to the fact that this ice load is often neglected, many telephone companies suffer severely in sleet storms even of moderate severity. The proper remedy is larger deflections, shorter spans, or stronger conductors; otherwise such conditions as those shown in Fig. 135 are unavoidable.

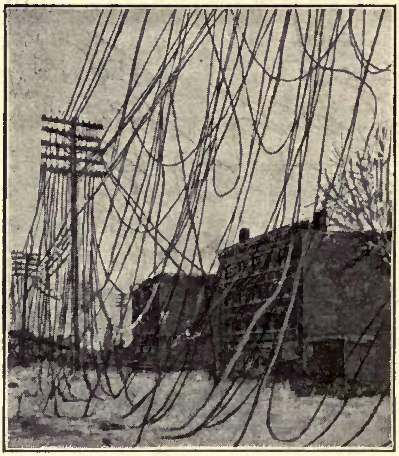

FIG. 135. — Effect of Ice Formation on Line Wire.

In addition to the ice load we have the wind pressure to consider. This pressure may be considered as acting at right angles to the weight of the wire, and its component of downward pressure frequently increases very considerably the resulting total stress. The pressure P to which the line wire is exposed may be expressed by the equation

$$P = 0.05\,pD, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

in which p is the normal pressure of the wind in pounds per square foot and D the diameter of the wire in inches. The pressure p may vary from a few ounces per square foot in a moderate breeze to from 30 to 40 pounds per square foot in a hurricane. We shall now assume that a No. 8 B. & S. wire is subject to the maximum pressure of 40 pounds per square foot, when the pressure p from the above formula is

$$0.05 \times 40 \times 0.128 = 0.256 \text{ pound.}$$

This pressure is exerted at right angles to the weight of the wire and, consequently, the resulting stress is

$$W = \sqrt{w^2 + p^2} = \sqrt{(0.049)^2 + (0.256)^2} = 0.261 \text{ pound.}$$

Substituting this value of W, 0.261, for W in equation (1), gives the tension on the wire under the assumed conditions of wind pressure of 40 pounds per square foot and a deflection of 0.534 foot. Thus

$$T = \frac{(130)^2 \times 0.261}{8 \times 0.534} = 1033 \text{ pounds.}$$

This stress is obviously more than the wire can stand without stretching or breaking, because it is 257 pounds greater than the breaking weight. In this calculation the wire was subjected to a wind load without sleet, and even then the stress was shown to be dangerous. Assuming now but half the wind pressure, or 20 pounds per square foot, in combination with the previous sleet load, it is evident that the result would be disastrous, for in this case D, the diameter of the wire, is 0.878 inch. Then

$$P = 0.05 \times 20 \times 0.878 = 0.878 \text{ pound,}$$

and

$$W = \sqrt{(0.286)^2 + (0.878)^2} = 0.923 \text{ pound.}$$

By substituting in equation (1),

$$T = \frac{(130)^2 \times 0.923}{8 \times 0.534} = 3650 \text{ pounds.}$$

This tension is nearly five times the breaking weight of the wire, which would consequently give way long before conditions as severe as those assumed have been reached. This shows that if the line is exposed to very severe conditions, similar to those assumed, a large initial factor of safety is necessary to insure uninterrupted service. It must be remembered, however, that in these calculations the supports were assumed to be perfectly rigid under all conditions of stress and the wire to be inelastic. This, of course, is never true in practice, as all material is more or less elastic, and the occasional changes in direction of a line relieve the stresses somewhat by bending of the supports. The standard practice of the American Telephone and Telegraph Company in this respect is as follows:

> "**Sag of Wires.** — The wire shall be strung with a uniform sag so that all the wires on each cross-arm shall be even and level, except where No. 14 N. B. S. G. wires are on the same arm with No. 8 B. W. G. or No. 12 N. B. S. G. wires.
>
> "The sag for No. 8 and No. 12 wires shall be as given in Table 4, making the allowance therein indicated for temperature and length of span.
>
> "The sag for No. 14 N. B. S. G. wires shall be at least two inches greater than that indicated in Table 4 for the same temperature and spans."

The deflections given in Table 4 apply to the entire plant of the American Telephone and Telegraph Company. Both theory and experience show that these deflections are inadequate for severe conditions, such as heavy sleet storms attended with considerable wind. But the deflections which would make the conductors theoretically safe under such conditions are not permissible, because the adjacent spans would often swing into contact. The only complete remedy is shorter spans or stronger wires.

For very long spans, such as river crossings, copper is not well suited because of its low elastic limit and moderate strength. Copper has a tensile strength of about three times its weight per mile, while steel has a corresponding ratio of 3.7. The ratios for silicon-bronze, phosphor-bronze and copper-clad steel are about 5; still higher ratios can be obtained with special grades of steel. A wire having a ratio of 10 has been used for spans of 2000 to 3000 feet, with satisfactory results. In all cases conductivity must be sacrificed to secure increased tensile strength.

TABLE 4

TABLE OF SAG IN HARD-DRAWN COPPER WIRES FROM THE PRACTICE OF THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY

Spans in Feet.	Deflection in Inches for Different Temperatures — Fahrenheit.						
	−30	−10	+10	+30	+60	+80	+100
75	1	1.5	1.5	2	2.5	3	4.5
100	2	2.5	3	3	4.5	5.5	7
115	2.5	3	3.5	4	5.5	7	9
130	3.5	4	4.5	5.5	7	8.5	11
150	4.5	5	6	7	9	11.5	14
200	8	9	10.5	12	15.5	19	22.5

Poles. — The poles used to the greatest extent in the United States are northern white cedar, chestnut, cypress, northern pine, redwood and juniper. Of these the cedar, chestnut, pine, and juniper are the most desirable in the eastern and central parts of the United States and cypress in the south; while west of the Rocky mountains, redwood is used to a great extent. In the selection of timber, the locality in which it is to be used must always be considered, both from the standpoint of its life in the soil and the distance it must be transported. Native timber is more economical, in some cases, by reason of the fact that it requires little or no transportation.

Of the kinds of timber mentioned, white cedar is undoubtedly the most extensively used and is generally regarded as the most satisfactory. The extensive demand for it has raised the price and diminished the supply, however, year by year. Chestnut, which is a tough strong wood possessing a strength equal to that of cedar and 50 per cent greater elasticity, is displacing cedar to a considerable extent. One objection raised against chestnut is its crooked growth; this is a valid point for city lines, but not in the case of ordinary toll lines in open country. One point in favor of chestnut, which should not be overlooked, is its resistance to fire, or slow combustion, in which respect it is superior to the other kinds of timber mentioned. Cedar, on the other hand, grows very dry with age and becomes somewhat brittle. This gives chestnut considerable advantage on or near steam railroad right-of-way.

TABLE 5

AVERAGE LIFE OF POLES

Wood.	Years.
Chestnut	8 to 15
Michigan white cedar	10 to 18
Juniper	12
Cypress	6 to 10

The best poles will be obtained from slow-growth timber and should be of sound live wood, squared at both ends, reasonably straight, and well proportioned from butt to top. They should be peeled, trimmed and shaved; the knots should be trimmed close and the final dimensions should be approximately as given in Table 6. A pole is considered commercially or reasonably straight when a bend in one direction does not exceed one inch in every five feet of length.

The season of the year at which poles are cut is also of considerable importance. Winter is generally accepted as the proper time for cutting, since the conditions at this season are the most favorable for logging operations; and at this season the tree sap contains fewer nitrogenous substances from which fungi obtain their food, than at other seasons, so that winter-cut timber is the least liable to attacks from this source. When cut during the other seasons, the pole is very likely to be subject to dry rot, and although the pole looks strong and substantial, it loses much of its strength from this cause. Furthermore, winter-cut poles will season more gradually, the wood fibers shrink more uniformly and checking is not as serious. Checking or splitting is due to uneven shrinkage as the process of seasoning goes on, and rapid shrinking, except after the wood is soaked or steamed, will almost invariably result in serious checking.

The height of the poles to be used on a line is naturally determined by local conditions and by the number of circuits that are to be ultimately strung, or by the ultimate number of cross-arms. A safe rule in this respect specifies that the wire shall not be less than 20 feet from the ground at any point; of course this rule is subject to exceptions in such cases as the crossing of railroad tracks, where the height of the wires should be sufficient to clear trainmen standing on box cars, with a safe margin. In fact the height of the wires at railroad crossings is usually regulated by state laws.

TABLE 6

APPROXIMATE SIZES OF POLES

Length in Feet.	Circumference at Top in Inches.	Circumference 6 Feet from Butt, in Inches.
30	22	36
35	22	40
40	22	43
45	22	47
50	22	50
55	22	53
60	22	56
65	22	59
70	22	62
75	22	65
80	22	69
85	22	72
90	22	75

Before leaving the subject of the material to be used for poles, the use of steel and reinforced concrete will be mentioned briefly. This type of construction is becoming more important because the price of timber is steadily advancing. The steel poles consist of three steel bars, which are imbedded in a concrete base and gradually taper toward the top, the bars being held in their relative positions by steel bands placed at regular intervals along the entire length of the pole. These poles can be made of much greater strength than the wooden poles, and if they are kept thoroughly painted should last almost indefinitely. Reinforced concrete poles are reinforced by steel rods that are placed three-quarters of an inch from the surface at the corners of the pole, as shown in the cross section in Fig. 136. Each pole is formed on the ground near the hole in which it is to be set. These poles are so heavy that the cost of transportation for any material distance is generally prohibitive. The framing, roofing, boring and stepping of the pole are all taken care of in the molding. These poles are naturally of very great strength and are practically indestructible; they should consequently be of great value for terminal poles. They require no attention after they are once set, as the painting necessary with other types of construction is eliminated and the concrete, when properly handled in construction, improves with age and is not subject to decay or corrosion.

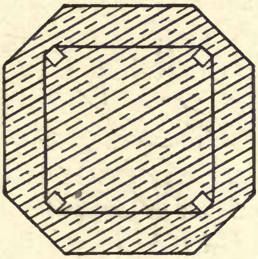

FIG. 136. — Cross Section of Concrete Pole.

The increased cost of timber has focused attention on the possible means of increasing its life, and the experiments with preservative treatments are worth careful consideration. Such treatment is strongly recommended by the United States Department of Agriculture, which, in conjunction with the American Telephone and Telegraph Company, has been conducting extensive experiments with various methods. It has been estimated by the government that there are 32,000,000 poles in use in the United States; assuming the average life of a pole to be twelve years, it will require 2,670,000 poles annually to maintain the lines now in operation. This enormous demand, considered in conjunction with new development, is a severe drain on the supply; consequently, any method which will prolong the life will conserve the forests and reduce the annual charges on wooden pole lines.

The point at which the pole enters the ground and where it first commences to decay is termed the wind and water line. Decay first manifests itself here because the combined effect of air and moisture are by far the greatest at this point; hence the portion of the pole which is from two to eight feet from the butt is the part most urgently in need of treatment. There are several methods of treating poles, the most important of which are known as the pressure method, the open-tank method, and the brush method — each of which will be treated very briefly in the order named.[1]

In the pressure method the entire pole is treated. In this process

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[1] For a more extensive description of pole treatment, see the bulletins of the United States Department of Agriculture.

the poles are drawn into huge horizontal cylinders which are then hermetically sealed. The timber is afterward subjected to live steam at a pressure of about 20 pounds per square inch, for several hours. The steam is then blown out of the retorts and vacuum pumps are employed to exhaust the air to the greatest practical degree. Then the preserving fluid, usually creosote, is run into the tank and forced into the wood under pressure. After this the surplus preserving compound is drawn back into storing tanks and the timber allowed to drip for a short time, when it is withdrawn from the retorts and the process is completed. The steam pressure to which the timber is subjected is sometimes allowed to exceed the twenty-pound figure, but this is done at the risk of injuring the strength. It should also be remembered that to secure the most satisfactory results, the timber should be thoroughly seasoned in the open air before treatment.

In the tank method the wood is first given a thorough seasoning; then the portion of the pole which is to be treated is immersed in an open tank containing a hot solution of the preserving compound. The poles are allowed to remain in this hot bath for five or six hours, during which time the air and moisture in the wood will expand and some of it will pass out and appear at the surface of the fluid in small bubbles. This part of the process is very similar to that used in boiling out cables in beeswax, in which the standard rule is that when bubbles cease to appear at the surface of the liquid, all the moisture that can be expelled has been driven out. After the poles have had the required hot bath they are transferred as rapidly as possible to a cold solution of the same compound, which causes a contraction of the air and moisture remaining in the wood; the partial vacuum thus created is destroyed by the entrance of the preserving fluid. It will be noted that the principles in these two processes are somewhat similar, in the respect that the preservative is forced into the timber through the application of pressure, artificial pressure being used in the pressure method, while the atmospheric pressure is utilized in the open-tank process.

The third or brush method consists, as the name implies, in painting the surface of the timber, by means of an ordinary brush, with two or more coats of hot creosote or other preservative. This is by far the cheapest method, but is not as efficient as the other two. In applying the preservative great care should be taken to thoroughly fill all checks, holes and other defects in the pole, since the solution will penetrate but a very short distance without pressure. However, as long as the coating of the preservative around the surface remains unbroken, the wood-destroying fungi cannot enter. For this reason it is especially important that the timber be thoroughly seasoned; otherwise, in this method, the drying out of the wood, with the accompanying shrinkage, will cause checking and thus expose the unprotected wood to fungus growths.

This last process should be used only when the number of poles to be treated is too small to warrant the expense necessary for the erection of a small treating plant. In all probability the time is rapidly approaching when the pole dealer will be required to treat the poles in the yard, before selling them, and thus the small as well as the large consumer will be able to obtain poles that have received proper treatment. The treatment of cross-arms and pins is also advantageous. This method of treatment does not weaken the wood unless it is subjected to too high a temperature or the process is too long continued. There are a large number of preservatives on the market, containing among other things, in different percentages, naphthaline and tar acids. As to the relative merits of these different solutions little can be said at present, owing to the lack of experimental data. Such data will be forthcoming, however, when extensive experiments which the government is conducting, in conjunction with the American Telephone and Telegraph Company, are concluded. These experiments are being carried out on three hundred cedar and three hundred chestnut poles, in the Southern Bell Telephone and Telegraph Company's line between Wilmington and Pisgate, North Carolina, on the American Telephone and Telegraph Company's lines from Dover, New Jersey, to Thorndale, Pennsylvania, and a portion of the line between Warren, Pennsylvania, and Buffalo, New York. In these lines all soil conditions, from high rocky ridges to low mucky swamps, are represented and much valuable information is hoped for.

The least that can be done in the way of preservation, if none of the previous treatments are utilized, is to heavily coat with pitch, tar, or asphalt that portion of the pole from the butt to a point two to four feet above the wind and water line, and give the wedge-shaped roof of the pole the same treatment.

The probability that the treatment will pay is best illustrated by the following quotations from the government circular 104, on "Brush and Tank Pole Treatments," by Carl G. Crawford.

"Though the length of time added to the service of these poles cannot now be stated, enough is known regarding the value of the preservatives as preventatives of decay to justify a conclusion as to whether the added life will repay the cost of treatment.

"By the brush method the average cost per pole was about 40 cents, or 29 cents in the case of creosote, of which 7 cents stands for the cost of oil. By open-tank process the average cost per pole with creosote (the only preservative used) was 67 cents, of which 22 cents stands for the cost of oil.

"Assuming that the cost of a standard 30-foot pole at the setting hole is $8, and that untreated it will last twelve years, the added life necessary to repay the cost of treatment with creosote by the brush method will be about six months and by the open-tank method about one year. A very conservative estimate of the added life by the brush method is thought to be three years, which would mean a great saving. In the tank treatment three times as much oil was absorbed as in the brush treatment, and the penetration was at least three times as great. If it results in prolonging the life of the pole in proportion to the oil absorbed, then it will be a very efficient treatment, and the economy of its use will be very great, not only in comparison with no treatment, but in comparison with the brush treatment. The manner in which preservative treatment serves to prolong the life of a pole is strikingly shown by Figs. 137 and 138."

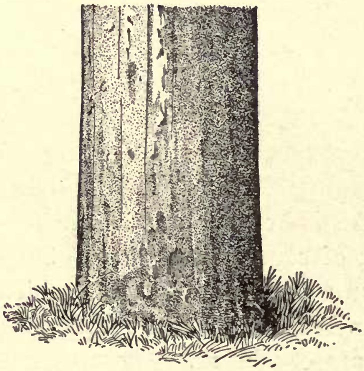

FIG. 137. — Treated Pine Pole.

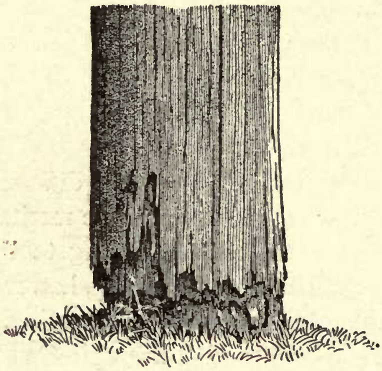

FIG. 138. — Untreated Chestnut Pole.

Pole Line. — The stability of the line depends, in a great measure, upon the proper distribution and setting of the poles. A consideration of the stresses which the poles must ordinarily sustain is particularly important, and necessary from the standpoint of laying out a route. These stresses on the pole can be readily divided into four distinct classes: first, the compression due to the weight of the cross-arms and the wire and the downward component of the wire tension; second, the bending moment due to the pull on the wires at angles or turns in the line; third, the wind pressure on pole, cross-arms and wires; fourth, the wind pressure plus the possible ice formation or sleet.

The first, or compressive stress, can be entirely neglected in the design of a line, as the ultimate compressive strength of timber used for poles amounts to about 5500 pounds per square inch, which obviously gives a safety factor great enough to insure the pole against failure even when exposed to the most severe conditions of sleet formation.

The second stress, or the bending moment, which is encountered at turns, very often becomes serious and reinforcement by guying is the remedy generally employed. On a straight line these severe stresses are not encountered, because the wire tensions on one side of the pole are almost entirely counteracted by those on the opposite side. This is evidently not the case at a turn, and an approximate determination of the stress at such a point is, consequently, most essential. The ultimate effect of this stress generally results in the breaking of the pole near the surface of the ground, by the crushing of the wood fibers on the side of the pole subject to compression and the tearing apart of those on the opposite side. Fig. 139 indicates the manner in which poles usually give way, which is a picture taken in 1909 of a wrecked line in upper Minnesota. The actual amount of pull or thrust required to break a circular pole by bending has been given much attention in the past; but nevertheless it remains rather an uncertain quantity. It may be expressed theoretically by

$$P = \frac{ASD}{8L}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which A is the area of the cross section, D is the diameter of the pole at the ground and water line, S is the tensile strength per unit of area and L is the distance from the ground to the center of pressure. For example, assume a 35-foot pole set six feet in the ground, with a diameter of 13 inches at the ground line; and assume that S is 6000 pounds per square inch and that the center of pressure is 24 feet above the ground, then the maximum allowable horizontal pull or load is

$$P = \frac{133 \times 6000 \times 13}{8 \times 24 \times 12} = 4500 \text{ pounds.}$$

The value of P just computed is the maximum allowable load for a fiber stress of 6000 pounds per square inch, but such a stress should never be permitted in practice; it is advisable to use a factor of safety of at least five, and in extreme cases where sleet storms and high winds are to be expected, ten may be none too high. The value of S for use in the above formula varies considerably, but the 6000 pounds per square inch assumed is generally a safe figure. In Table 7 are given the maximum and minimum values commonly accepted for the tensile strength of pole timber used in construction work. These values apply to full-sized poles and are considerably below the values which can be obtained with small test pieces, of much more perfect character.

FIG. 139. — Effect of Sleet on Pole Line.

The safe maximum value of P being ascertained, it is next in order to compare this figure with the load at a corner or turn in the line.

TABLE 7

TENSILE STRENGTH OF POLE WOODS IN POUNDS PER SQUARE INCH

Timber.	Minimum.	Maximum.
White cedar	4,000	8,000
Chestnut	6,000	10,000
Yellow pine	4,000	8,000
Cypress	5,000	8,000
White oak	3,000	8,000

Referring to Fig. 140, it has been assumed that the total tension *T* in one direction is equal to T_1 in the second direction. These two forces are counteracted by two equal and opposite forces such as T' and T_1', or by R' their resultant force, determined by constructing a parallelogram of forces with T' and T_1'. This resultant force R' is equal and opposite to the force *R*, which is the resultant of the weight and tension of the wires in each direction, and which tends to bend or finally break the pole in the direction of *R*, as shown in the diagram. Therefore the fiber strength of the pole must be great enough to resist this pull, exerted through a lever arm equal to the distance from the center of pressure to the ground and water line, as previously explained. If the angle made by the wires in the turn of the line be termed *A*, then, since $T' = T_1'$, the angle made by the

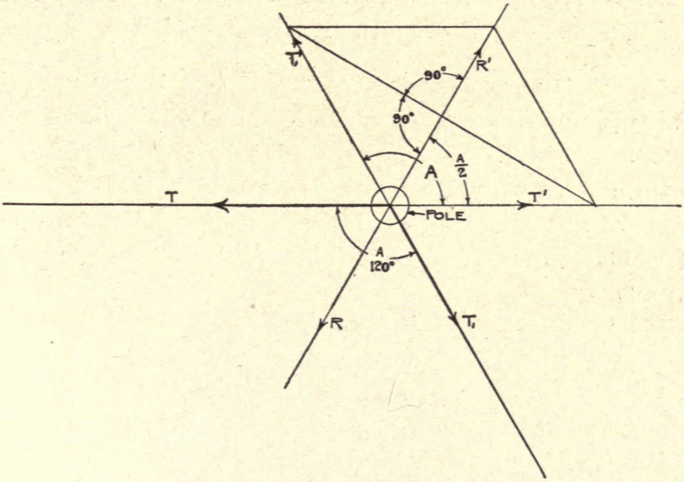

FIG. 140. — Diagram of Forces Acting on a Corner Pole.

resultant force R' and either of the component forces T' or T_1' is $\frac{A}{2}$. Since the parallelogram is equilateral, the diagonals intersect each other at right angles; therefore

$$\cos\frac{A}{2} = \frac{\frac{R'}{2}}{T'}$$

or

$$T' \cos\frac{A}{2} = \frac{R'}{2}.$$

Hence the resultant is

$$R' = 2\,T' \cos\frac{A}{2}. \quad \ldots\ldots\ldots \quad (7)$$

Assuming again the use of No. 8 B. & S. copper wire, stressed to one-fourth of its ultimate strength, a specific value of R' can be found. Assuming that the angle between the wires is 120°, that the pole carries four cross-arms with 40 wires, and using for T' the value of 194 pounds per wire, the resultant load is

$$R' = 2 \times 194 \times 40 \times \cos 60^\circ = 7760 \text{ pounds.}$$

This value is more than the breaking load and guying is therefore, in this case, a necessity.

The third force to which a pole is exposed is the wind pressure. The effect of this pressure on the wires has been determined, and the same formula will suffice for ascertaining its effect on the poles. In the formula

$$P = 0.05\,pD,$$

p, as before, is the normal pressure in pounds per square foot and D is the mean diameter of the pole in inches. The value of P thus obtained is the normal pressure per lineal foot, and hence the total pressure is obtained by multiplying this quantity by the number of feet of exposed pole. To illustrate, assume a 35-foot pole, set six feet in the ground, with a 13-inch diameter at the ground and a seven-inch diameter at the top, or a mean diameter of ten inches. Then if we assume a wind pressure of 40 pounds per square foot, the total lateral pressure on the pole becomes

$$0.05 \times 40 \times 10 \times 29 = 580 \text{ pounds.}$$

For approximate purposes this pressure can be considered as acting at the middle of the pole; hence the corresponding force exerted at the top would be one-half of 580 pounds or 290 pounds. To this wind pressure of 290 pounds, acting on the pole, must be added the lateral pressure exerted by the wires. The lateral pressure on a No. 8 B. & S. wire, in a wind having a pressure of 40 pounds per square foot, has been previously computed as 0.256 pound per linear foot. Then assuming four cross-arms per pole, which will carry forty wires, the poles being spaced at 130 feet, the total wind pressure on the wires is

$$0.256 \times 40 \times 130 = 1330 \text{ pounds.}$$

Added to the 290 pounds of wind pressure exerted on the pole itself, at the top, this gives a total load of 1620 pounds. This is well below the ultimate strength of the pole, but the assumption of a moderate load of sleet, in addition, will carry the stresses far beyond the safe limit. Thus a wind pressure of 20 pounds per square foot, with an ice coating on No. 8 B. & S. wires of three-eighths of an inch, gives, from previous calculations, a load of 0.923 pound per lineal foot. This gives in turn, for 40 wires with a span of 130 feet, a wind load of

$$0.923 \times 40 \times 130 = 4800 \text{ pounds.}$$

Adding to this the wind load on the pole alone gives a total of 5090 pounds, or more than the breaking load, assuming that the wires themselves would sustain their individual loads. The effects that a storm will have on a line that is faulty in design and one that is well reinforced is clearly shown in Figs. 141 and 142. These lines paralleled one another and the effect of the storm was to completely wreck the one, while the other remained uninjured. This shows the advisability of utilizing a large factor of safety in the design of the line.

In some parts of the country where severe sleet storms and high winds are of frequent occurrence, a special type of construction has been used. This consists of setting two poles where it is the usual practice to set one. These two poles are set about six feet apart at the bottom and brought together and firmly bolted at the top, and the cross-arms fastened to both poles. This undoubtedly greatly strengthens the line, but like results can be obtained by decreasing the span and thus the strain on the wires. However, the local conditions in each case must determine which is the best practice.

A thorough grasp of the principles involved in the design of a pole line is very essential in laying out a route. The first step in actual location, which should precede the distribution of material, is staking out the route. Assuming that the poles are to be spaced 130 feet apart, the staking is commenced by driving a stake into the ground where the first pole is to be located and at the proper distance from the center of the road or the fence. The succeeding stakes are located by measuring off 130-foot lengths on the straight sections, while at curves or corners the poles must be placed as near together as may be necessary to carry the ultimate number of circuits for which the route is designed.

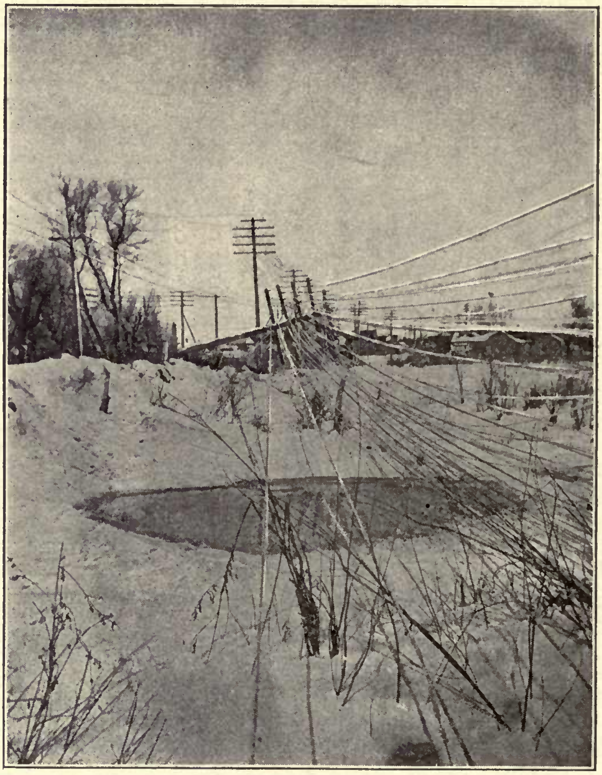

FIG. 141. — Effect of Sleet on a Poorly Constructed Pole Line.

It is customary, in order to reduce the stress on the pole, to limit the spacing of the poles on either side of a corner, at right-angled corners and road crossings, to 75 feet. Also the last section at a line terminal and the sections on either side of a long span, say 200 feet or more, should not exceed 75 feet. In placing the stakes it is advisable to sight from stake to stake so as to insure a straight line.

In crossing rivers and surmounting other natural obstacles great care should be exercised in locating the poles, to secure a setting in firm soil; it is well, for example, not to approach too close to the edge of a river or stream, even at the expense of lengthening the crossing. If, in so doing, the length of the span greatly exceeds the standard of 130 feet, the poles at the banks must be extra large and well guyed to stand the additional stresses which they will receive.

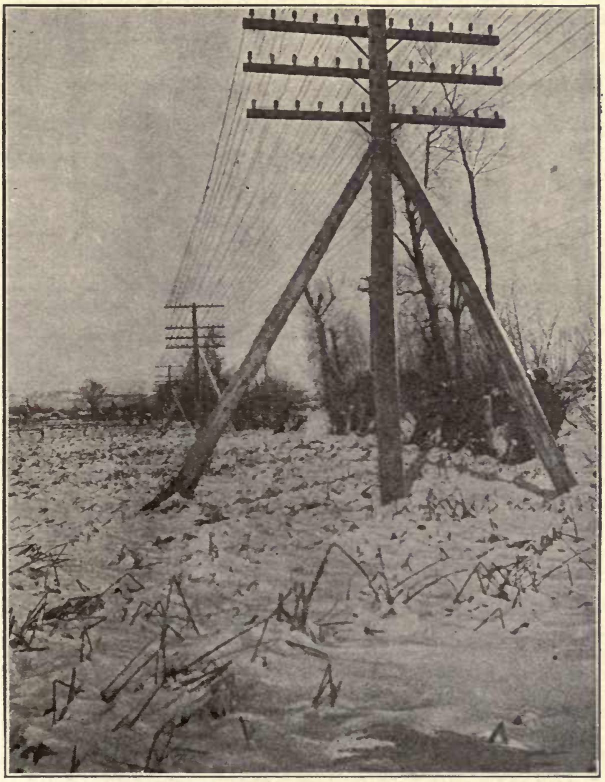

FIG. 142. — Effect of Sleet on a Properly Braced Pole Line.

It is very desirable to lay out a map of the pole route, showing the proposed location of stakes and the distances between them, before the final route is selected. In building lines along the right of way of a railroad, it is best to keep the poles at a distance of 12 feet from the edge of the nearest rail, unless the lowest cross-arm is placed more than 22 feet above the top of the rail, in which case the pole may be set not less than seven feet from the rail.

All poles on which turns are made are exposed to extra stresses and should be well guyed. It is therefore essential to show on the map, previously referred to, the location of the guy stubs and anchors, so that they may be staked off when the pole route is being laid out. Another item that should be considered in planning the pole route is the matter of grading the pole tops. This is of little if any importance in a level country, but in a hilly country it should receive ample consideration, as will be evident by a glance at Figs. 143 and 144.

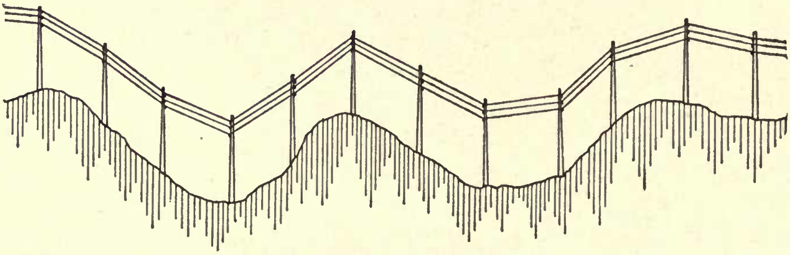

FIG. 143. — Ungraded Pole Line.

It is apparent that the length of the poles should be proportioned to the contour of the country, thus avoiding any abrupt changes in the level of the wires; for if the poles are all of the same length, those on either side of the one at the bottom of the valley will be subjected to extra stresses, while the pole in the valley would have an upward pull, which is very likely to pull off insulators and in extreme cases lift the pole out of the ground. The rise or fall in the level should not exceed five feet between poles. Fig. 144 shows how this difficulty is very easily overcome by the use of long and short poles. The required lengths of the poles can be readily estimated by an experienced man, if the level of the country is not subject to unusual variations; but in very hilly country it may be profitable to make a preliminary survey of the route, from which a profile map may be prepared to aid

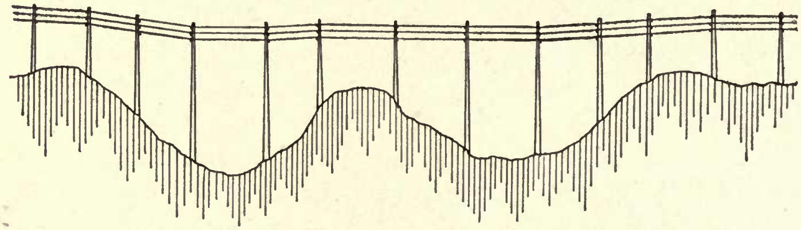

FIG. 144. — Graded Pole Line.

in selecting pole lengths. When these preliminaries have been completed the distribution of material may be commenced.

In this connection it should be remembered that the pole ought to be placed with the butt end closest to the stake, and that if the country is hilly the small end of the pole should be located at the highest point of the grade. By observing these suggestions the work of the pole-raising gang will be greatly facilitated. It hardly seems necessary to add that the stoutest poles should be placed at the corners and points where exceptional stresses are likely to be encountered. The poles of best appearance should be used in towns and cities. The method of distribution is governed, to a very large extent, by local conditions. However, when the route parallels a railroad it is often feasible to drop the poles at their proper places from the car on which they have been transported.

After the poles have been distributed, and before they are set, they should be properly framed and gained. Poles are usually received from the yards with their butt ends nearly flat; if this is not the case, they should be so cut before setting. The pole should be cut for the ultimate number of cross-arm gains, and the small end of the pole roofed as shown in Fig. 145. These gains should measure 4 by 4¼ inches and one-half inch deep, when braces are used, as shown in the figure. If no cross-arm braces are used it is advisable to make the gain at least three-quarters of an inch deep. The center of the upper gain should be ten inches from the apex of the pole. When the gains have been cut, and before the cross-arms are placed in position, a ⅝-inch hole should be bored through the pole at the center of each gain, but no holes should be bored in the spare gains. The remaining gains should be bored when used. The roof and the gains should be painted with two or three coats of the best white lead, or carbolineum avenarius. This prevents the moisture from entering the wood and helps materially to prolong the life of the pole.

The cross-arms should be made of sound, thoroughly seasoned, straight-grained wood which is free from heart and sapwood and free from all such knots as would tend to weaken them. All cross-arms, when not creosoted, should be thoroughly painted with two coats of standard paint. The wood that is used for cross-arms is regulated, like the timber for poles, by the locality where it is to be used. The timbers most preferred are Norway pine, long-leaf yellow pine, and red and black cypress. The top of the cross-arm should be rounded,

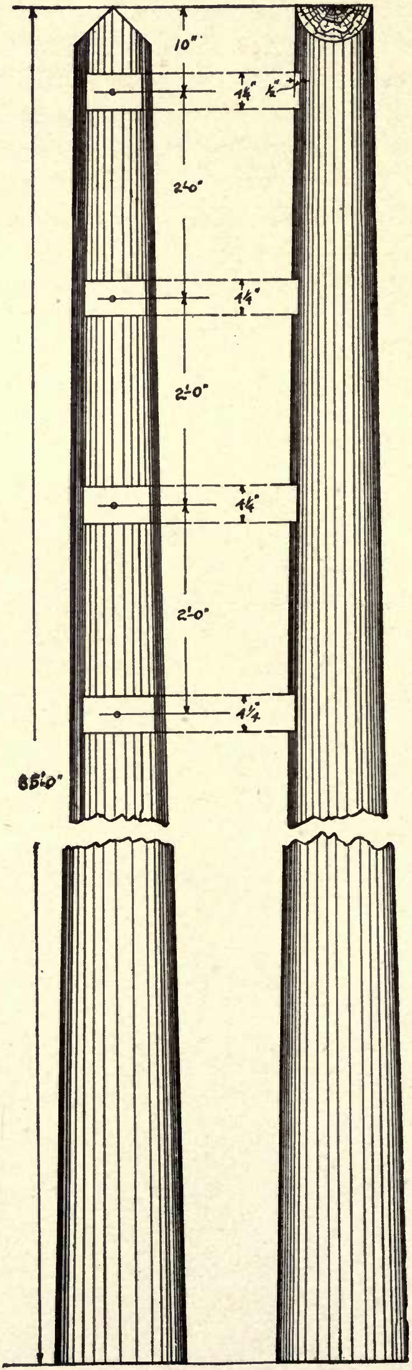

Fig. 145. — Pole With Gains Cut for Cross-Arms.

so that the rain will readily run off. The dimensions naturally depend upon the load it will be required to carry. Two regular sizes are on the market, the standard arm and the telephone arm; for toll work the former should be used exclusively. Standard cross-arms measure $3\frac{1}{4}$ by $4\frac{1}{4}$ inches and vary in length from three to ten feet, depending upon the number of pins. The dimensions of a standard ten-pin arm are shown in Fig. 146; the number of pins, the distances between them, and the approximate weights, for various lengths, are given in Table 8.

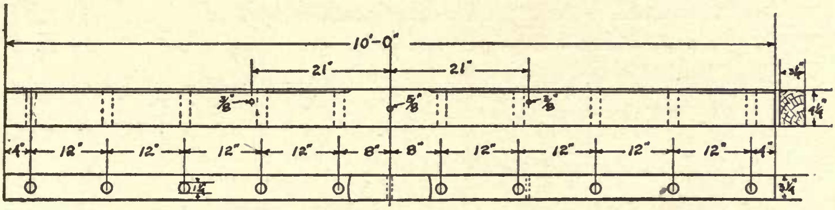

FIG. 146. — Standard Ten-pin Cross-Arm.

TABLE 8

DIMENSIONS OF STANDARD CROSS-ARMS

Length in Feet.	Number of Pins.	Spacing of Pins in Inches.			Approximate Weight in Pounds.
		Ends.	Center.	Sides.	
3	2	4	28	....	9
4	4	4	16	12	12
5	4	4	18	17	15
6	4	4	22	21	18
6	6	4	16	12	18
8	6	4	18	17½	24
8	8	4	16	12	24
10	8	4	17½	15¾	30
10	10	4	16	12	30

The cross-arms are best secured in position by a ⅝-inch iron machine bolt, which passes through the pole. The bolt should be long enough to go through the cross-arm and the pole without cutting away the back of the pole. It should be driven through from the back of the pole, a large square washer being placed under the head. A similar washer should be placed on the cross-arm under the nut. This construction is much superior to the old practice of fastening the cross-arm with two lag screws; it also facilitates renewals, since the lag screws tend to loosen as the pole ages.

The cross-arm should be further secured by means of two iron or mild steel braces, of the dimensions shown in Fig. 147. They are usually 20 to 30 inches long and 1¼ inches wide, by one quarter of an inch thick. Each pair of braces is fastened to the pole by means of a single lag screw, about five inches long; the opposite ends are attached to the cross-arm above by means of ⅜-inch carriage bolts. There

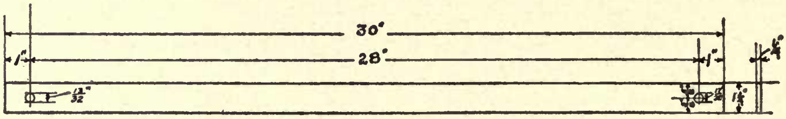

Fig. 147. — Standard Cross-arm Brace.

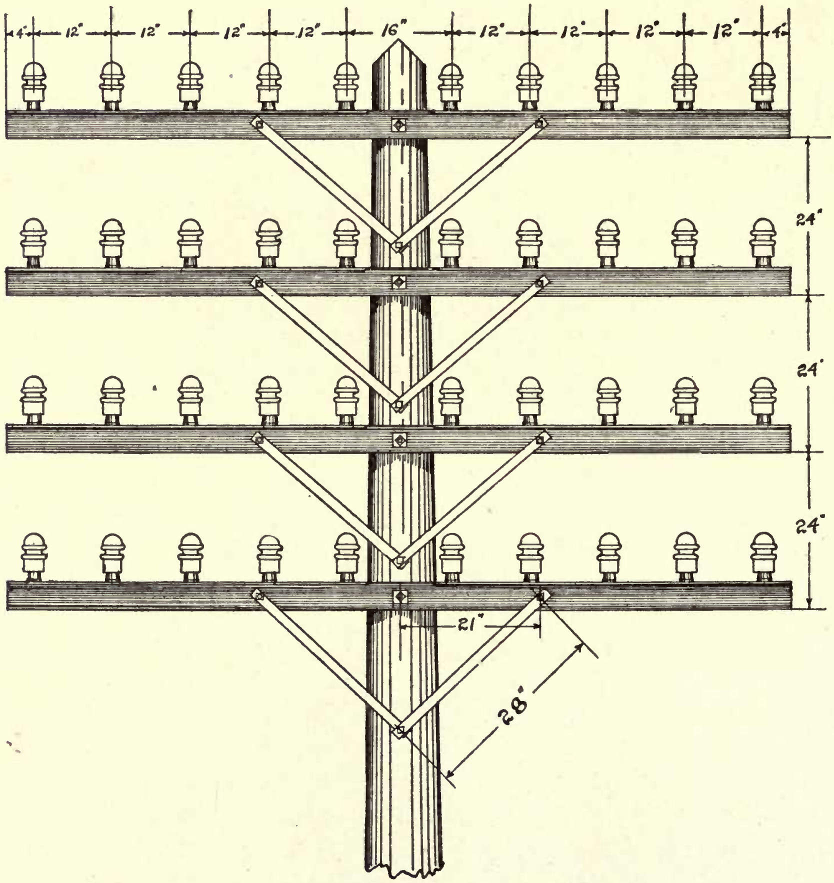

Fig. 148. — Standard Method of Bracing.

should be washers under each end of the bolt and the nut should be on the brace side of the arm. The standard method of bracing is shown in Fig. 148. The use of braces keeps the cross-arms in alignment and allows the gains to be shallow, thus adding strength to the pole. The braces should be attached to the front of the arm and the bolts should be slightly above the center.

At all points where the load will be exceptional, such as office terminal poles, railroad and river crossings, or exceedingly long spans, the poles should be equipped with double cross-arms. In these cases the double arms should be provided with blocks of wood between them, held in place by carriage bolts which pass through the blocks and both arms.

The cross-arms should always be drilled for the ultimate number of pins. There are three standard sizes of pins, as shown in Fig. 149;

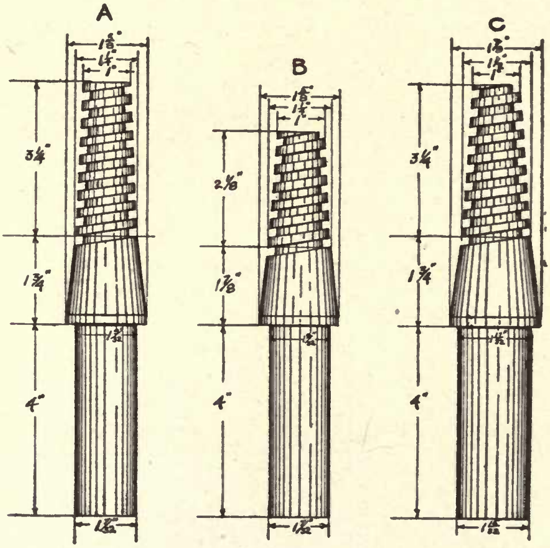

FIG. 149. — Standard Sizes of Pins.

A is the transposition pin, *B* the ordinary line pin and *C* the terminal pin. These pins are commonly made of locust, chestnut or oak. The locust pin is much stronger than oak and should be employed for toll-line construction, although the original cost is greater. The specifications usually require that the pin shall be made of the best quality of split locust, sound, straight-grained and free from knots and sapwood.

The shank of the pin is usually tapered toward the end, where it is about one thirty-secondth of an inch smaller than the hole in the cross-arm. Thus it is readily driven into the arm and held securely. It should also be fastened in place by means of a six-penny nail, driven through the arm. The upper part of the pin is tapered slightly and provided with a coarse thread to receive the insulator. Steel pins can also be obtained and are used to some extent on telegraph lines; the top of the pin is provided with a wooden thimble to receive the insulator. Such pins are rarely used in telephone construction and are not recommended.

It is standard practice to fit every tenth pole and each office or terminal pole with lightning rods, which consist of No. 6 or No. 8 B. W. G., heavy galvanized iron wire. About six feet of this wire should be formed into a flat coil and placed in the hole under the butt of the pole; it should be stapled up the pole on the side opposite the cross-arm and project several inches above the top.

TABLE 9

DEPTH OF POLE SETTING

Length of Pole in Feet.	Depth in Ground in Feet.	Remarks.
30	5½	Straight line.
30	6	Corner.
35	6	
40	6	
45	6½	
50	7	
55	7½	
60	8	
65	8½	
70	9	
75	9½	
80	10	
85	10½	
90	11	

In setting the poles each hole should be dug with the marking stake as a center and made large enough to admit the pole freely, which means that the hole should be from four to six inches larger than the base of the pole. The hole should be full size at the bottom so as to permit the proper use of tamping bars. The depth to which poles should be set is naturally governed by their height and the nature of the soil. For average conditions the depths are given in Table 9. In order to prevent caving, the excavations should stand open but a short time. This may be accomplished by setting the entire gang digging holes in the forenoon and setting the poles in the afternoon or dividing the gang in two parts. As to the number of poles that should be set per day little can be said, as this is governed entirely by the number of men and the local conditions and can be readily determined by the foreman after the gang has been working several days. It may be of interest to note, however, that it takes about six men to raise a 35-foot pole, and this number gradually increases with the weight and length of the pole; in extreme cases from 15 to 20 men are required. These figures are based upon the assumption that the poles are raised by the ordinary method of pike poles (Fig. 150), deadman (Fig. 151), pole support (Fig. 152), and raising fork (Fig. 153), which is the usual practice on toll lines, as a derrick wagon can only be used under favorable conditions.

FIG. 150.
Pike Pole.

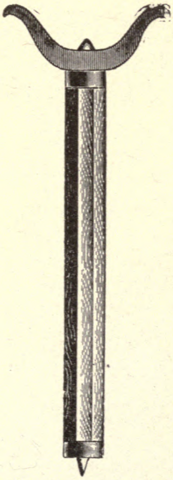

FIG. 151.
Dead Man.

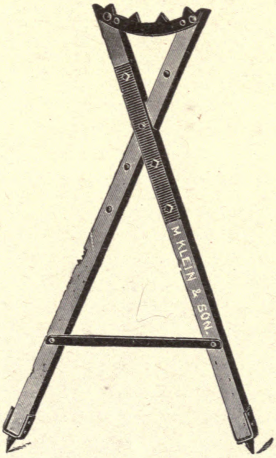

FIG. 152.
Pole Support.

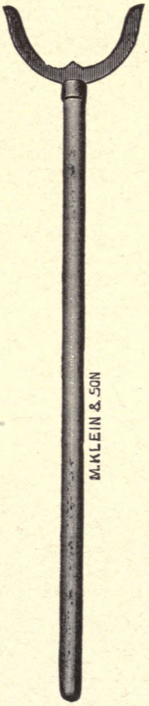

FIG. 153
Raising Fork.

After the pole has been brought to a vertical position it should be turned by means of a cant hook (Fig. 154), until the cross-arm is at right angles to the direction of the line. The proper facing of cross-arms on a tangent is shown at *A* in Fig. 155, which prevents them from stripping from the poles under excessive longitudinal stresses. Further rules regarding the facing of cross-arms are as follows: On long sections the cross-arms shall be placed on the side of the pole away from the span, and at the terminals the cross-arms on the last two poles shall be placed on the side of the pole facing the terminal. On all curves the cross-arms shall be placed on the side of the pole facing the middle of the curve, while at road crossings they shall be placed on the side of the pole that faces the road, as at *B* in Fig. 155.


Fig. 154. — Cant Hook.

When the raised pole has been turned to the proper position it should be temporarily braced, which may be accomplished by means of four pike poles. The back filling and tamping should be done carefully and thoroughly, so as to give the pole a firm setting. A standard tamping bar is shown in Fig. 156. The soil should then be firmly banked around the pole about one foot above the surface of the ground. If the work is done properly this will generally dispose of all excavated material. The foreman should so divide the labor that every man will be at work, practically without interruption or delay, and to this end he should remain with the gang at all times. If it is occasionally necessary for him to be absent, a competent assistant should be left in charge.

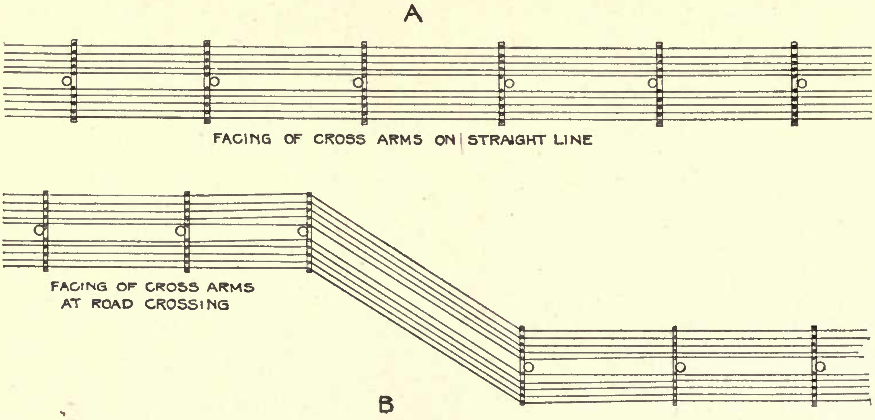

Fig. 155. — Facing of Cross-Arms on Pole Line.

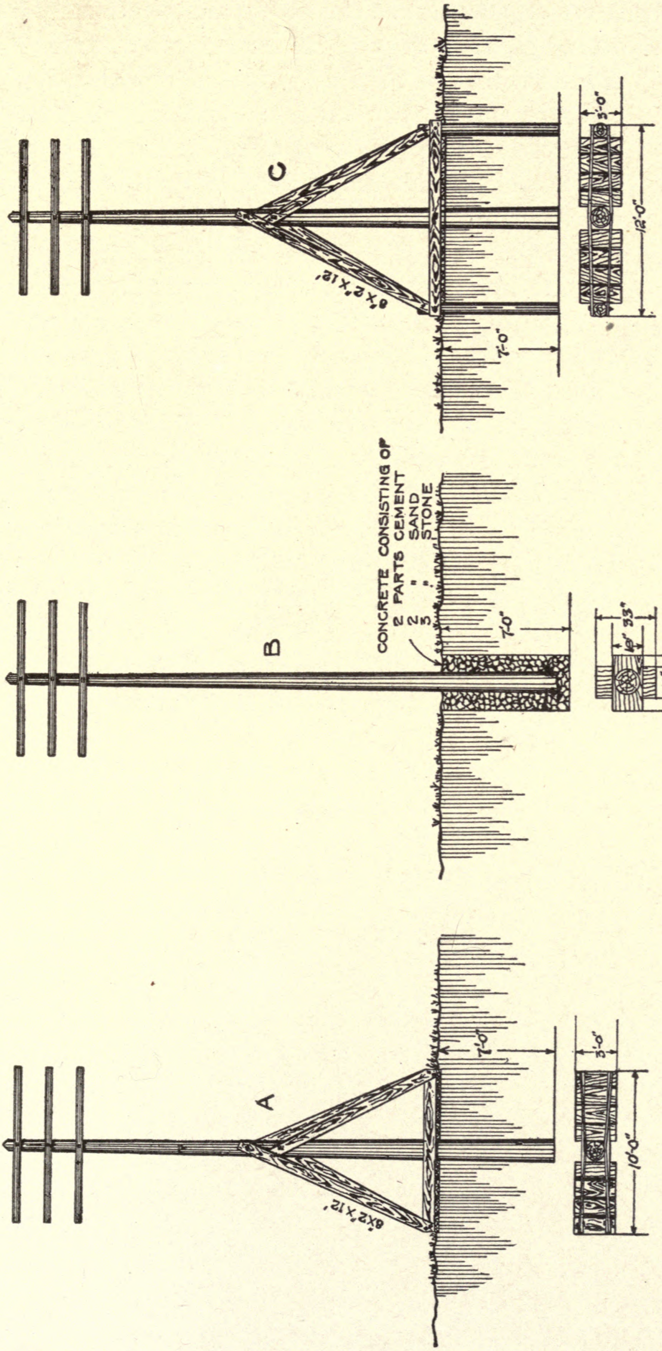

Fig. 157. — Method of Setting Poles in Marshy Ground.

At all points where poles will be exposed to an exceptionally heavy load they should be given an angle of inclination in a direction opposite from that of the load. This is termed raking, and the rake should vary from 12 to 18 inches, depending upon the stresses. In some cases the next three or four poles on either side are raked also, each in a gradually decreasing proportion until the vertical position is again obtained.

FIG. 156. — Tamping Bar.

Quite frequently it becomes necessary to set poles in soft ground such as marshes and swamps, and in these cases artificial foundations must be resorted to. Of course the type of foundation is regulated, to a large extent, by the local conditions. Several methods are shown in Fig. 157. It will be observed that in all these schemes, except the one in which concrete is employed, a flat wooden structure is built at the base of the pole so as to provide a large bearing surface and secure bracing. On curves, in soft ground, a method of bracing such as that shown in Fig. 158 is often used to great advantage. The logs attached to the pole greatly increase the bearing surface and add to the general stability.

Guying. — The extra loads at corners, curves, terminal poles and long spans make it necessary to reinforce the line by guying. Braces are often used in place of guys and are frequently superior. The method of reinforcement depends to a large extent upon local conditions. Some of the standard methods are shown in what follows.

One form of guy is shown in Fig. 159, and is known as the Y guy. With this form of guy the stress is about evenly divided between the two branches of the Y. A straight guy attached to the pole near the center of the load is easier to install and about as effective; it is the type generally employed. The guy should never be attached to the top of the pole or below the arms.

Another method of reinforcement is known as head guying and is shown in Fig. 160. In this method the top of the pole is guyed to the bottom of the next, at a point 10 to 12 feet above the ground. For general reinforcement head guys should be run in each direction. The bracing of the line in both directions can also be accomplished between one pair of poles by what is known as double head guying,

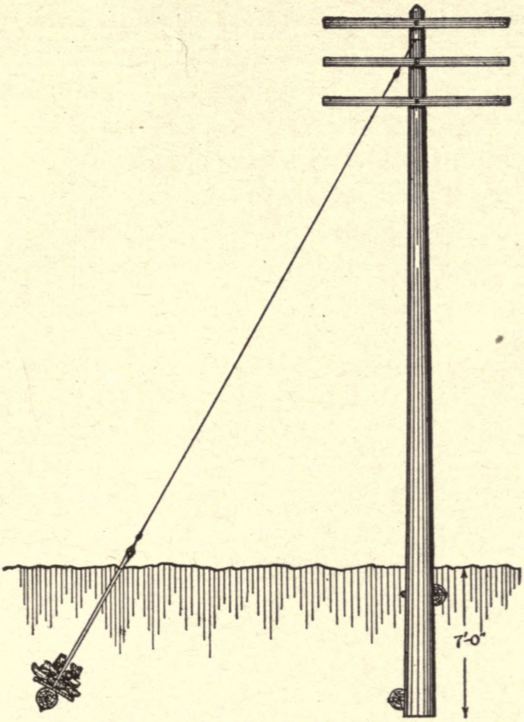

FIG. 158. — Method of Bracing Pole in Marshy Soil.

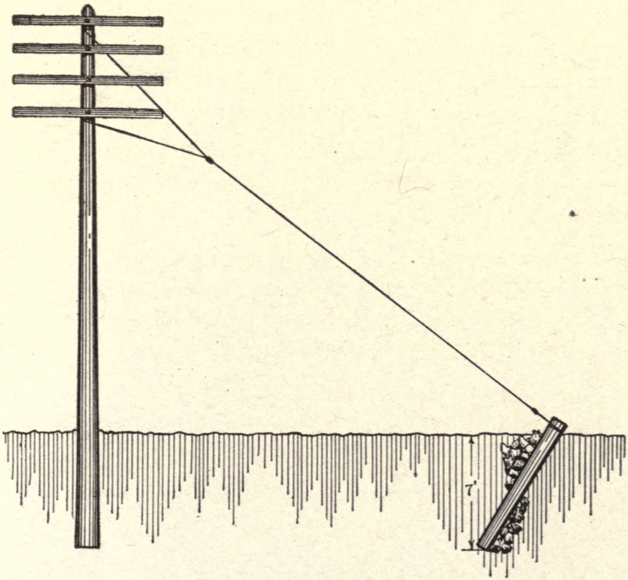

FIG. 159. — Side Guying.

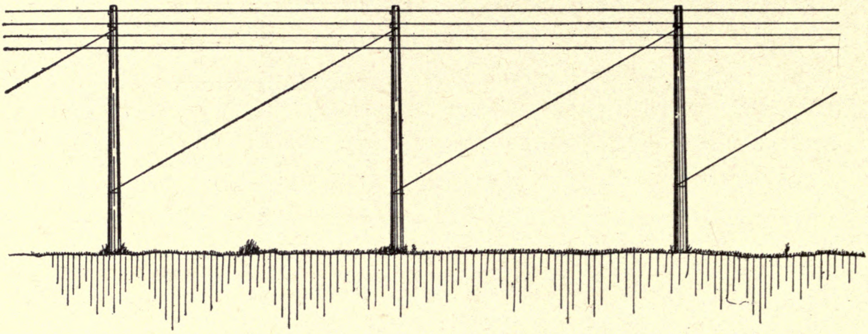

FIG. 160. — Head Guying.

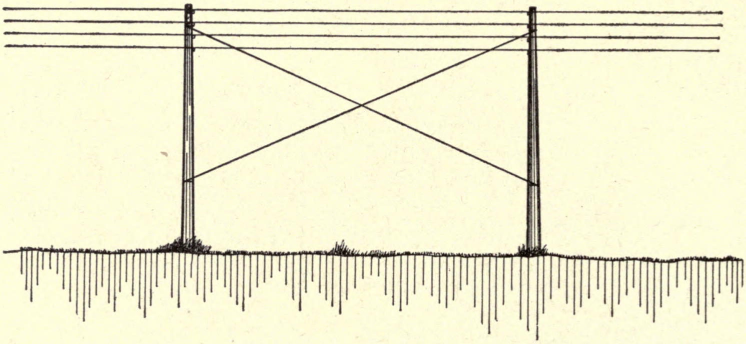

FIG. 161. — Double Head Guying.

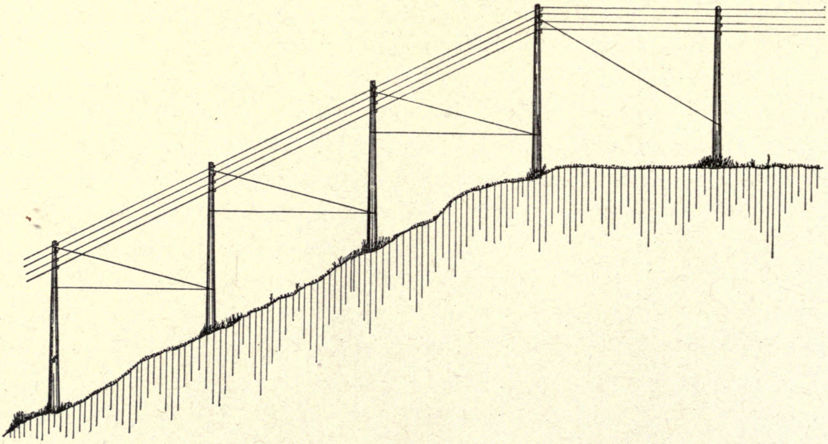

FIG. 162. — Head Guying on Grades.

as shown in Fig. 161. In general it is superior practice, however, to attach the guys to anchors instead of the butts of poles. A method of head guying on heavy grades, to carry the weight of the line, is shown in Fig. 162. This method does much to relieve the component of load on the poles caused by the downward tension of the wire, which tends to pull the top of the pole downhill.

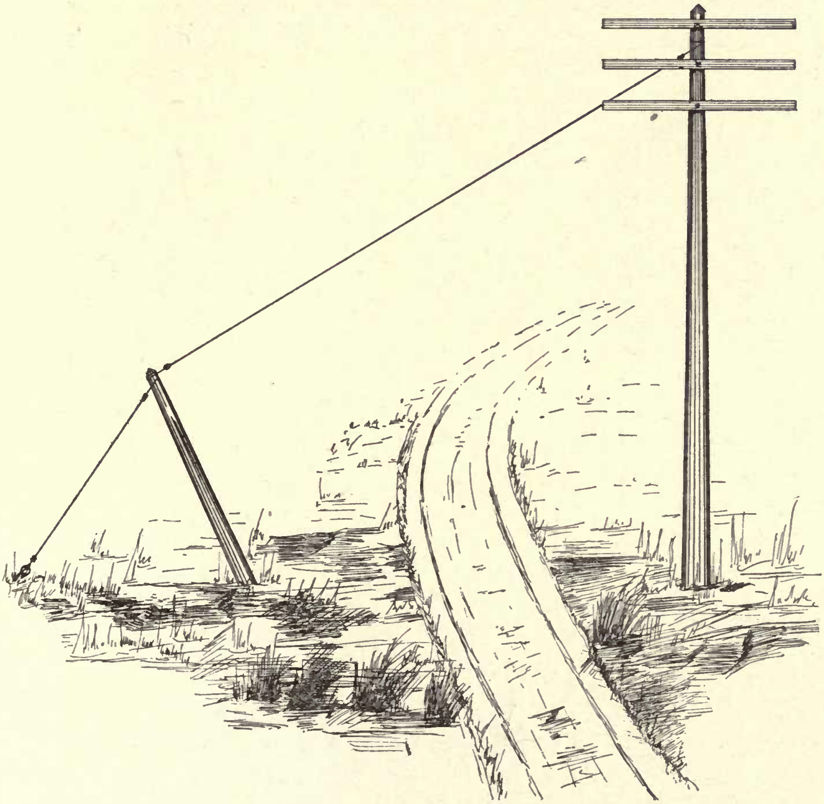

FIG. 163. — Guy Stub and Anchor.

The methods of anchoring guy wires which take up the side strains naturally vary according to conditions. The usual method when direct anchoring is not practical is to use a guy stub. The poles used for guy stubs should meet the general specifications required for standard poles.

There are several methods of installing a guy stub. The one shown in Fig. 159 is used to some extent, but the one shown in Fig. 163, utilizing a guy stub and anchor, is more generally employed. The stub shown in the latter figure should be roofed, after the manner of poles, and all stubs when not creosoted should be treated in a manner similar to that specified for poles. When it is impossible to locate an anchor for a guy stub as shown in Fig. 163, the stub should be braced as shown in Fig. 164. When possible all guy stubs should be set in the ground to a depth of six feet and should be inclined or raked away from the pole as shown in Fig. 164. Modern practice has revolutionized the methods of guying; it was customary formerly to use a guy stub whenever conditions were favorable, but its use is now confined to such places as road crossings, where an anchor guy is not permissible.

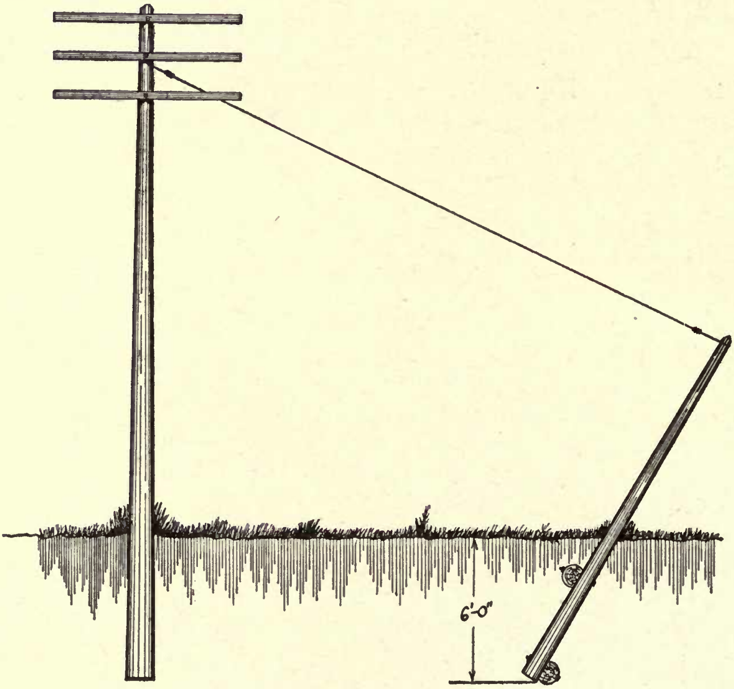

FIG. 164. — Method of Bracing Guy Stub.

The old standard method of anchoring a guy is by means of a guy rod and anchor log as shown in Fig. 158. The standard guy rod should be made of good wrought iron and of the general dimensions shown in Fig. 165. This rod is passed through the center of the anchor log and is fastened by means of a square washer and nut. The excavation for a log, ten inches in diameter and $4\frac{1}{2}$ feet in length, should be six feet. If it is impossible to attain this depth, on account of the nature of the soil, an excavation of only four feet will suffice, but in this case the dimensions of the log should be increased. In Table 10 are given the general dimensions of anchor logs and the depths to which they should be buried. The log should be firmly anchored by a covering of planks, logs, rocks or any other available material that will increase the bearing surface.

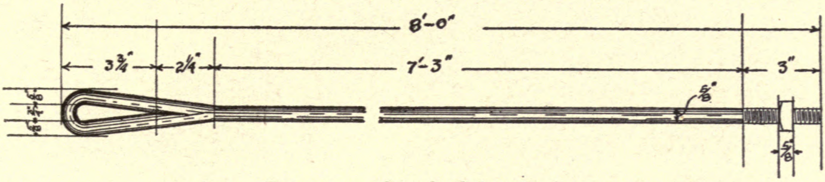

FIG. 165. — Standard Guy Rod.

Another type of guy anchor that seems to have met with considerable satisfaction is the one manufactured by the Miller Anchor Company. Fig. 166 shows the anchor and the method of installation, from which it will be noted that the method of setting is exceedingly simple. The anchor is first inserted in a hole which has been bored at an angle that the guy will ultimately assume, and then the upper end of the spoon is tilted downward with an ordinary bar. This causes the lip to engage with the soil or gravel and when the rod is pulled upward the spoon will assume a position at right angles. The hole is then refilled and well tamped. The spoons are made of cast iron, while the rods are wrought iron. The anchor has a great holding power due to the fact that when it opens out a firm grip is secured on the undisturbed earth on either side of the hole. It should be set from five to ten feet deep, depending upon the load which it is to carry. The manufacturer advises that the load should be governed by

TABLE 10

DIMENSIONS OF ANCHOR LOGS

Depth of Excavation.	Length of Log.	Diameter of Log.
5 feet	5 feet	16 inches
5 "	8 "	10 "
4 "	5 "	23 "
4 "	8 "	14 "
4 "	10 "	12 "

the size of the wrought-iron rod, which will break before the spoon will pull out. The tensile strength of these rods is given in Table 11.

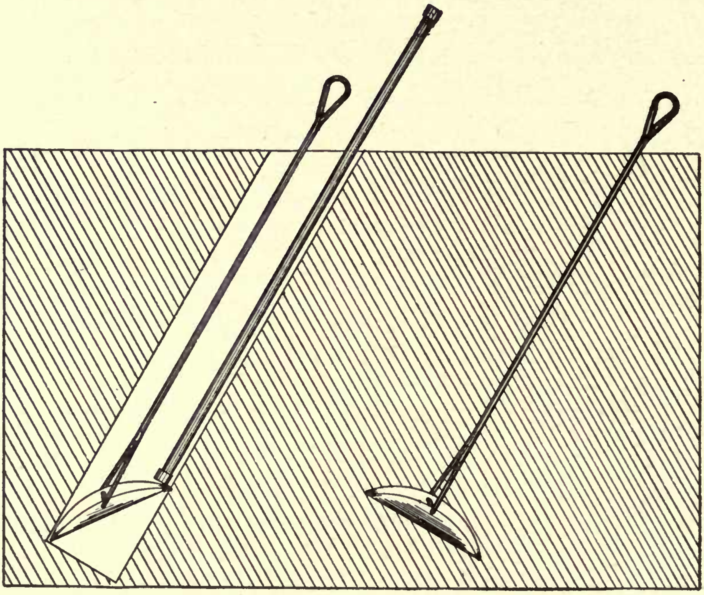

FIG. 166. — Miller Anchor.

Still another type of guy anchor is the Matthews, formerly known as the Stombaugh, which consists of a steel rod and eye to which is rigidly attached a piece of cast iron, helical in shape; the lower edge of the helical piece is sharp and will screw into the ground without disturbing it. When thus embedded in solid undisturbed earth it has a very great holding power. Owing to the simplicity with which it

TABLE 11

STRENGTH OF WROUGHT-IRON ANCHOR RODS

Diameter in Inches.	Tensile Strength in Pounds.
½	9,800
⅝	15,340
¾	22,090
1	39,270
1⅛	49,700
1¼	61,360

can be installed, it is frequently used where soil conditions are favorable. These anchors are shown in Fig. 167, and in Table 12 is given the holding power of the different-sized anchors when screwed five feet into clay soil, as calculated by Professor R. C. Carpenter.

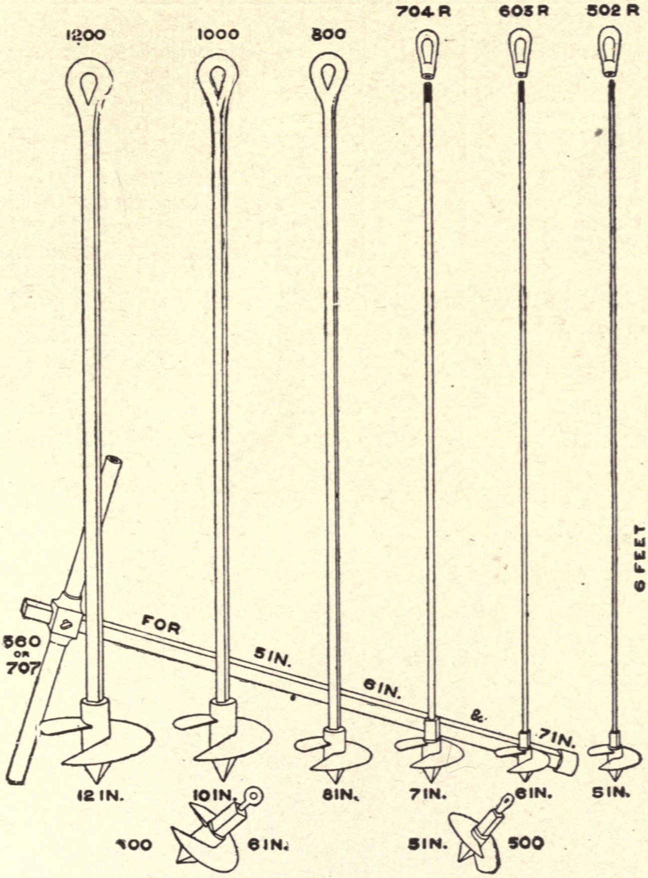

FIG. 167. — Matthews Anchor.

Fig. 168 illustrates the theory from which the holding power of this type of anchor is deduced. The resistance offered by the earth is represented by the weight of an inverted cone, the angle of whose apex is 90°. The holding power will be readily seen to be very great when the weight of the earth in the cone and the cohesive qualities of the undisturbed ground are taken into consideration. For instance, consider a 12-inch anchor bored five feet into the ground; the resistance

TABLE 12

SIZE AND HOLDING POWER OF MATTHEWS GUY ANCHORS

Diameter in Inches.	Size and Shape of Rods.	Weight in Pounds.	Holding Power in Pounds.	Remarks.
5	None.	$2\frac{1}{2}$	12,500	Used where no objection exists to burying strand.
6	None.	$4\frac{1}{4}$	15,000	
5	$\frac{1}{2}$ in. round.	$6\frac{1}{2}$	12,500	These sizes require a wrench for installing.
6	$\frac{5}{8}$ in. round.	10	15,000	
7	$\frac{3}{4}$ in. round.	15	17,500	
8	$1\frac{1}{8}$ in. square.	38	20,000	These sizes are installed by placing a digging bar through the eye.
10	$1\frac{1}{4}$ in. square.	50	25,000	
12	$1\frac{1}{2}$ in. square.	80	30,000	

to an upward pull will be represented by a cone which is five feet from apex to base (or surface of the ground) and approximately ten feet across the base, assuming a perpendicular axis. (The anchor should always be installed, however, at the same angle as the guy wire.) This cone contains a little over 170 cubic feet of earth, which weighs in the neighborhood of 20,000 pounds. The balance of the resistance is due to the cohesive properties of the undisturbed ground. This also applies to the smaller anchors, in a less degree. The holding power of one of these anchors, according to Professor Carpenter, can be computed by the formula,

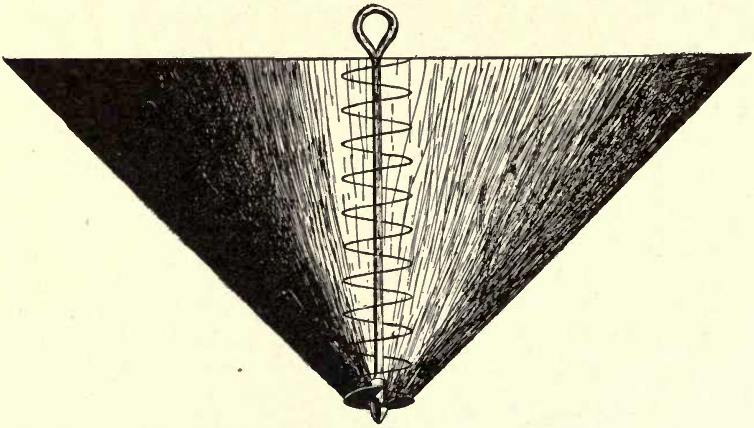

FIG. 168. — Theory of Holding Power of Matthews Guy Anchor.

$$R = 100\, D H^2, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

in which R is the pull on the guy wire in pounds, H is the depth in feet to which the anchor is placed and D the diameter of the helix in inches. Thus if the anchor having a helix 12 inches in diameter is screwed to a depth of five feet, the total holding power would be

$$R = 100 \times 12 \times 25 = 30{,}000 \text{ pounds.}$$

The following is a quotation from the instructions issued by a large telephone company showing how and where this anchor is to be used.

" Where the soil conditions are favorable (sand, loam or clay), the Matthews' Anchor may be used as a substitute for the standard log or plank anchor as enumerated below.

" This type of anchor in six-inch, eight-inch, and ten-inch sizes is approved for use as follows:

"(*a*) Toll lines of 12 to 20-wire capacity, six inches or eight inches, according to strain.

"(*b*) Toll lines of 40-wire capacity, except for heavy corners or route ends, eight inches only. Log or plank anchors must be used for points of heavy strains except as above.

"(*c*) Farmers' lines, six inches under all conditions.

"(*d*) Exchange aërial open-wire leads not exceeding 40 wires, eight inches or ten inches, according to strain and soil.

"(*e*) Exchange aërial cable not exceeding 100-pair, No. 22 gauge, eight or ten inches on all main leads and on branches larger than 25-pair, six inches on legs not exceeding 25 pairs.

"All anchors must be set at least five feet below the surface of the earth."

There are several other types of anchors on the market which have given more or less satisfaction, but the limits of space prevent their description in detail.

Guys are sometimes attached to suitable trees, providing the consent of the owner can be obtained. The attachment should be made to the trunk of the tree as shown in Fig. 169, but may, in exceptional cases, be fastened to a live limb close to the trunk, as indicated in Fig. 170, providing the limb is at least five inches in diameter. The trunk or the limb of the tree should always be protected from injury by strips of hard wood, each strip being about one inch thick, 12 inches long and not over two inches wide. The guy wire is then looped about the tree and fastened with a guy clamp. The provision of these blocks under the guy wire prevents injury of the bark, which would

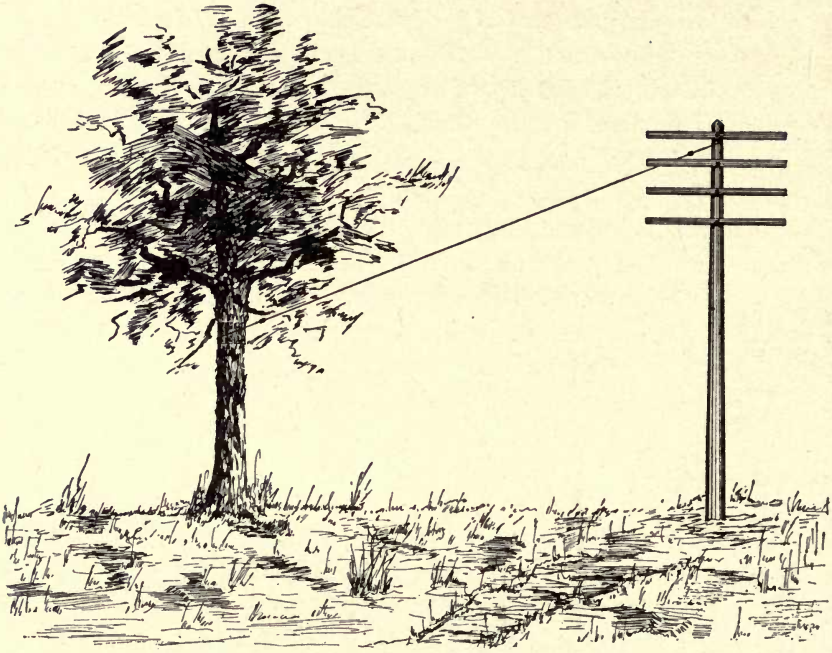

FIG. 169. — Guying to Tree Trunks.

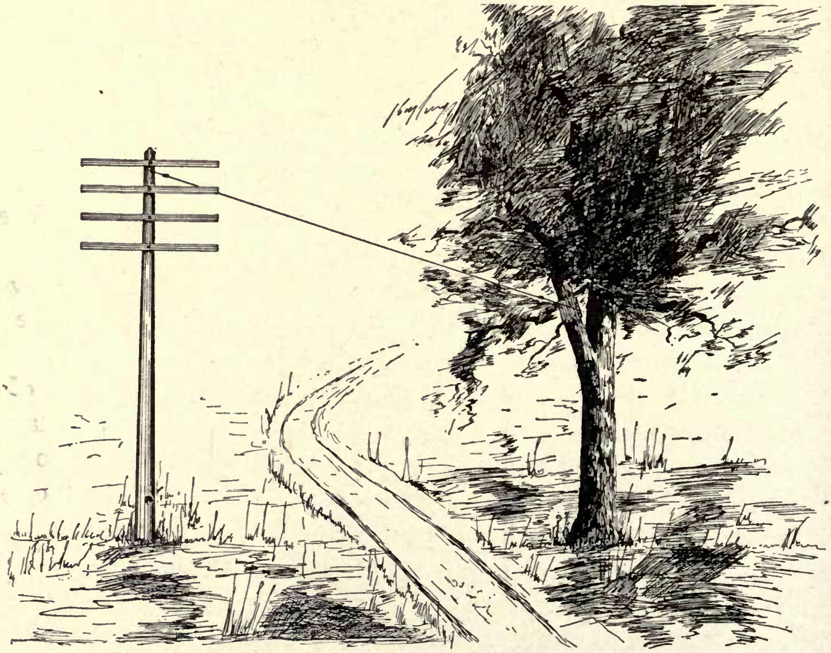

FIG. 170. — Guying to Tree Limbs.

otherwise suffer severely from abrasion, possibly to the extent of killing the tree. The protection of the property of abutting owners can never be too seriously considered, as right of way and trimming privileges are seldom easily obtained, and it requires but a few instances of real damage to make the securing of these privileges well-nigh impossible. Nothing is more detrimental to the telephone company than to be on hostile and unfriendly terms with the property owners that adjoin the right of way.

When it is convenient or necessary, guys may be attached to solid rock as shown at *A* in Fig. 171. Care should be given to the selection of rock which is in good physical condition. If the rock has a tendency to split, an eyebolt should be used which has a tensile strength of 60,000 pounds per square inch, placed as shown at *B* in Fig. 171. The depth to which this bolt should be embedded is regulated by the nature of the rock. It is advisable to pour sulphur or lead into the hole to provide a firm anchorage.

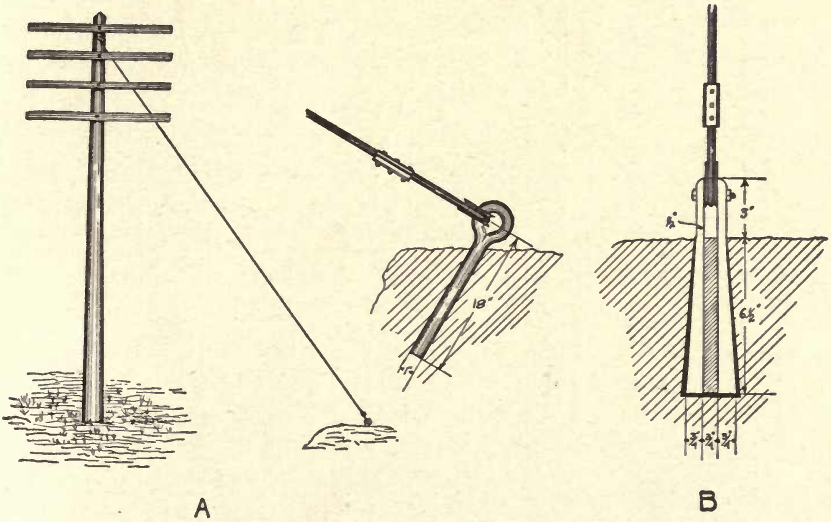

Fig. 171. — Rock Guying.

The rock anchor shown in Fig. 172 is one manufactured by the Miller Anchor Company. The rod *A* is securely fastened to the smooth piece *B*, and *B* constitutes one-half of a cylinder of which *C* is the other half. *B* and *C* are both wedge-shaped, the tapers on the two pieces being in opposite directions. The part *C* is corrugated so that it will take a firm hold in the rock, while *B* has a smooth surface which allows it to slide readily. This anchor is best installed by tying the piece *C* to *A* and *B* and then inserting them in a hole drilled just large enough for a sliding fit. The wedge *C* is then driven down slightly so that the corrugations will take a firm hold in the rock. If tension is applied to the rod *A* the anchor will tighten, due to the wedge-shaped pieces; hence the greater the load the tighter they will be held in position. These anchors will stand a stress of 15,000 pounds.

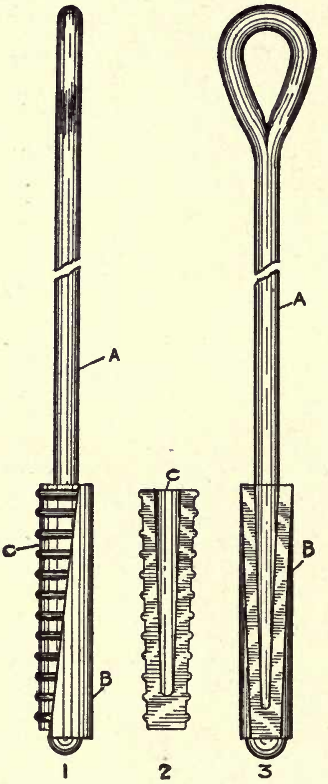

FIG. 172. — Miller Rock Anchor.

On all toll lines exposed to sleet and wind loads, a regular system of storm guying should be utilized to prevent the wrecking of long sections of line. The practice of storm guying has become quite general on heavy lines, and in what follows the methods used by the American Telephone and Telegraph Company are described.

On straight lines carrying one cross-arm, a head guy and a side guy should be placed at least once every mile.

On a line containing two cross-arms and more than ten wires the line should be double head guyed and double side guyed every mile.

On a line containing three cross-arms and more than 20 wires the line should be double head guyed and double side guyed every half mile.

On a line containing four cross-arms and more than 30 wires the guys on corner poles should be doubled. The line should be double side guyed every quarter mile, double head guyed every half mile, and additional side guys should be used whenever necessary.

These requirements may seem excessive, but experience proves their ultimate economy in zones where combined wind and sleet are regularly encountered.

All terminal poles, and those which support long spans of say 200 feet or more, should be specially guyed. In general the adjacent poles should be head guyed to the terminal pole; and the terminal pole, whenever it is possible, should be side guyed in both directions. All curves and corners should be thoroughly guyed as shown in Fig. 173. It will be noted that the arrangement at *B* shows the corner guyed in two directions — one guy to relieve the longitudinal pull of the straight line and the other to counteract the side pull at the turn. When it is impossible to guy in this manner, the method shown at *A* in the same figure may be employed. All poles on a curve should be guyed, as shown at *C*, owing to the fact that the direction of the line wires is continually changing. When the radius of the curve is large and there are few wires, it may be sufficient to rake the poles; but in most cases guying is economical or even necessary.

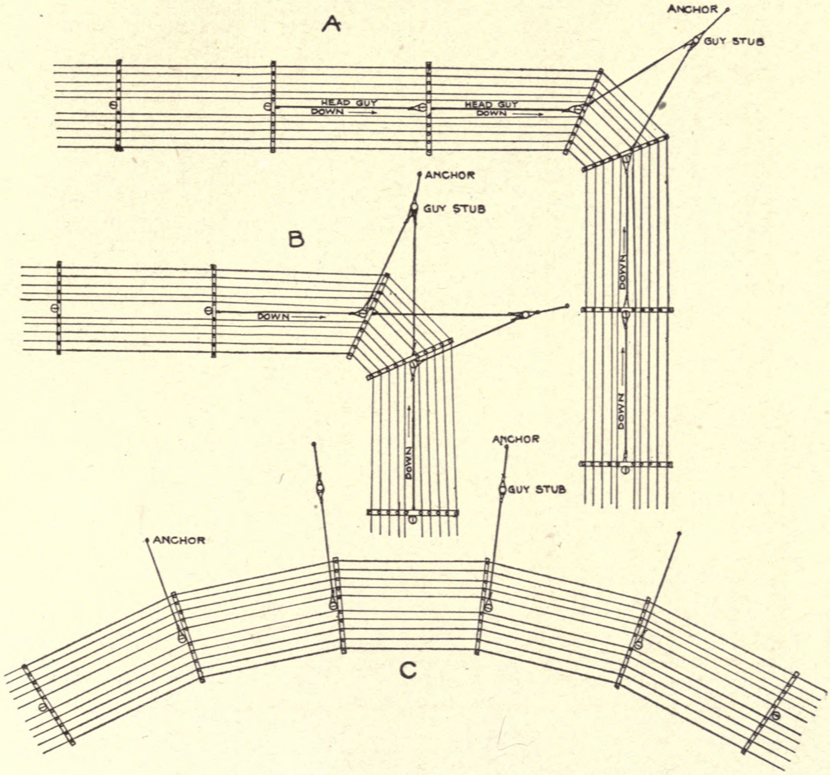

FIG. 173. — Guying at Curves and Corners.

Bracing is superior in general to guying, but sometimes more expensive in respect to first cost. One of the feasible methods is shown in Fig. 174. It is well to set the butts of the braces from three to four feet in the ground and anchor them in such a manner as to distribute the weight and reduce the pressure per unit area.

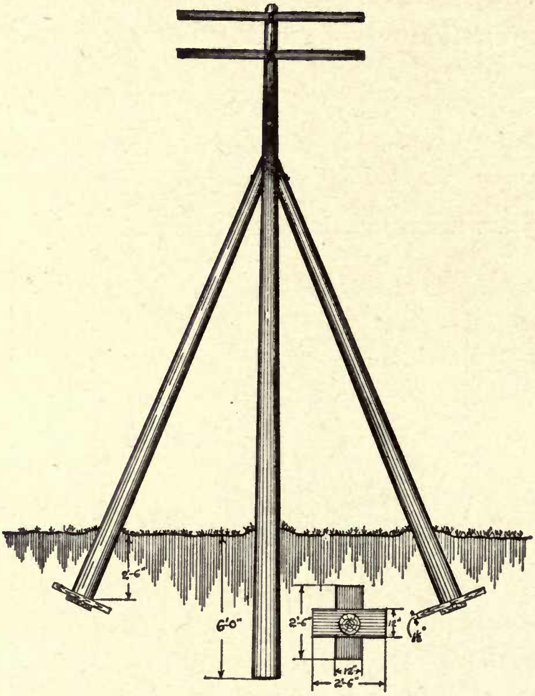

FIG. 174. — Double Pole Braces.

Miscellaneous Material. — Stranded wire rope is manufactured especially for guying purposes and is usually composed of seven No. 12 B. W. G. galvanized steel wires. The external diameter of this rope varies from one-quarter to three-eighths of an inch; the minimum breaking strength should be 6000 pounds. The strands should be free from scales, inequalities, splints, flaws and all other imperfections, and should be of circular section with uniform diameter. Each strand should be drawn in one continuous length and free from factory joints.

All guy strands and all iron and steel fittings should be heavily galvanized to prevent corrosion, or delay its appearance as much as possible. The galvanizing should consist of a coating of zinc, evenly and uniformly applied, and should adhere firmly to the surface of the iron or steel.

Any specimen should be capable of withstanding the following test. The sample should be immersed in a saturated solution of copper sulphate for one minute, then thoroughly washed in water and wiped dry. This process should be repeated several times. If, after the fourth immersion, there should be a copper-colored deposit on the sample, or the zinc should have been removed, the lot from which the sample was taken should be rejected. The solution should have a specific gravity of 1.185 at 70° F. While a sample is being tested, the temperature of the solution should at no time be less than 60° nor more than 80° F. The threads on all iron or steel bolts, on which nuts are to be used, should be galvanized in the following manner. The threads should first be cut with a small die, galvanized, and then recut with a die of standard size, which should leave a coating of zinc on the threads.

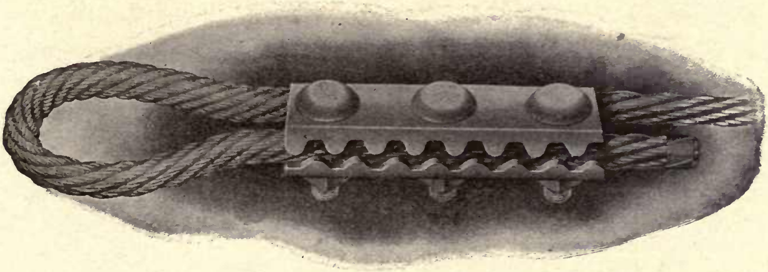

FIG. 175. — Three-bolt Guy Clamp.

There are several methods of fastening a guy strand. One way is by means of wrought-iron clamps, but the malleable iron three-bolt clamp shown in Fig. 175 is superior; there the bolts are made of high-carbon steel. Whenever it is desired to attach the guy wire to an eye, as in an anchor rod, for example, a thimble like that shown in Fig. 176 should be used to interlink the guy rope and the rod. When the guy wire is attached to a stub the proper method of fastening is to pass the rope twice around the pole and then through a clamp.

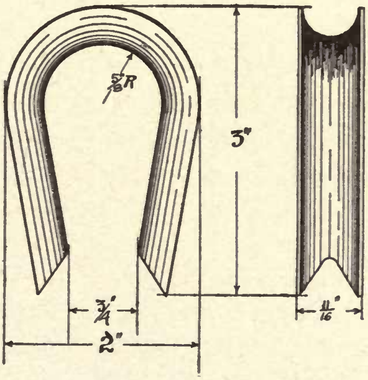

FIG. 176. — Standard Thimble.

The use of clamps is recommended because they can be easily removed without waste of material, which is not possible with a wrapped connection.

Of the material used in ordinary lines we have now discussed all but the insulators. These are constructed either of porcelain or glass, of which the latter is used almost universally in this country. The leakage is made a minimum by making the diameter of the insulator as small as possible, and by adding to the length of the leakage path by means of two or more petticoats. This increases the insulation resistance, which depends greatly upon the surface accumulations of dirt and other foreign matter; the resistance falls materially in foggy or rainy weather. The general form of the standard line insulator is shown at *B* in Fig. 177, while an insulator with a double petticoat is shown at *B* in Fig. 178. This latter, in addition to the advantage of having a long leakage path, has also the advantage that the second petticoat is completely protected from falling rain. The standard two-piece transposition insulator used by the American Telephone and Telegraph Company is shown at *A* in Fig. 177. This insulator is much heavier and larger than the ordinary line insulator

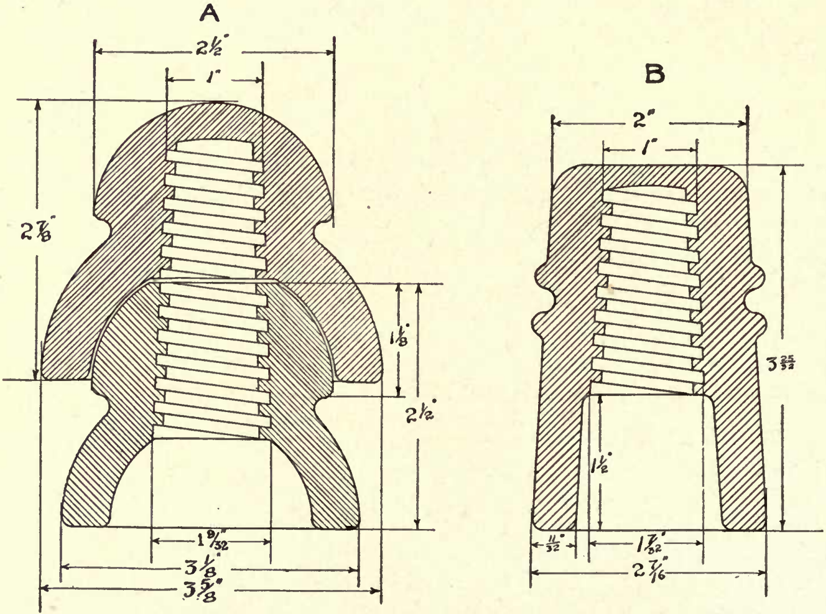

Fig. 177. — Standard Line Insulator and Two-piece Transposition Insulator.

and, as previously stated, requires an extra long pin. Most of the independent telephone companies use the one-piece transposition insulator as shown at *A* in Fig. 178.

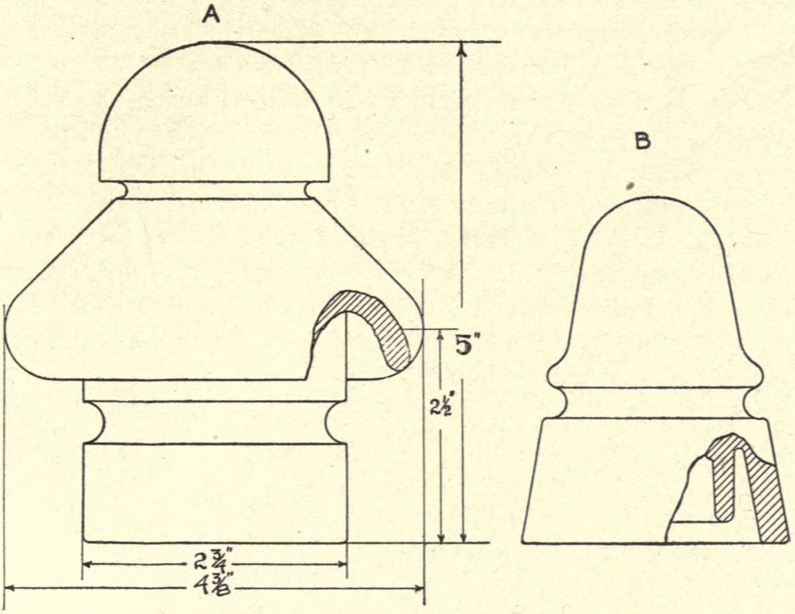

FIG. 178. — Double Petticoat Line Insulator and One-piece Transposition Insulator.

Wire Stringing. — The remaining feature of construction to be considered is wire stringing. When only one or two wires are to be strung, one end of the wire is attached to the cross-arm at the beginning of the section, and the wire is unreeled along the pole route, using a pay-out reel mounted on a hand barrow as shown in Fig. 179.

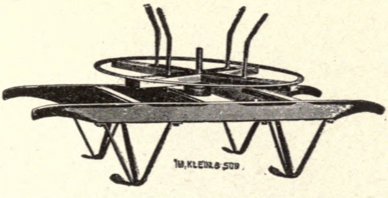

FIG. 179. — Pay-out Reel.

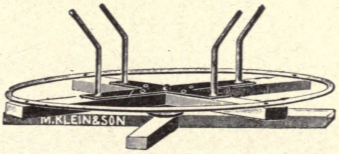

FIG. 180. — Wagon Pay-out Reel.

However, several toll circuits are usually strung at a time and the wire wagon and running board are employed. The wire wagon is very solidly constructed and carries wire reels as shown in Fig. 180, five on each side of the wagon. At the back of the wagon is placed a wooden bar in which ten guides are cut; these guides serve to separate the wires and thereby greatly reduce the trouble in handling them. When the wires have been passed through the guides they are fastened to a running board such as that shown in Fig. 181. This consists of a triangular piece of iron to one corner of which is attached a ring and swivel. The side of the triangle opposite the pulling ring is perforated with eleven holes to receive the wires. The wires may be fastened directly to the bar, or, as often the case, they can be secured by snaps so as to facilitate rapid removal at each pole of the five wires which must pass around the pole on the side opposite from the pulling rope. This is not necessary on new work, however, for then the wires should be pulled over the top cross-arm and then dropped into place. The eleventh hole in the running board is provided so that a suitable "fish wire" may be pulled through, by means of which the hauling rope can be pulled back for the next group of wires. A suitable wire or a rope should be attached to one end of the running board to prevent it from twisting and turning, as otherwise the wires might twist or tangle. In hauling the wire, a strong rope which has been previously passed over the cross-arms from the far end of the section is attached to the pulling ring.

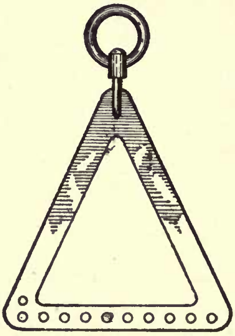

FIG. 181. — Running Board.

The wagon with the pay-out reels is stationed at the beginning of the run and a team of horses, at the far end of the section, is hitched to the pulling rope. A man is stationed on each pole to lift the running board over the cross-arm and to separate and place the wires. In this manner ten wires can be strung in one haul. When wires are strung on the lower cross-arm it is well to use two running boards, attaching five wires to each and thus avoiding the necessity of passing five of the wires around each pole, as would be the case if all ten wires were attached to one running board. The two running boards can readily be pulled in one haul, a separate rope being attached to each board. After about one-half mile has been strung as described, the wires should be stretched and tied. The stretching is accomplished by means of a "come-along" (Fig. 182) and pulleys. The "come-along" shown in the figure has met with general satisfaction for pulling hard-drawn copper, due to the fact that the jaws are smooth, straight and parallel, thus avoiding to the greatest possible extent the likelihood of nicking the wire. This is of great importance, and it should also be remembered that a kink should never be allowed to remain in hard-drawn copper wire. The proper remedy is to cut out the kink and make a sleeve joint. In using the "come-along" the tension is applied at the eyelet and it will be noted from the construction that as the tension increases, the hold on the wire correspondingly increases. When the tension is removed the jaws of the appliance are automatically opened. In stretching the wire, conductors of the same size and material may be pulled up together. If six wires are being pulled up, a three-sheave block should be used; for eight wires, a four-sheave block; and for ten wires a five-sheave block, as shown in Fig. 183.

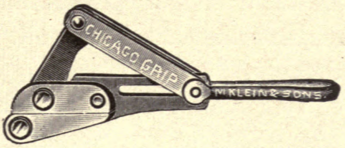

FIG. 182. — Come-Along.

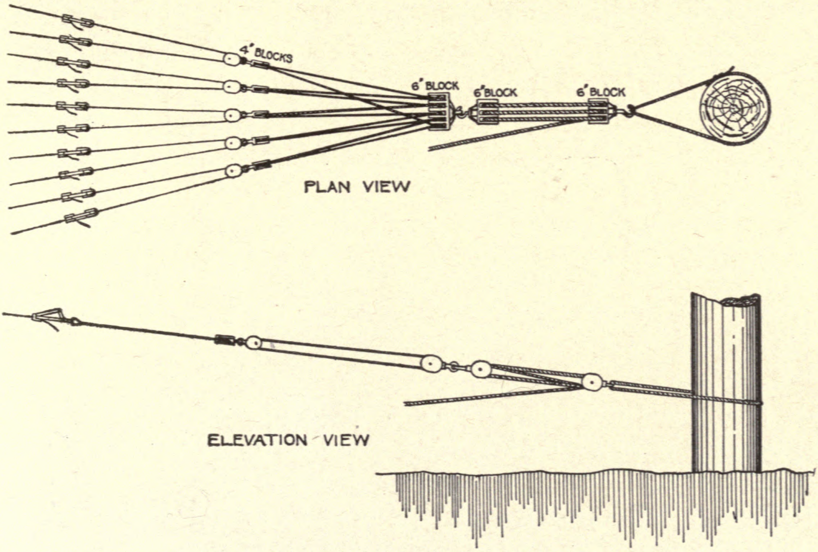

FIG. 183. — Pulling Up Line Wire.

After the wire is stretched to the proper tension and deflection, the man handling the " come-alongs " and pulleys gives the signal to the men on the poles to " tie in," and they then proceed to permanently fasten the wires to the insulators. It should be remembered in this connection that hard-drawn copper wire is likely to stretch, and several months after a new line has been built the deflections may have increased considerably.

The best method of tying copper wire to an insulator is shown in detail at *A* in Fig. 184. The tie wire and the line wire are laid in the groove and the tie is passed once around the insulator. One end of the tie wire is now brought down over the line wire, while the other end is brought up under it, in the opposite direction. The two projecting ends are then given five turns around the line wire, and the tie is complete as shown in the central view in the figure. The tie wire should be of soft copper of the same size as the line wire. For No. 14 N. B. S. G. wire the ties should be 17 inches in length, for No. 12 N. B. S. G. wire, 19 inches and for No. 8 B. W. G. wire, 24 inches. The standard method of tying iron wire is shown at *B* in Fig. 184.

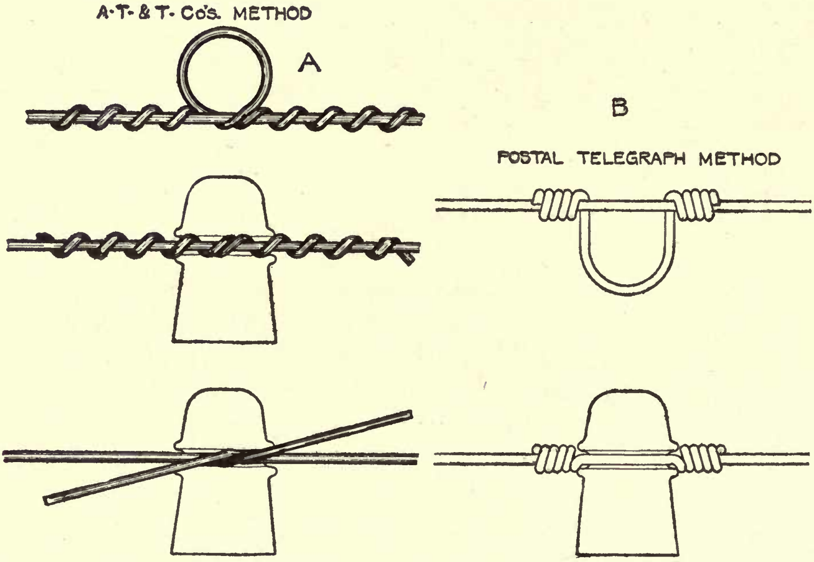

FIG. 184. — Method of Tying Wire to Insulator.

The proper location of the line wires with respect to the insulators for tangent sections and curves is shown at *A* and *B*, respectively, in Fig. 185. It will be observed that on tangent or straightaway sections the line wires on the four outer pins are placed on the sides of the insulators next to the pole, while on the two inner insulators the line wires are located in the reverse position. At curves the line wire should always be placed on the side away from the center of the curve, so that the stress due to the angle in the line will be exerted on the pin and not on the tie. When the wire is attached to the last insulator on the line, or terminated at some intermediate point, generally termed "dead-ending," it should be looped around the insulator as illustrated in Fig. 186. The wire should always be looped

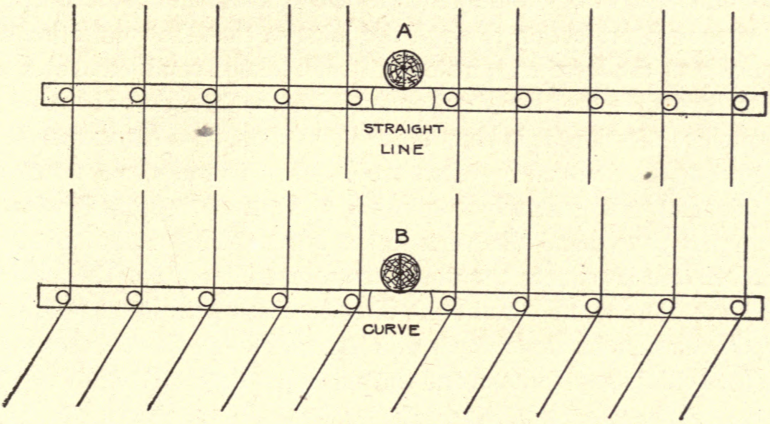

FIG. 185. — Location of Wire on Insulators.

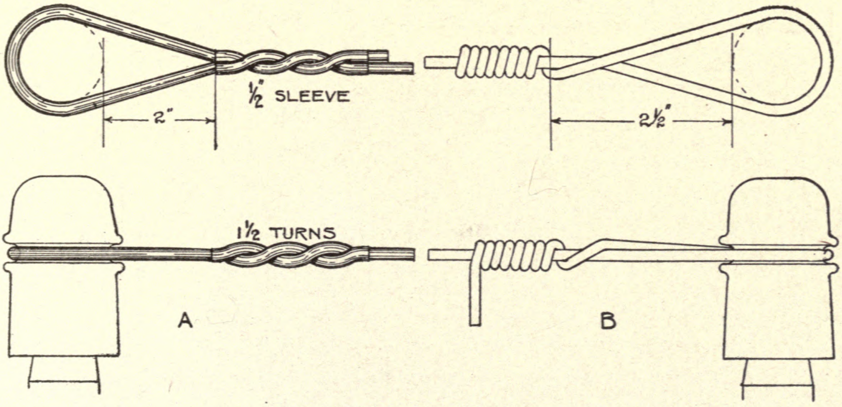

FIG. 186. — Dead-Ending.

as shown, and should never be wound around the insulator. A dead-end can be fastened by means of a half sleeve, as shown at *A*, or the wire may be wrapped about itself for about ten turns as shown at *B*. When another wire is to be joined to the dead-ended line, it is well to allow enough projection through the joint so that the connection can be made to the loose end, instead of the stressed conductor, or span. When two lines are thus dead-ended with the intention of making a through connection, it is best to dead-end them on a single cross-arm instead of the double arm often used. For this purpose a transposition insulator is generally employed, one wire being dead-ended in the upper groove and the other in the lower. This method is advisable because it reduces the pin stress to a minimum, as the pull due to the tension of the wire in one direction is practically counteracted by the tension in the opposite direction. When double cross-arms are used this is not the case, and the pins must support the full tensions of the spans.

All joints in copper should be made by means of sleeves, a typical example of which is the Cook joint shown in Fig. 187. There are many forms of these joints on the market but they all operate on about the same principle, so a description of one will suffice. The old practice of making a twisted splice, with the use of solder, should never be followed. In making a sleeve joint, each end of the wire should be passed through the sleeve so as to project about one-quarter of an inch. A tie wrench or connector is placed at each end of the sleeve, with about one-quarter of an inch projecting, and the required number of twists is then given. The sleeves are made for the different sizes of wire and the number of twists varies accordingly; thus the sleeve for a No. 14 or a No. 12 N. B. S. G. wire should have four complete twists, while a No. 8 B. W. G. wire requires four and one-half twists.

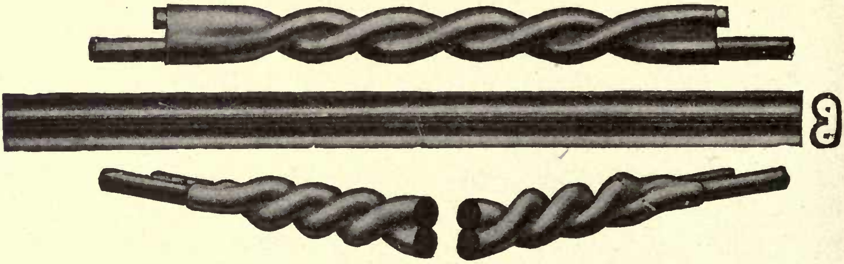

FIG. 187. — Cook Wire Joint.

CHAPTER XVIII

ELECTRICAL REACTIONS IN TELEPHONE LINES

TOLL-LINE construction, outside of urban districts, is comprised almost wholly of open-wire circuits of the type previously considered. Circuits of the cable type are much less efficient in general than open wires and hence undesirable in long toll lines. But cable construction is often unavoidable; this holds true in nearly every case at city terminals or terminal offices, where several miles of underground cable is quite common. Submarine crossings at rivers and bays are also unavoidable in many instances. In general, the total length of cable should be made a minimum, in order to secure an adequate standard of transmission at a minimum of cost.

The development of the loading art has relieved the cable difficulties to some extent, but not completely. There are many sections of cable in a long line of open wire which cannot be loaded efficiently. Toll cables of special design are very essential in securing maximum transmission efficiency at minimum cost.

In the early stages of toll development it was permissible to locate a toll office well within the limits of a fairly large city without the use of much cable, but this condition now rarely exists because of the general practice of requiring all wires to be placed underground. Following the requirements last mentioned it became the policy to situate toll offices outside of the underground limits, often near the city outskirts. Since the introduction of special toll cables, and loading, however, the policy has been reversed to some extent and the more recent large installations have been located near the center of local distribution.

In dealing, then, with toll lines of the general type, there are two distinct classes of circuits to consider, one comprised of cable and the other of open wire. The properties of these two kinds of circuits are essentially different, and hence their reactions are different also. In order to comprehend their actions fully, it is necessary to consider the most general type of circuit first.

General Properties. — The general type of toll circuit, whether grounded or metallic, possesses four distinct properties. These will be explained from the standpoint of metallic circuits, which is the only suitable type for general service and particularly for long-distance service. These four properties are resistance, inductance, capacity and leakage.

Resistance is so well understood that it needs no explanation. It is analogous to friction in mechanics and wastes energy in proportion to the product of the square of the current, the resistance and the time; this lost energy appears as heat and is radiated to the atmosphere or surrounding bodies. It is necessary to distinguish, however, between true or ohmic resistance and apparent or effective resistance. There is no difference between the two for continuous and low-frequency alternating currents, with conductors of the size used in telephony. But with the relatively high frequencies reached in telephony, the difference becomes appreciable and the effective resistance is the greater. This is due to a lack of penetration of the current to the center or core of the conductor, and to local or eddy currents in the conductor; when iron is employed, hysteresis is also a factor. The increase of effective over true resistance is termed the skin effect. This effect is not of consequence with copper wires until the higher frequencies are considered, unless the wires are unusually large; but with iron wires it is very prominent, because of their large magnetic permeability. In general the effect increases with the frequency, the size of the conductor and its permeability. A mathematical discussion of the subject is too complex for presentation here, but it has been exhaustively treated by several eminent authorities whose writings may be consulted.

Inductance is the property of a conductor which exists by virtue of the fact that every electric current establishes a magnetic field. When the current is variable, the field varies also, and induces in the conductor a counter E.M.F., which absorbs or neutralizes a component of the impressed E.M.F. and causes the current to lag in time or phase behind the impressed E.M.F. The absolute value of the inductance is the product of the number of lines of magnetic flux and the number of turns of the conductor which conveys the exciting current and with which they are linked; or expressed more briefly, it is the total number of flux linkages with the circuit. Inductance, then, causes the current to lag behind its impressed E.M.F. and consumes a component of the E.M.F. It does not, however, consume energy. The instantaneous value of the energy stored in a pure inductance whose coefficient of self-induction is L, when the current is i, is $\frac{1}{2} Li^2$; but all the energy which the inductance receives in a given half-cycle is returned during the succeeding half-cycle. Inductance coupled in series with resistance, in a simple series circuit, gives rise to the impedance

$$Z = \sqrt{R^2 + L^2p^2}, \quad \ldots\ldots\ldots \quad (1)$$

where p is $2\pi n$ and n is the frequency in cycles per second. The coefficient of self-induction for a pair of suspended parallel wires, expressed in henrys per mile, is

$$L = \left(0.1609 + 1.482 \log\frac{d}{r}\right) 10^{-3}, \quad \ldots\ldots \quad (2)$$

where d is the distance between the wires and r is their radius, in like units. This formula does not hold when $\frac{d}{r}$ is small or, that is, for wires near together in comparison with their common radius; cable circuits form a case in point, but there the inductance is so small as to be negligible.

Capacity is the property of a circuit which exists by reason of the fact that the two opposite sides of the circuit form a condenser. Whenever the terminals of the circuit are connected to a source of E.M.F., the conductors become charged like the opposite plates of a Leyden jar or condenser. When a condenser is connected to a source of continuous E.M.F., a transient current exists while the condenser is being charged and then ceases. But when a condenser is connected to a source of alternating E.M.F., it alternately charges and discharges with the alternations of impressed E.M.F. and in effect an alternating current flows through it. At any instant the charge is proportional to the product of the capacity and the instantaneous E.M.F. But the current is proportional to the rate of change of the charge with respect to the time, and is therefore 90° ahead of the impressed E.M.F. if the latter is periodic and sinusoidal. The condenser, like an inductance, consumes a component of the impressed E.M.F., but instead of causing the current to lag, makes it leading. Similarly it consumes no energy. At any instant the energy stored in the condenser is $\frac{1}{2} Ce^2$, where C is the coefficient of capacity and e is the instantaneous value of E.M.F. But the energy which the condenser receives in one half-cycle is returned in the next, or, in other words, charge and discharge are equal. The impedance due to simple resistance and capacity in series is given by

$$Z = \sqrt{R^2 + \frac{1}{C^2 p^2}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where p is $2\pi n$ as before. The capacity of a pair of parallel suspended wires in microfarads per mile is

$$C = \frac{0.1942}{\log \frac{d}{r}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where d and r have the previous meanings. This formula holds only when $\frac{d}{r}$ is large, and therefore does not apply to cable circuits. In the latter case, however, the capacity depends in addition upon the specific inductive capacity of the insulation and it is more direct to find the capacity by actual measurement.

Leakage is not a property of the wires themselves, but of the insulation. It is commonly spoken of in terms of leakage or insulation resistance. In cable circuits it depends upon the specific resistance of the insulating material, which should be as high as possible; in well-made cables the leakage should be negligible. In lines of open wire, dependence for insulation is placed upon the insulating supports, of glass or porcelain. When the insulators are made of high-grade material, the insulation depends in great part upon the surface conditions, which in turn vary in a large degree with weather conditions. Leakage, or leakage resistance, absorbs energy and dissipates it as heat, after the manner of resistance of any kind.

The properties of a telephone circuit, consisting of a pair of very long parallel wires, are not like those of simple resistances, inductances and capacities. This arises from the fact that resistance, inductance, capacity and leakage in a telephone line are uniformly distributed, whereas in the usual theoretical treatment of alternating current problems they are taken as concentrated or lumped. This difference is of fundamental importance and alters the whole theoretical treatment. The resistance and the inductance are serially connected with respect to the circuit and act, for any small portion of the circuit, just as simple or concentrated resistance and inductance would act.

The capacity and the leakage are connected in shunt with the circuit and divert current from it; the capacity and the leakage are also in shunt or parallel with each other.

The complete theoretical treatment of such a circuit will not be given, but the general subject of attenuation will be explained briefly. Attenuation implies the progressive loss of amplitude or strength which a wave of current or E.M.F. suffers in traveling along the circuit from the origin to the distant terminal. In general, neglecting reflection at the terminals, the strength of a current wave of initial strength I_o, when it has traveled a distance l from the outgoing end or terminal, is

$$I_l = I_o \epsilon^{-\beta l}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where ϵ is the base of the Napierian system of logarithms and β is the attenuation constant, l being in miles.

$$\beta = \sqrt{\frac{Cp}{2}\left(\sqrt{R^2 + L^2p^2} - Lp\right)} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where R, L, and C are the respective constants per mile and p is $2\,\pi n$. The minimum rate of attenuation depends upon the minimum value of β, the attenuation constant. Obviously this value of β corresponds to minimum values of R and C and a maximum value of L, or minimum resistance and capacity and maximum inductance. It is also true that the leakage should be a minimum. An inspection of the formula for β also shows that the attenuation increases with the frequency.

Efficient transmission implies efficiency with respect to both volume and quality. In telephony the actual line current is very complex because so many frequencies are present. The range of frequency is ordinarily accepted as from 100 to 2000 cycles per second. Since the rate of attenuation increases with the frequency, it is evident that all the components of a complex wave will not be transmitted with like efficiency, but those of highest frequency will be attenuated most.

The timbre or quality of sound depends upon the pitch and the relative intensity of the component partials, and in order to fully preserve the quality of transmitted speech, it is evident that the component frequencies of any complex wave must be transmitted with equal rates of attenuation. Where this is not the case, distortion, or impaired quality, will unavoidably occur. The effect of distortion is a matter of degree, however, and there is a noticeable difference between circuits in cable and those of open wire.

Cable Circuits. — In circuits of the cable type the inductance is practically negligible and the formula for the attenuation constant is

$$\beta = \sqrt{\frac{RCp}{2}}. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (7)$$

This gives the foundation of the so-called *KR* law, where *K* is the symbol for capacity and *R* for resistance. Assuming a given frequency, it is evident that two unlike cables, of equal length, will cause the same attenuation if the product *KR* in the two cases is the same, and knowing by experience the limit of length of a cable of given resistance and capacity, a limiting value of *KR* can be found. Evidently

$$\beta l = l\sqrt{\frac{RCp}{2}} = \sqrt{\frac{(lR)\,(lC)\,p}{2}}; \quad . \; . \; . \; . \; . \qquad (8)$$

lR is the total cable resistance and lC the total capacity, so that the product of total resistance and total capacity is the total *KR*, on which a limit can be placed for efficient transmission and by means of which dissimilar cables can be compared. Cable efficiency is obviously increased by diminishing the resistance and the capacity per mile.

The first cables generally used in toll lines were those which were standard for local systems, or No. 19 B. & S. gauge, with a mutual capacity of 0.054 microfarad per mile. High-capacity cable of the same gauge has a mutual capacity of 0.080 microfarad per mile. No. 22 B. & S. gauge, with a capacity of 0.069 microfarad, has been used a great deal for local work and, in some cases, in toll lines. About the year 1900 a good deal of development work was commenced on toll cables of higher efficiency. It is impracticable to reduce the capacity of cables of larger gauge to any appreciable extent, and the special toll cable is practically like the early types, except that it has larger conductors.

The insulation used on the conductors in these cables consists of a loose wrapping of very porous dry paper, which permits the inclosure of the greatest possible amount of dry air. This is very beneficial, inasmuch as air, next to hydrogen, possesses the lowest specific inductive capacity of any known substance. The two wires which form each pair are twisted together, the length of a complete twist being not greater than three inches. These twisted pairs are then formed into a core arranged in reversed layers, and the whole covered with a layer of heavy tough paper. Around this paper covering is placed a sheath composed of lead and tin, which should have a thickness of at least one-eighth of an inch. In the manufacture of the cable, the core is thoroughly baked before it is inclosed in the lead sheath, thus excluding all moisture. A cable thus constructed is known, therefore, as the dry-core cable. Due to the fact that the insulation and capacity of the cable depend upon keeping the core perfectly dry, the sheath at either end should be hermetically sealed at all times, except when it is necessary to expose the conductors for splicing or other work. The sheath should be sealed up immediately after all work is completed, due caution being exercised to drive out, by a suitable bath in hot paraffin, any moisture that may have crept into the exposed end. This brief description applies to all types of dry-core paper cables. The size of conductor varies considerably; in cables for local work conductors as small as No. 24 B. & S. have been employed, while toll cables have been made with conductors as large as No. 10 B. & S. Of course the size of conductor ranges all the way between these limits, depending principally upon the length of the cable, the total length and character of the circuit and the specified standard of transmission. The capacity depends upon how compactly the core is formed and can be varied considerably.

By mutual capacity is meant the capacity between each wire and its mate, in distinction from grounded capacity, which is the capacity of one conductor measured against all other conductors grounded on the sheath of the cable. The insulation resistance of each wire in the cable should be at least 100 megohms per mile when the cable is all laid, spliced and ready for operation. In Table 13 are given the standard requirements of a number of trunk and toll-line cables.

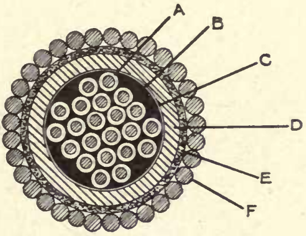

FIG. 188. — Cross Section of Armored Cable.

The type of cable just described is not suitable for submarine crossings in navigable waters, where it may become fouled by the anchors of boats. For such work the sheath is surrounded by an armor of steel wire, over which is placed a heavy braid thoroughly impregnated with a water-proofing compound. These cables are often of special construction. The Ameri-

TABLE 13

ELECTRICAL PROPERTIES OF TRUNK AND TOLL CABLES

Size of Wire, B. & S. Gauge.	Number of Pairs in Standard Full Size Cable, 2⅝ In. Inside Diameter.	Capacity in Microfarads per Mile.		Maximum Resistance of Circuit in Ohms per Mile at 68° Fahr.
		Minimum.	Maximum.	
10	35	.072	.080	11
13	75	.072	.080	22.5
13	55	.066	.074	22.5
14	100	.072	.080	30
14	80	.066	.074	30
16	150	.074	.081	46
16	100	.060	.068	46
19	300	.074	.081	92
19	180	.054	.060	92

can Telephone and Telegraph Company have used a type shown in Fig. 188; there *A* is the regular paper insulation, *B* is a filling of asphalt, *C* is a wrapping of cotton, *D* is the lead sheath and *E* is a wrapping of marlin; over the whole is placed the steel wire armor, *F*. The detrimental effect of capacity is felt to even a greater extent in submarine cable than in standard underground cable, owing to the much higher specific inductive capacity.

Uniformly distributed capacity can be likened to an infinite number of infinitesimal condensers, connected in shunt with the line, at equal intervals. For experimental purposes an artificial line can be constructed which is almost an exact counterpart of a real line, by using small lumped resistances and capacities, each representing but a very short portion of an actual line. This is indicated in Fig. 189. When the key is depressed there is a large rush of current to charge the line, which finally decreases to a steady Ohm's law value. The current

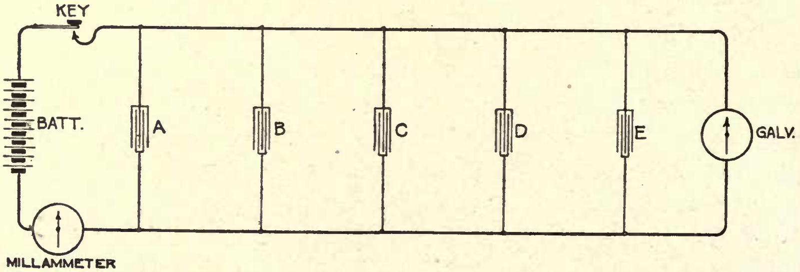

FIG. 189. — Artificial Line with Distributed Capacity.

arrives at the distant end gradually and finally builds up to Ohm's law value. Fig. 190 shows the outgoing current from the battery end, represented by the curve *AB*, and the arrival current at the receiving end is shown by the curve *CD*. The slight difference between *B* and *D* is attributable to leakage. If the closure of the key is momentary, the current curves will be similar to those shown in Fig. 191. If a succession of short impulses are imparted to the line, such as *A*, *B*, *C* and *D* in Fig. 192, the arrival current will be similar to that shown at *E*; this shows how the impulses trail together or blur during transmission, which is a species of distortion.

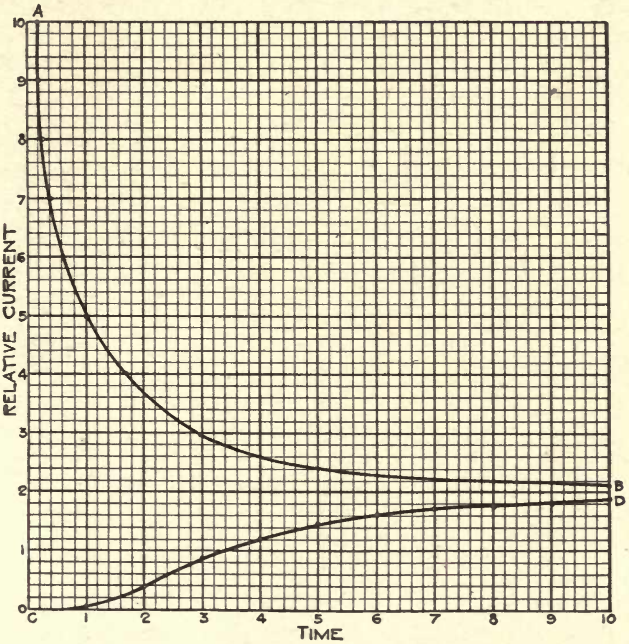

FIG. 190. — Outgoing and Incoming Currents on a Cable with a Constant Impressed E.M.F.

In a cable telephone circuit, like that shown in Fig. 193, the reactions are more complex. The curves in Fig. 190 show clearly that the line must become fully charged before the full current strength arrives at the distant terminal. But when a rapidly alternating E.M.F. is impressed on the cable, there is insufficient time during a half cycle for the circuit to become fully charged, and hence attenuation occurs. The potential falls from point to point along the circuit, due to the ohmic resistance; and the current falls likewise, owing to a

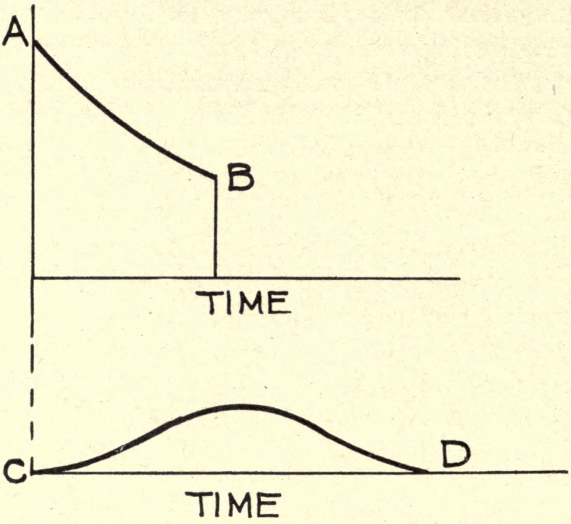

FIG. 191. — Effect of Closing Key Momentarily.

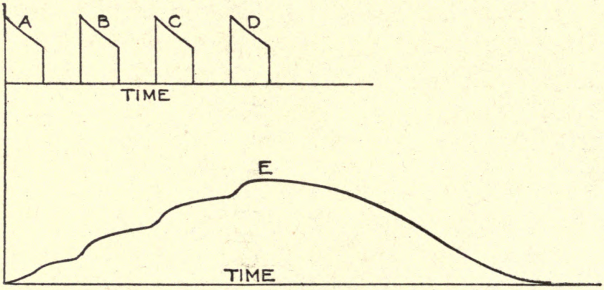

FIG. 192. — Effect of Succession of Impulses.

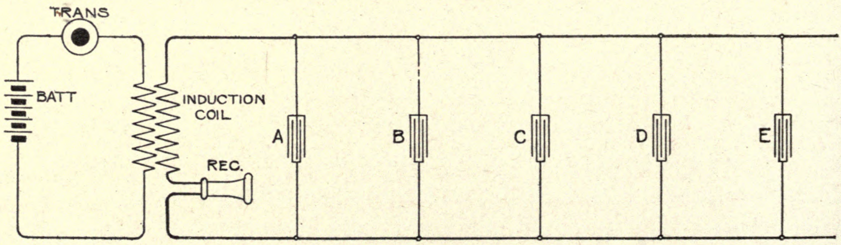

FIG. 193. — Cable Telephone Circuit.

constant absorption which is the result of charging the elementary or infinitesimal condensers. The resultant or compound effect produces very rapid attenuation. At the same time, the wave components of highest frequency will be attenuated most, with resultant distortion.

The *KR* law has sometimes been applied to the determination of the maximum permissible length of a given cable for efficient transmission. Sir William Preece has stated a limit of 15,000 for the value of *KR*. This law can be used without doubt for first approximations, but it takes no account of wave reflection at the terminals or at junctions of dissimilar portions of the circuit. Hence it should be used with care and should be supplemented by more elaborate calculations in the actual work of design.

Open-wire Lines. — In addition to resistance and capacity, lines of open wire possess inductance and leakage. The natural inductance is comparatively small, amounting to a few milli-henrys per mile. The leakage varies greatly with weather conditions; the insulation resistance varies from perhaps fifty megohms per mile in clear dry weather to a fraction of a megohm per mile during a rainfall. Theory and experience show that a moderate degree of leakage improves the quality of transmission, that is, reduces distortion. But extreme values increase the attenuation and thus reduce the total efficiency.

For moderate distances of a few hundred miles or less, No. 12 N. B. S. G. wire of hard-drawn copper has been used a great deal, with satisfactory results. The very long circuits require No. 8 B. W. G., which is about two and one-half times the weight of No. 12. Other sizes have been used to some extent, notably No. 14 N. B. S. G., for short lines, but it lacks sufficient tensile strength. Iron has been used a good deal in rural service and is satisfactory for very short lines, but extremely inefficient compared with copper, because of its very high effective resistance.

The efficiency of open-wire lines will be increased in general by diminishing the resistance and the capacity and increasing the inductance and the insulation resistance. When a metallic circuit of copper, of a stated size of wire, is erected with a fixed separation between the wires the inductance and the capacity are also fixed. The separation ordinarily employed is about 12 inches, which cannot well be increased if there are several circuits on the poles or cross-arms. High transmission efficiency is therefore obtained by diminishing the resistance, that is, by using larger conductors.

Several attempts have been made to increase the natural inductance, but without successful results. The introduction of inductance does not, as sometimes stated, neutralize the capacity after the manner so well understood in simple series circuits. Here the inductance is serially connected with the circuit, while the capacity is connected in shunt, and the frequency varies over a great range. The effect of inductance is to increase the impedance of the circuit and diminish the current, but less energy is frittered away as heat through resistance losses and a larger percentage of outgoing current reaches the distant terminal, when inductance is present.

The advantages of large inductance were early pointed out by Oliver Heaviside and in 1893 he suggested the introduction of lumped artificial inductance, distributed at intervals along the line. This was attempted later with very large inductances placed many miles apart, but the effect was detrimental. Nothing was accomplished until Dr. Michael I. Pupin investigated the problem mathematically and experimentally and announced the results, in 1900.

Loaded Lines. — The underlying theory of loaded circuits requires the extended use of mathematics and has been so extensively treated elsewhere that it will not be given here. Dr. Pupin thoroughly expounded the subject in a paper read before the American Institute of Electrical Engineers, in 1900. In explaining the benefits of inductance loading he made use of a mechanical analogy which is of great assistance in grasping the subject. Quotations from Dr. Pupin's paper follow.

" The main features of this theory are extremely simple and can be explained by a simple mechanical illustration. Consider the arrangement in Fig. 194. A tuning fork has its handle *C* rigidly fixed. To one of its prongs is attached a flexible inextensible cord *BD*. One terminal of the cord is fixed at *D*. Let the fork vibrate steadily, the vibrations being maintained electromagnetically or otherwise. The motion of the cord will be a wave motion. If the frictional resistances opposing the motion of the cord are negligibly small the wave motion will be approximately that of stationary waves as at 2. The direct waves coming from the tuning fork and the reflected waves coming from the fixed point *D* will have nearly equal amplitude and by their interference form approximately stationary waves.

" If, however, the frictional resistances are not negligibly small, then there will be dissipation of the propagated wave energy. Hence the direct and the reflected waves will not have equal amplitudes and, therefore, their interference will not result in stationary waves. The attenuation of the wave is represented graphically at 3. Experiments will show that, other things being equal, increased density of the string will diminish attenuation, because a larger mass requires a smaller velocity in order to store up a given quantity of kinetic energy, and smaller velocity brings with it a smaller frictional loss. This is a striking mechanical illustration of a wave conductor of high induct-

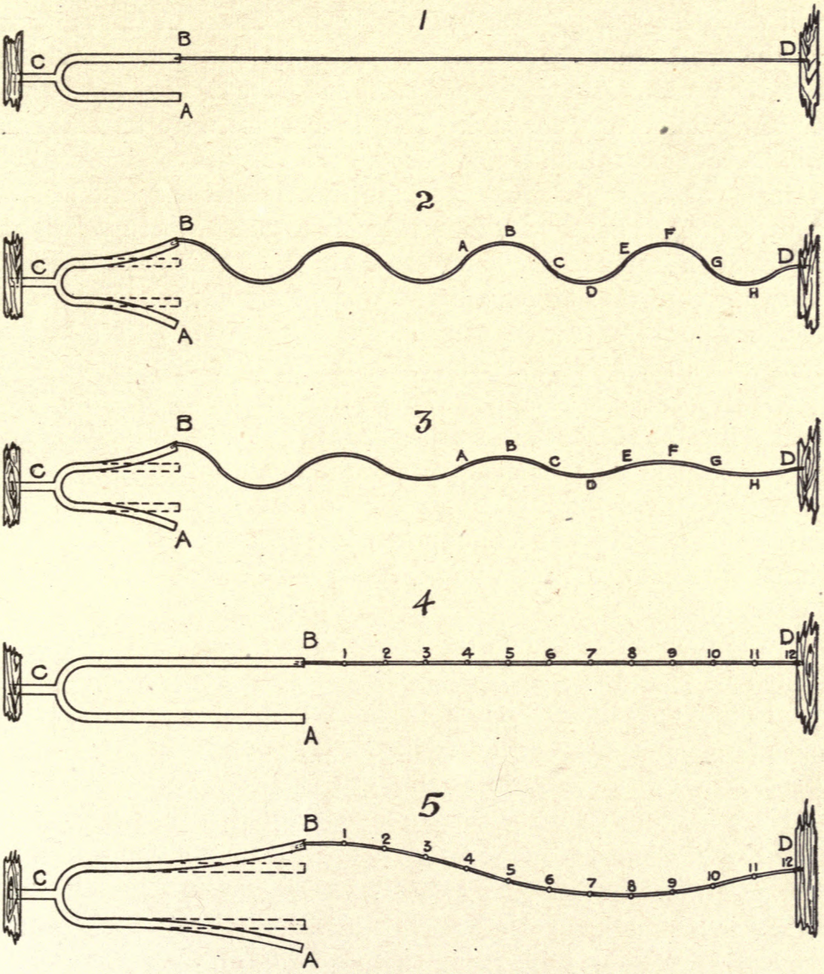

FIG. 194. — Mechanical Analogy of a Loaded Circuit.

ance. It should be observed here that an increase of the density will shorten the wave length.

"Suppose now that we attach a weight, say a ball of beeswax, at the middle point of the string, in order to increase the vibrating mass. The weight will become a source of reflection and less wave energy will reach the point *D* than before. The efficiency of transmission will be smaller now than before the weight was attached. Subdivide now the beeswax into three equal parts and place them at three equidistant points along the cord. The efficiency of wave transmission will be better now than it was when all the wax was concentrated at a single point. By subdividing still further the efficiency will be still more improved; but a point is soon reached when further subdivision produces an inappreciable improvement only. This point is reached when the cord thus loaded vibrates very nearly like a uniform cord of the same mass, tension, and frictional resistance. Such a loaded cord with a tuning fork attachment is shown at 4.

"If an increase in efficiency of wave transmission over a cord thus loaded is to be obtained, it is evident that the load must be properly subdivided and the fractional parts of the total load must be placed at proper distances apart along the cord, otherwise the detrimental effects due to reflections resulting from the discontinuities thus introduced will more than neutralize the beneficial effects derived from the increased mass.

"The problem of finding the proper distance at which the loads should be placed is a definite mathematical problem of Analytical Mechanics, but unfortunately it has never been solved. In Fig. 194, diagram 5 represents a cord carrying loads at proper distances apart. Experiments with cords of this kind will soon convince one that the distance between loads should be considerably smaller than one-half of the wave lengths of the wave which is to be transmitted. So that though a given cord may be properly loaded for some wave lengths it will not be properly loaded for shorter wave lengths. It is impossible to load a cord in such a way as to make it equivalent to a uniform cord for all wave lengths; but if the distribution of the load satisfies the requirements of a given wave length it will also satisfy them for all longer wave lengths. It should be observed now that the wave length which is considered here is not the wave length of the cord without the loads, but the wave length which the frequency under consideration will have on the properly loaded cord, or, what is the same thing, on a uniform cord of the same mass, tension, and frictional resistance, as the loaded cord. This point is of fundamental importance, for the wave length corresponding to a given frequency may and generally will be much shorter on the loaded cord than on the cords without the loads.

" A cord of this kind is a mechanical analogy to an electrical wave conductor. The mathematical law in accordance with which such a cord moves is the same as that in accordance with which the electrical current is distributed over the wave conductor under the action of similar forces. The reason for that is not far to seek. We have the same reactions, viz.: kinetic or mass reaction, tensional reaction, and the resistance reaction in the case of the cord. Electro-kinetic reaction, capacity reaction, and ohmic resistance reaction in the case of the wave conductor. The mathematical form of these reactions is the same in both cases, hence one is an exact analogy of the other."

It will be noted that Dr. Pupin lays considerable stress upon the expression, " equivalence between a non-uniform conductor and its corresponding uniform conductor." The meaning of this expression may be understood more readily by remembering that a wave of a given frequency has a particular wave length and a certain amount of attenuation. Hence, if a wave of a given frequency has the same wave length and attenuation on a non-uniform conductor that it has on a uniform conductor, the two conductors are equivalent to each other.

The factors which enter into transmission problems are numerous and complicated. Commencing with the energy of sound vibrations as they impinge upon the diaphragm of the transmitter, and passing through all the steps of transformation and transmission, to the energy emitted by the receiver diaphragm at the distant terminal, shows most forcibly how complex the problem becomes when adequately treated. Theoretical considerations are indispensable in practical design, but considerable data of an empirical nature must necessarily be employed, particularly in the matter of transmission standards and the efficiency of terminal equipment.

The reduction of attenuation in loaded lines has been clearly brought out in Dr. Pupin's paper, before referred to; the following is a quotation.

" To bring out the physical meaning of the attenuation constant consider two consecutive half wave-lengths at any moment. The one nearest to the transmitting apparatus shall be denoted by A and the other by B. The wave energy stored up in the medium surrounding A is greater than that stored up in the medium surrounding B. Hence the wave energy is gradually dissipated during its propagation from the transmitting to the receiving apparatus, and therefore the amplitude of both current and potential becomes smaller as the energy progresses along the transmission line. Let U be the amplitude of the current at the transmission end, and U_S be the amplitude at the distance s, then if the line be considered infinitely long

$$\frac{U_S}{U} = \epsilon^{-\beta S}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (9)$$

where ϵ is the base of Napierian logarithms. The constant β is called the attenuation constant. The mathematical expression for β is well known.

$$\beta = \sqrt{\frac{1}{2} pC(\sqrt{p^2L^2 + R^2} - pL)}, \quad . \quad . \quad . \quad . \qquad (10)$$

where L, R, C are the inductance, resistance, and capacity respectively of the wave conductor per unit length and p is the frequency speed."

This expression for β shows that it depends upon the frequency, increasing with it. Therefore the highest notes or harmonics are attenuated most and this impairs the quality of transmission, or produces distortion. The effect of this is to render transmitted speech less intelligible. Dr. Pupin has shown that high inductance obviates this difficulty; for if the inductance is large in comparison with the resistance, the expression for β becomes

$$\beta = \frac{R}{2}\sqrt{\frac{C}{L}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (11)$$

Now as this equation is independent of the frequency, all the frequencies will be attenuated alike. Thus a relatively large inductance not only tends to decrease attenuation but also eliminates distortion. This assumes, however, that the coils themselves offer the same properties at all frequencies, which is not fully realized in practice.

The method of inserting the inductance coils in the lines is shown in Fig. 195 in which the condensers shown serve merely to represent the distributed capacity of the line. Each coil consists of two windings, one for each limb of the circuit, wound on a ring-shaped or toroidal core which is composed of fine soft iron wire, thoroughly insulated so as to reduce eddy currents to a minimum.

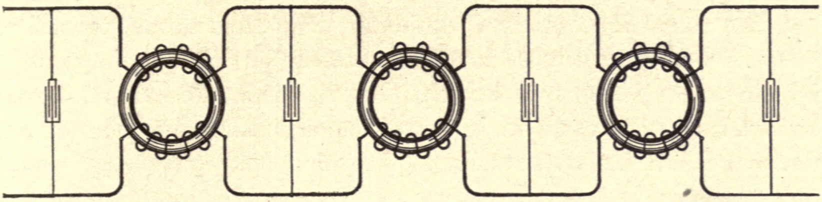

FIG. 195. — Method of Inserting Pupin Coils in Telephone Line.

The greatest benefits from loading are secured with cable circuits, whose normal efficiency is low. Loaded cables are now extensively used, both in this country and abroad. The loading of aërial lines seemed at first to be successful, but it was found that the normal gains could not be maintained at times of minimum insulation. The early loading was carried out with coils having about 2.5 ohms of true resistance and 0.25 henry of inductance, spaced 2½ miles. It was found later that the spacing could be increased to eight miles without any sacrifice of efficiency.

Maintenance troubles later developed, due to breakdowns of coil insulation from lightning. This was overcome by the use of special arresters. The loading of aërial lines was abandoned temporarily, until a new and more efficient insulator was developed. This is a double-petticoat porcelain type, somewhat larger than and about four times as expensive as the standard pony glass. The results obtained with it are quite satisfactory and extensive loading of aërial lines is now under way, including phantom circuits.

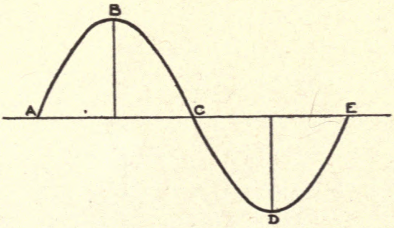

FIG. 196. — Sinusoidal Wave.

A very complete discussion of the practice of loading was given by Mr. Hammond V. Hayes, in a paper read before the International Electrical Congress at St. Louis, which is abstracted in what follows.

In every problem affecting the transmission of telephone waves over a line there are two factors to be considered, the attenuation and the distortion of the waves. The loss of energy of the waves on the line must be kept at a minimum; and the several component telephone or voice waves must be transmitted with equal relative impairment. The introduction of lumped inductance in the form of loading coils tends to increase the distortion by the possible unequal reflection, at the coils, of the component waves of different frequencies, and by the possible unequal attenuation of the several waves in passing through the coils. This action was referred to by Dr. Pupin in his mechanical analogy of wave motion, which has already been discussed.

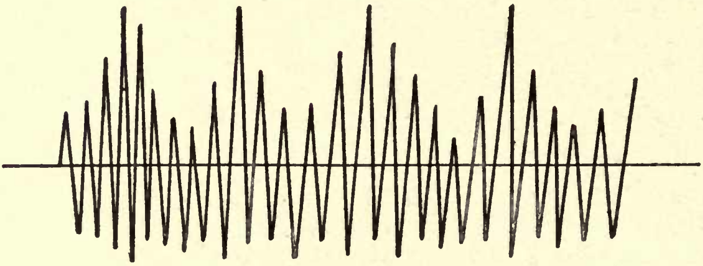

FIG. 197. — Complex Voice Wave.

The mathematical work of Doctors Pupin and Campbell shows conclusively that if several loading coils lie within a wave length, on any particular loaded circuit, and the coils themselves are theoretically perfect, the circuit is distortionless. The spacing of the coils in practice, therefore, depends simply upon a determination of the highest frequency that materially affects the quality of speech. It has been found convenient, in studying the spacing of loading coils, to determine the number of coils on each particular circuit that will be passed by some given point of a wave in one second. As the velocity of all waves on a given circuit is nearly the same and as the wave length at a given frequency can be determined from the velocity,[1] the number of coils lying within any particular wave length can be readily determined. A large number of long telephone circuits have been equipped with loading coils and very carefully tested. The spacing of the coils is such as to produce a range of the number of coils per

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[1] The wave length is equal to the velocity divided by the frequency.

second between 13,000 and 7000. A comparison of the transmission over various circuits has shown that the quality of transmission is not appreciably impaired, even with the lower number of coils per second. As this would materially attenuate the waves of very high frequency, it seems to indicate the lack of importance of the overtones of very high periodicity in the successful transmission of speech.

It can be said, therefore, with great certainty, that the distortion due to line reflection losses in a loaded telephone circuit can be neglected, provided that the coils are so spaced along the line as to give at least 7000 coils per second, and provided that this spacing is substantially uniform throughout the line. To entirely eliminate distortion in a loading coil, it must be designed so that the effective resistance or impedance of the coil to all telephonic frequencies is the same. Such a coil is theoretical and cannot be obtained in practice.

A loading coil is primarily designed to provide the required amount of inductance, and must of necessity consist of numerous turns of wire. Moreover, to minimize attenuation, it is imperative that the resistance of the coil be kept as low as possible. To make the resistance of the coil low, the wire employed should be of copper, of large size, and the number of turns of wire in the coil should be kept small. A reduction in the turns can be most easily obtained by the use of iron for the core. If the coil is made entirely of copper, the effective resistance will differ from the ohmic resistance by an amount corresponding to the loss due to eddy currents in the copper. If iron forms the core instead of air, there will be, in addition to the eddy-current losses in the copper, eddy-current losses and hysteresis losses in the iron, which will augment the difference between the ohmic resistance and the effective resistance. As it is impossible to eliminate the eddy-current and hysteresis losses entirely, the effective resistance of a loading coil will vary with different periodicities, and thereby produce distortion in the transmitted telephone waves. The difference between the ohmic resistance and the effective resistance at telephonic frequencies can be made much smaller in a coil composed entirely of copper than in one having an iron core. But practical and commercial reasons demand the latter, provided that such a coil can be so designed that its use in a telephone circuit will not be productive of appreciable distortion.

To determine whether, in practice, there is appreciably more distortion introduced by loading coils having iron cores, as compared with those made entirely of copper, two circuits were equipped, one with iron-cored coils and the other with copper coils. The circuits were each about 1000 miles in length. The coils had the same inductance and, approximately, the same ohmic resistance. The impedance of the coil having an iron core was about 15.5 ohms at a frequency of 2000 per second, and that of the copper coil 11.8 ohms at the same frequency. These circuits thus loaded were compared with the greatest care, and no difference was apparent either in the character or the quality of the telephone transmission. These tests are again confirmatory of the fact that suppression, or reduction, of the voice waves of the highest frequencies does not appreciably affect the quality or intelligibility of transmitted speech. This experiment was considered as demonstrating conclusively the possibility of the commercial use of loading coils having cores of iron.

A discussion of the theoretical dimensions of loading coils for the different classes of circuits may be found in Dr. G. A. Campbell's paper in the *Philosophical Magazine* for March, 1903. In practice, the size and cost of the coils are factors requiring serious consideration. For aërial circuits, where the line wire is large and, consequently, the resistance of the circuit is small, it is of the utmost importance that the effective time constant $\frac{L'}{R'}$ of the coil should be made as large as consistent with reasonable cost. Except in so far as the cost is affected, the size of the aërial loading coil is of no special moment, as the coils may be mounted singly upon the poles. The time constant of a coil can be increased by enlarging its size, but this increases the cost. Following the theoretical considerations as deduced by Dr. Campbell, the resistance of the coils that have been used on aërial circuits has been made 2.4 ohms. The design of the core, the permeability of the iron and the subdivision of the iron and copper have been made such that a loading coil has been produced having an inductance of 0.25 henry, a time constant of 0.048 second at a frequency of 1000, and a bulk of approximately 314 cubic inches. This coil is toroidal in shape, ten inches in diameter and four inches high. It has an effective resistance of 15.5 ohms at 2000 periods per second.

Coils designed for use in cable circuits, in which the size of wire is much smaller, do not need to be made of as low resistance as the coil above described. Consequently, their size and time constant may be made much smaller. Large numbers of loading coils have been placed in service, their design varying with the character of the circuit on which they were used.

In the terminal apparatus at present used in telephony, or where there is a condition of non-uniformity in the character of the line, the telephone waves suffer reflection; this, in many cases, is effective in materially increasing the attenuation. The reflection is particularly pronounced at the point where an unloaded section is connected to a loaded section. The amount of reflection is greater, the greater the divergence from homogeneity. Thus, a section having a large inductance per mile, when connected with a non-loaded section, exerts a larger reflective action than one having a smaller inductance per mile. In practice, the effect of reflection is of considerable importance, particularly when the loaded section is relatively short. Theoretically, these reflections may be eliminated by the use of a perfect transformer (repeating coil) introduced at every point of non-uniformity in the line. Even if such a perfect transformer could be made, its introduction on commercial circuits is open to practical objections and, as a substitute, a terminal taper, which consists of a series of coils of varying inductance, has been employed. The arrangement of the several coils constituting the taper is such that a coil having an inductance somewhat less than that of the coils used on the loaded section is placed nearest the loaded portion of the line, a coil of inductance somewhat less than the first is placed next in order and a coil of still smaller inductance is placed nearest the non-loaded section, or the terminal apparatus. The spacing of coils in the taper corresponds with that of the coils on the line of which it is to form the terminal.

The following figures, as given by Mr. Hayes, illustrate the results which have been obtained on several typical commercial circuits. In what follows, all comparisons are made on the basis of relative attenuation between similar circuits loaded and unloaded, without reference in any way to distortion or quality of transmitted speech. The curves shown in these figures are the results of actual tests, made on commercial loaded circuits, using standard terminal apparatus at the transmitting and receiving stations.

In Fig. 198 are shown the results obtained in tests of heavily loaded standard telephone cable. In this cable the wires are 0.03589 of an inch in diameter, having a resistance of about 96 ohms per mile of metallic circuit. The mutual capacity between the two wires of the circuit is 0.068 of a microfarad per mile. The inductance added to the circuit by the loading coils amounted to about 0.6 of a henry per mile. In the figure, the abscissæ represent lengths of cable and the ordinates the relative strengths of current. Curve 1 is that representing the attenuation of current on an unloaded circuit as the length of the cable is increased.

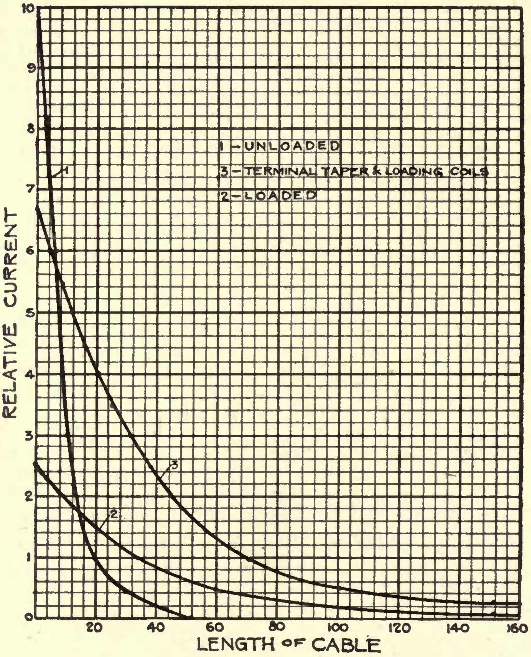

FIG. 198. — Heavily Loaded Cable.

It will be seen that the attenuation increases very rapidly as the length of the cable increases. Curve 2 represents the attenuation on a similar circuit, but loaded as above described, the terminal telephone being placed directly at the ends of the loaded cable, thereby obtaining the full effects of reflection. It will be noticed that the initial current on the loaded circuit is about one-quarter of that on the unloaded circuit. Moreover, the transmission on shorter lengths of the loaded circuit, under these conditions, is much poorer than the transmission over similar lengths of the same circuit unloaded. But the rate of attenuation per unit of distance is much less on the loaded than on the unloaded circuit; so that for the longer lengths of circuit, the transmission is superior on the loaded circuit to that on the same lengths unloaded. Curve 3 shows the attenuation where terminal tapers are employed at the two ends of the loaded circuit and the telephone transmitting and receiving apparatus is connected directly to the tapers. Here, again, the initial current is considerably less than that on the unloaded circuit and the transmission on short lengths of circuit is better on the unloaded than on the loaded conductors. But the introduction of the tapers on the loaded circuit has more than doubled the initial current and has shortened the equivalent length of the circuit by more than one-half. A comparison of curves 2 and 3 shows how great a factor reflection losses are between the terminal apparatus and the line and the importance of the taper in reducing these losses. In practice it has been found that reflection losses can be still further reduced and, under special conditions, almost entirely eliminated.

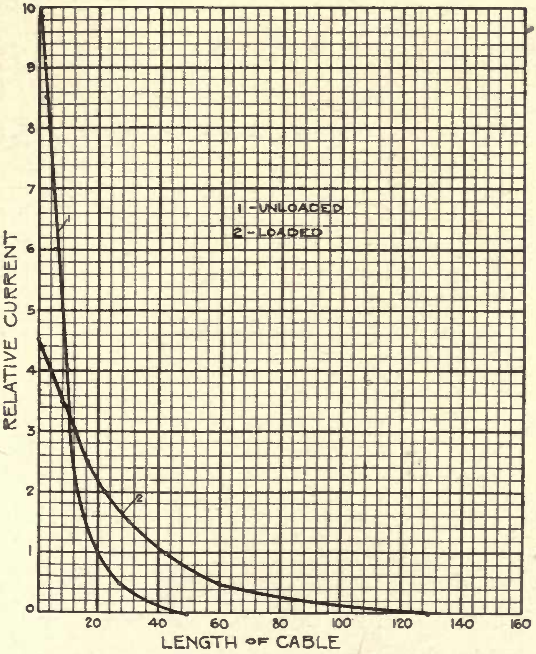

Fig. 199. — Cable With Medium Loading.

In the case above described, a large amount of inductance has been added to the circuit. The results which have been obtained upon cables where less inductance has been added are shown in Fig. 199.

In this case the cable is substantially similar to that previously described. Upon it loading coils are placed so as to bring the inductance of the circuit down to approximately 0.17 of a henry per mile. In other words, the inductance is less than one-third of that in the case just described. In Fig. 199 curve 1 is similar to that in Fig. 198, and represents the attenuation of the telephone current in an unloaded circuit. Curve 2 represents the attenuation in the lightly loaded circuit when no tapers are employed and the telephone transmitting and receiving apparatus is placed at the terminals of the cable. It will be noted that the reflection losses are much less in the case of the lightly loaded cable than in the previous case. In fact, in the shorter lengths of cable the lighter loading is more effective than the heavier. For the longer lengths, however, the heavier loading gives better results. With proper apparatus at the terminals of the loaded cable to reduce reflection losses, much less attenuation would result than is indicated by curve 2.

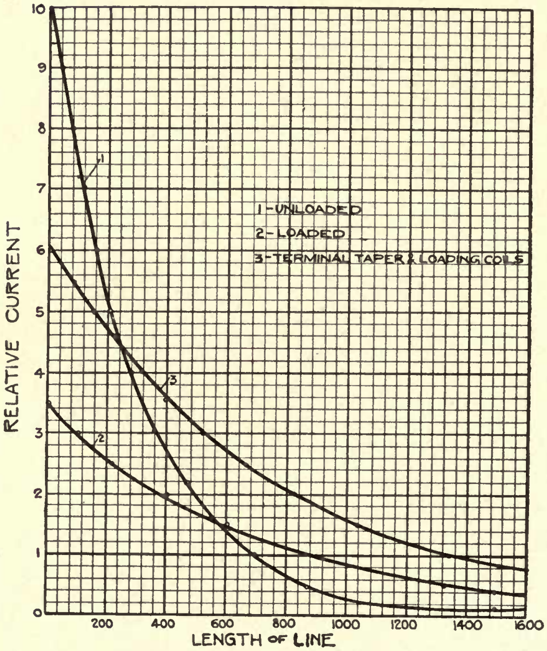

FIG. 200. — Loaded Circuit of No. 8 B.W.G. Copper Open Wire.

In Fig. 200 are shown the results which have been obtained on open-wire circuits, composed of copper weighing 435 pounds to the mile. On these circuits loading coils were so placed as to give an inductance of about 0.1 of a henry per mile. Curve 1 shows the attenuation, with various lengths of line, upon a similar unloaded circuit; and curve 2 shows the attenuation on the loaded circuit when the telephone transmitting and receiving apparatus is placed directly at the end of the line without tapers. Curve 3 shows the attenuation under similar conditions when tapers are employed. The results resemble those obtained with loaded and unloaded cables. There is a large reflection loss which is considerably reduced when tapers are employed. Even with tapers the loaded line for shorter distances is inferior to the unloaded.

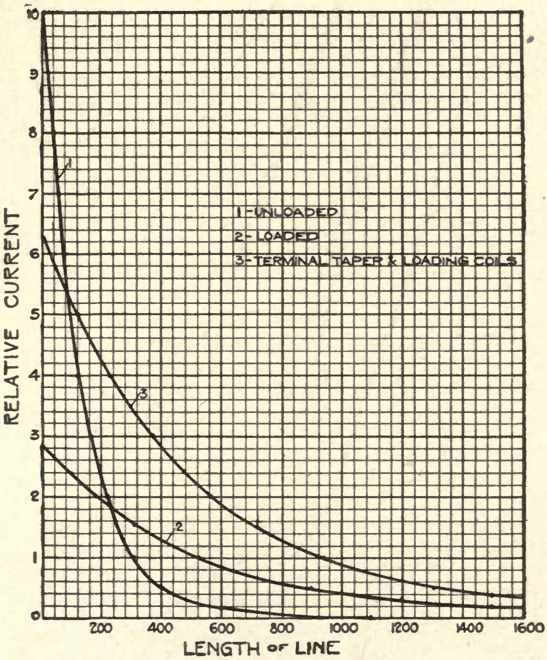

FIG. 201. — Loaded Circuit of No. 12 N. B. S. G. Copper Open Wire.

Fig. 201 illustrates the results which have been obtained from loading open-wire circuits, using a conductor weighing 173 pounds per mile and having an added inductance equal to about 0.1 of a henry per mile. As before, curve 1 represents the attenuation on a similar unloaded circuit; curve 2, the loaded circuit without tapers; and curve 3, the loaded circuit with tapers.

The following are Mr. Hayes' general conclusions. The curves show the results which have been obtained by the use of considerable inductance added to open-wire and cable telephone circuits, and may be considered as typical of the results obtained on similar circuits of different capacity or composed of wires of different size. As before stated, the curves illustrate simply the relative volume of transmission under the various conditions described. In the case of cables, there is a distinct improvement in the quality of transmission produced by the introduction of load coils, that is, a reduction in distortion and again in intelligibility. The high insulation that can be maintained at all times on cable circuits renders it possible to introduce loading coils without danger of materially augmenting leakage losses. The marked diminution in attenuation, the improvement in quality of transmission, and the ease with which inductance coils can be placed on cable circuits without introducing other injurious factors, such as leakage or cross talk, render the use of loaded cable conductors especially attractive. The reduction of attenuation that can be obtained by the use of load coils on aërial circuits, even under theoretically perfect conditions, is less than can be obtained on cable circuits. The difference in the effectiveness of loading, between the two classes of circuits, so far as attenuation is concerned, can be explained by the fact that in a cable circuit the capacity is large and the inductance of the circuit itself is practically negligible, due to the close proximity of the two conductors forming the circuit. In aërial circuits, on the other hand, the distance between the two conductors is such as to make the capacity of the circuit much less and its inductance much greater. The larger self-inductance of the open-wire circuit operates to decrease the attenuation and decreases the relative usefulness of the load coils. The insulation of an aërial circuit cannot be maintained either as high or constant as that of a cable, and the introduction of loading coils tends to increase the losses due to leakage. Moreover, there is not the same improvement in the quality of transmission on a loaded aërial circuit, as compared with a similar unloaded circuit, as there is between loaded and unloaded cables. Initially, open-wire circuits are largely free from distortion; whereas the distortion on long cable circuits is considerable. The addition of load coils to aërial circuits cannot be expected, therefore; to effect much improvement in the quality of transmission.

The recent developments in loading underground toll cables are especially noteworthy as marking a distinct advance in the art. The first long cable of this character was installed between New York and Philadelphia, a distance of 90 miles. It consists of 112 pairs of No. 14 B. & S. copper conductors, with dry paper insulation. The resistance is 13.7 ohms and the mutual capacity is 0.065 microfarad per mile. The loading coils are spaced 1.25 miles apart and have an inductance of 0.25 henry. The commercial efficiency of transmission has been termed by Mr. J. J. Carty a "fourteen mile talk." The general standard of comparison is one mile of No. 19 B. & S. standard (or low-capacity) cable. The 85-mile cable between Chicago and Milwaukee is composed of 120 pairs, of which 60 are No. 14 B. & S. and 60 No. 16 B. & S. In every case these cables have dry paper insulation and are very carefully balanced to avoid cross talk.

CHAPTER XIX

CROSS TALK AND INDUCTIVE DISTURBANCES

The effects of distributed resistance, inductance, capacity and leakage upon the transmission of energy in a telephone line were shown in the preceding chapter. It was there assumed, however, that the line had no inductive relations with other lines, or in other words, that no parallel lines existed anywhere in its neighborhood. Such isolation is very infrequent in practice and inductive relationships must ordinarily be taken into account. In general these relationships are of two kinds: first, those which exist between two or more parallel telephone lines; and second those which exist between a telephone line and some line of different character, as for example a power transmission line, or a railway feeder.

Induction of the first kind is generally termed cross talk, because it destroys the secrecy of communication and results in overhearing messages or conversations in neighboring lines. That of the second kind is generally known by the broad term induction, which implies any kind of foreign disturbance. Both kinds are objectionable and injurious to service, and their prevention or elimination forms an important branch of telephony. Cross talk can only manifest itself in a single form, but induction takes many forms. The latter, for example, is often a steady hum or tone of constant fundamental pitch, caused by exposure to parallel lines carrying alternating current at 25 or 60 cycles; or it may have a variable pitch and intensity, corresponding to the commutation of electric railway motors, in the case of exposure to trolley or feeder circuits; or again it may be harsh and uneven, caused by exposure to telegraph circuits operating with some form of morse transmission.

But so-called induction is not always caused in the manner its name implies; it is sometimes conductive, due to imperfect insulation and attendant leakage. There is no leakage, of course, between insulated metallic circuits on different pole lines, but only between lines on the same poles. In the case of grounded lines, or metallic lines carrying normal grounds, differences in earth potentials may cause foreign currents of a conductive nature. Such potential differences are caused in general by the track return circuits of electric railways, with their differences of potential between different points when cars are in operation. It is characteristic of such potentials to fluctuate from moment to moment, corresponding to variations in the demands for power.

In the very early stages of telephone development, the grounded line was employed exclusively. But its limitations soon appeared; it was subject to severe inductive disturbances which it seemed hopeless to prevent. Parallel lines of this type are subject both to excessive cross talk and severe foreign disturbances. The latter appeared in a prominent degree with the introduction of electric traction, caused by the commutation of the motors. Each car as it started caused a disturbance, commencing with a note or tone of very low pitch, rising as the car gathered speed and becoming very shrill. The fluctuations of earth potentials added to the difficulties. These conditions practically forced the adoption of the metallic form of circuit, which is not only subject to less severe induction initially, but can also be transposed to reduce or eliminate it. Grounded lines are still employed extensively in rural service, but the extensions of interurban electric railroads and high-tension power transmission are making it more difficult to maintain them. In all toll systems of any size or importance, metallic circuits are imperative to good service.

Induction is theoretically of two kinds, electromagnetic and electrostatic; neither kind ever exists wholly independent of the other, but one kind may predominate. The first kind is the easier to understand in a physical sense, because it is merely a form of transformer action, in which the foreign or disturbing line is the primary and the telephone line the secondary. The first sets up a magnetic field, which is the inseparable accompaniment of every electric current, and some portion of this field links itself with the telephone line. Then, as the primary field changes in direct proportion with the primary current, from instant to instant, some of the lines of the field cut the telephone conductors and induce an E.M.F. therein. The general laws of electromagnetic induction apply to this case, of course, but as compared with an ordinary transformer the transfer of energy from primary to secondary is exceedingly inefficient. At the same time the secondary action may be large in a telephonic sense, and quite possibly so severe as to interfere with service or even prevent it entirely.

The character of the magnetic field surrounding a single conductor, whose return lies at a considerable distance, is illustrated by Fig. 202. The lines are most dense at the surface of the conductor, and the density diminishes very rapidly with increasing distances from the conductor. At any given point the field intensity is proportional to the current, and changes instantaneously as the current changes, assuming that the field lies in a dielectric medium such as air. The flux lines are concentric circles about the conductor so long as the return is very distant, but they change position as the return is brought nearer, and in some cases change in shape. Magnetic flux lines are in longitudinal tension and thus tend always to shorten; it follows that transversely they are in compression.

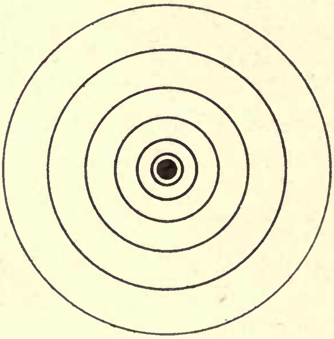

FIG. 202. — Character of Magnetic Field Surrounding a Single Isolated Conductor.

The electric field is less readily understood, but in fact almost as simple in its nature. Just as currents set up magnetic forces and fields of flux, so electric potentials set up electric forces and corresponding fields of flux. But in general, electric fields are everywhere in the dielectric at right angles with the magnetic fields, both of which spring from the same circuit. Wherever differences of electric potential exist, there is an electric field and a charged dielectric. A potential difference implies that relatively one point or terminus is positive and the other negative; the point of highest potential is always positive, that is, it tends to send a current toward the point of lower potential. At the same time, in an absolute sense, both points may be positive, or both negative.

The flux lines issue from the positive terminal and end on the negative terminal, so that a free positive charge would be impelled from the positive to the negative pole. These lines are in tension and thus oppositely charged points attract each other; conversely, like charges repel each other. While a magnetic flux line is always closed on itself, an electric flux line has two free ends, one of which, however, must terminate on the positive point or pole and the other on the negative pole.

Fig. 203 illustrates the field of electric flux between two parallel plates, oppositely charged, as in a simple elementary condenser. It is a well-known fact that such a condenser stores a definite quantity of electricity, and this storage, termed an electric charge, accompanies every potential difference and its inseparable electric field. The storage actually takes place in the dielectric which composes the field and is sometimes spoken of as electric displacement. The displacement can be compared with the deflection of the free end of a beam when a load is applied. In reality, an electric charge represents the unbalanced condition of the dielectric under potential stress, where the deflection or charge is proportional to the force applied. The charge is also proportional to the volume of dielectric placed under stress, assuming a simple arrangement like that in Fig. 203, with plates separated by a fixed distance.

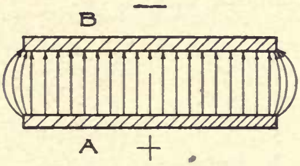

FIG. 203. — Lines of Electric Force and Flux Between Two Oppositely Charged Plates.

The electric stress or potential in the dielectric falls from the positive value, at the surface of the positive plate, to the negative value at the opposite plate, in a gradual manner. This potential gradient varies, however, with the form of the plates or terminals and their separation.

It will now be evident that any two points taken at random in the charged field may be at different points on the potential gradient. If these points are imagined to be the terminals of a second condenser, they are obviously charged by induction. Thus if a metallic body were inserted in the field, there would be an exchange of charges, by means of momentary currents, between its several parts, in obedience to the potential differences in the dielectric which it replaced. This is illustrated by Fig. 204, which shows a charged sphere *A* and a cylinder *B* charged by induction. The electric displacement in the cylinder corresponds to the displacement in the dielectric and a positive charge passes from *X* to *Y*, leaving *X* negatively and *Y* positively charged.

If the impressed electric force is alternating, the displacements or charges alternate likewise, and in effect an alternating current flows through the dielectric, or the condenser. At the same time any conducting bodies within the field will circulate local alternating currents, caused by the alternating potential gradient which they intercept. For example, if the sphere *A* in Fig. 204 is charged from an alternating source, local alternating currents will circulate in the cylinder *B*, between *X* and *Y*.

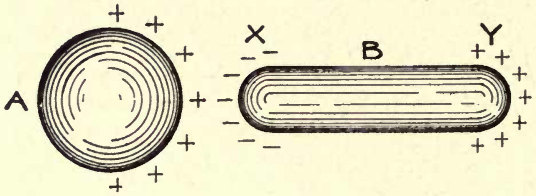

FIG. 204. — Induced Electric Charges.

The nature of electrostatic induction in the case of two parallel grounded wires is shown by Fig. 205. The induced charge on the telephone line is proportional at every instant to the impressed potential on the disturbing wire, and if the latter is alternating there will be induced alternating currents in the telephone line. When the potential of the disturbing wire is constant throughout its length at any instant, there will be no current at the center of the telephone line, because here the induced charge divides and half flows to earth through each terminal.

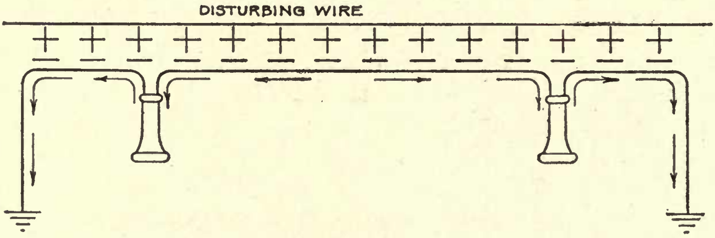

FIG. 205. — Electrostatic Induction Between Parallel Wires.

When electromagnetic and electrostatic induction occur simultaneously, as they do in nearly all cases, the induced current and E.M.F. are the resultants of both kinds of induction. The electromagnetic effect is an induced E.M.F. in the telephone line, which gives rise to a flow of current when the circuit is closed; and at any instant the whole flow is in the same direction, thus differing from the case of pure static induction.

When the disturbing circuit is energized by a purely sinusoidal alternating current and E.M.F., the induced current and E.M.F. will be sinusoidal likewise and of the same frequency. When the inducing or primary current is a complex wave representing transmitted speech, however, a counterpart of these currents will appear in the secondary or telephone line, and will reproduce the original voice sounds, which is simply cross talk.

The problem of eliminating or preventing cross talk is a most important one for the telephone engineer, not only as it concerns the outside plant, but switchboards, apparatus and office wiring and cables. In devising methods to prevent it, there was considerable speculation as to whether electrostatic or electromagnetic effects predominated. The experiments carried out by Mr. John J. Carty[1] in this connection are especially interesting. He concluded that the electrostatic effect predominates almost completely for telephone circuits in general.

A mathematical analysis of the case by Mr. Louis Cohen, given in another paper before the American Institute of Electrical Engineers, in June, 1907, shows that for short lines the electromagnetic effect greatly predominates, but becomes relatively less for longer lines and for very long lines is entirely overpowered by the electrostatic effect. He also points out that under the conditions of Mr. Carty's experiments, the electrostatic effect necessarily predominated, on account of the alteration of the line characteristics produced by the introduction of telephone receivers.

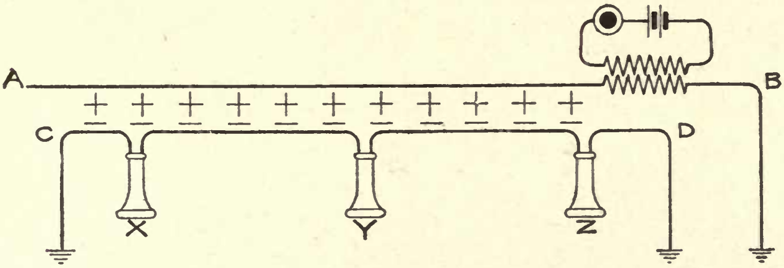

FIG. 206. — Carty's Experimental Circuit for Demonstrating Electrostatic Induction.

Fig. 206 shows the arrangements in one of Mr. Carty's experiments. *AB* is the disturbing wire, which contains the secondary of an induction coil; a vibrating tuning fork in front of the transmitter was used to set up the disturbing E.M.F. in the line. The receiver *Y* is at

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[1] See the Transactions of the American Institute of Electrical Engineers, 1891, Vol. VIII, p. 114.

the center of the line, *X* at one end and *Z* at the other. These lines were about 200 feet in length and parallel at a distance of one-eighth of an inch. The induced charges on *CD* have an outlet to ground through the terminal receivers. It was found that the receiver *Y* was silent, while *X* and *Z* responded, proving the electrostatic nature of the induction; this result could not have been obtained if electromagnetic induction were present, because in that case a current would flow around the circuit *CD* as a whole and in one direction only at any given instant. In the case considered, the charges divide at *Y* and flow in opposite directions, which was proven by opening the line at that point, without affecting the disturbances in the receivers at *X* and *Z*.

No electromagnetic effect could be observed even when the line *AB* was grounded at *A*, so as to produce a large flow of primary current. These observations were further confirmed by short-circuiting one of the receivers in *CD*, as shown in Fig. 207. By closing the key at *C* one end of the line was directly grounded, and in that case no disturbance was observed at *Z*, because the whole induced charge passed over the low-resistance line and through *C* to ground. This demonstrated again the electrostatic nature of the induction and the absence of electromagnetic effect.

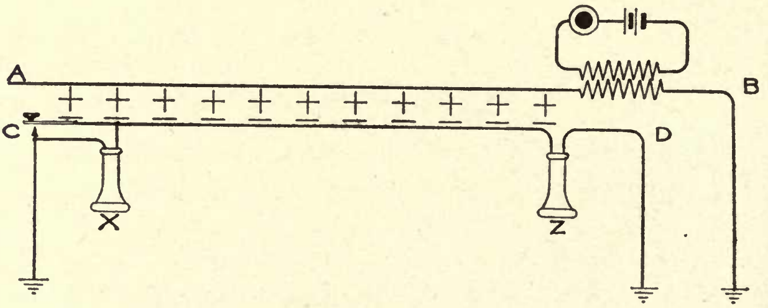

FIG. 207. — Carty's Experimental Circuit for Demonstrating Electrostatic Induction.

In considering the feasible or possible methods of preventing induction, the most obvious simple plan is that illustrated in Fig. 208, where the telephone wires are placed equidistant from the disturbing wire, and hence at equal points on the electrostatic potential gradient and also at points of equal field strength magnetically. That is, *CD* is as far from *AB* as *EF*, and a reference to Fig. 202 will show that each is linked with the same magnetic flux set up by the current in *AB*. It is important to observe, however, that the immunity from disturbance is absolutely dependent on the perfect balance of the telephone circuit, in every respect. But this means of preventing induction has only a limited application.

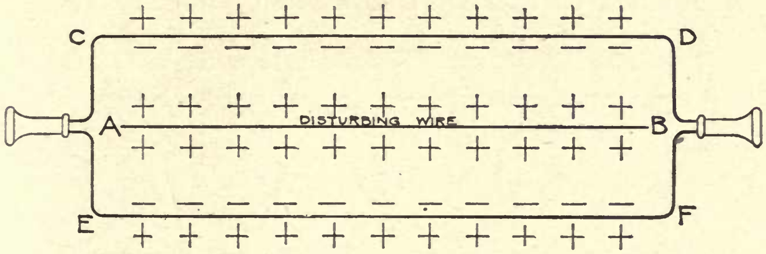

FIG. 208. — Arrangement of Disturbing Wire and Metallic Circuit for Preventing Induction.

The conditions often met are shown in Fig. 209, where the disturbing wire lies wholly on one side of the telephone line. The wire *CD*, being nearer *AB* than *EF*, is at a higher induced potential electrostatically than *EF*, and at the same time has induced in it a larger electromagnetic E.M.F. If the current in *AB*, the disturbing wire, is in the direction shown by the arrows in the figure, the secondary electromagnetic currents will flow instantaneously in the direction shown by the heavy arrows and the static currents as shown by the light arrows.

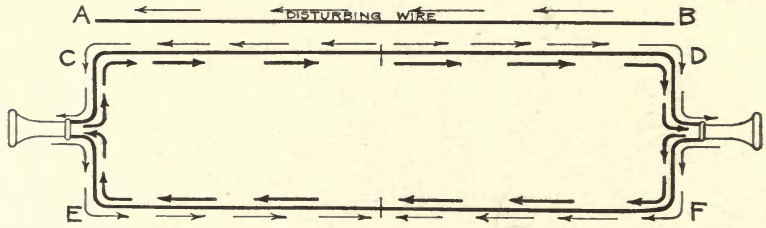

FIG. 209. — Unbalanced Exposure and Resulting Induction.

Evidently the average distance between the telephone wires and the disturbing wire can be equalized by a transposition of the former at the center of exposure, as illustrated in Fig. 210. This will completely balance the electromagnetic induction and eliminate all disturbances at the terminals due to that cause. But the same result will not be obtained with reference to electrostatic induction; there the effect is shown by Fig. 211. The major portions of the induced charges will neutralize themselves through the transposition, but a small portion in each case flows through the terminals. There will be four neutral points at which the charges divide and flow in opposite directions, shown at *W*, *X*, *Y* and *Z* in the figure. These points are much nearer the terminals than the transposition.

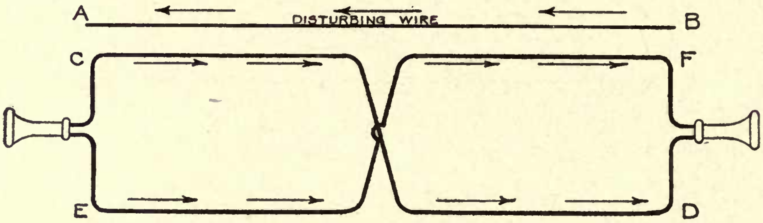

FIG. 210. — Effect of Single Transposition on Electromagnetic Induction.

A single transposition will not entirely eliminate the electromagnetic effect if the section is comparatively long, because of the attenuation of the current. Practical results are secured by diminishing the section to a fraction of a mile; in this way the neutral points are made to approach the ends of the section so closely that the resulting disturbance in the terminal receivers is negligible, or inaudible. Half-mile or quarter-mile sections are sufficient to prevent cross talk with the volume of transmission which occurs in ordinary practice.

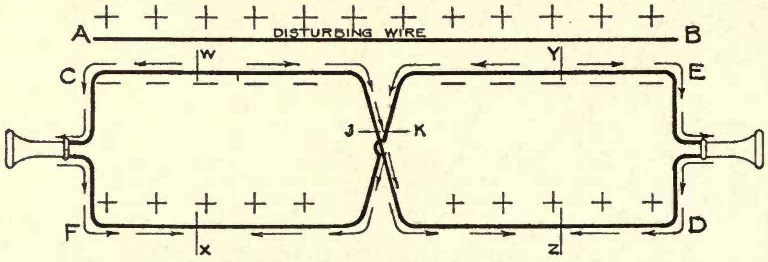

FIG. 211. — Effect of Single Transposition on Electrostatic Induction.

In the discussion of inductive disturbances thus far, a disturbing circuit consisting of only one wire has been considered, since this simplifies in a measure the explanation of the reactions. In the study of the transposition of telephone circuits as regards one another, however, it is necessary to deal with two wires for each circuit; and in this case, when the transposition of numerous circuits is contemplated, the problem becomes rather complicated and requires considerable study. The transposition of a two-wire metallic circuit consists, as previously indicated, of interchanging the relative positions of the two wires, or rotating the plane of the circuit through 180 degrees. Then if only two telephone circuits are considered, which are relatively short, a transposition of one of them at its middle point will serve to eliminate cross talk between the two circuits. It will also prevent foreign circuits from affecting the transposed circuit, but not the other. These exterior disturbances may arise from a power circuit or from other telephone circuits, and when more than two circuits are considered, all but one will have to be transposed. Also each individual circuit must be transposed with reference to each of the other circuits; it will not be sufficient to transpose them all in the same manner. The reason for this will be appreciated by referring to Fig. 212, in which is shown a power circuit *A*, paralleled by

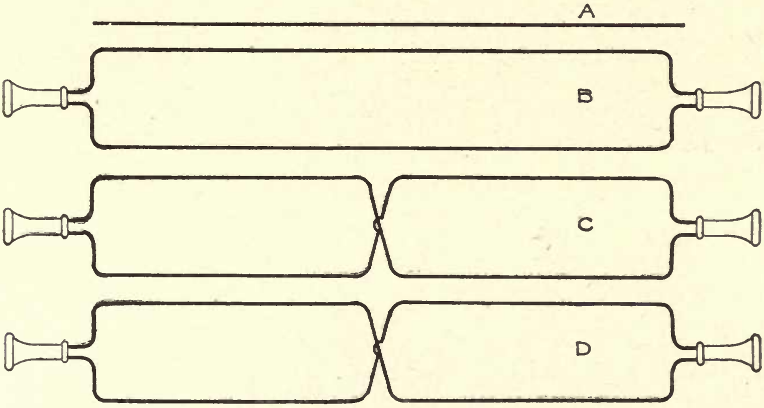

FIG. 212. — Example of Improper Transpositions.

three telephone circuits *B*, *C* and *D*. The telephone circuit *B* is not transposed, while the telephone circuits *C* and *D* are each transposed at their middle points. Then if the lines are relatively short, circuits *C* and *D* will be free from the inductive disturbance of the power circuit, while circuit *B*, which is not transposed, will not. Regarding the inductive action between the telephone circuits, it will be seen that circuits *C* and *D* are not subject to cross talk from circuit *B*, and *vice versa;* but circuits *C* and *D* are each transposed at the same place, and with respect to each other are not transposed at all. In Fig. 213 are shown the conditions assumed in Fig. 212, with the telephone transpositions corrected so as to eliminate both the cross talk between the telephone circuits and the disturbing induction from the power circuit.

The transposition of telephone lines for the elimination of mutual disturbances, as well as the prevention of disturbances from power circuits, was considered from both theoretical and practical standpoints by Mr. F. F. Fowle in a paper read before the Association of Railway Telegraph Superintendents in May, 1903; and again before the American Institute of Electrical Engineers in October, 1904. These papers have been drawn upon freely in the following discussion of the general problem.

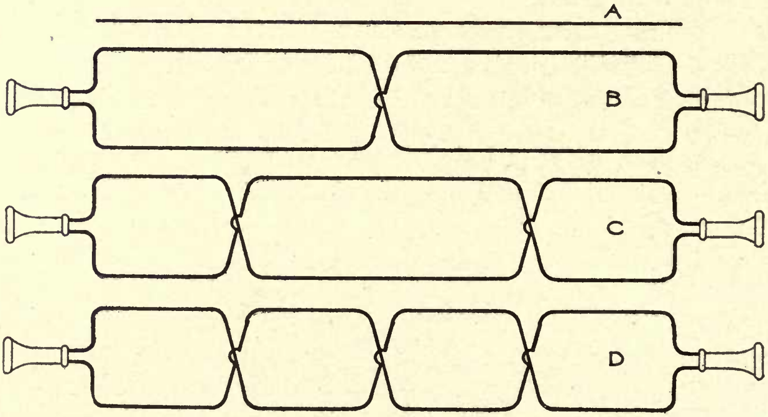

FIG. 213. — Example of Correct System of Transposition, Correcting the Faults Shown in Fig. 212.

In the transposition of telephone lines it is very essential to adopt a certain standard length of section within which all the wires shall be transposed, and the mutual disturbances eliminated. The general procedure is a consecutive application of the standard section, commencing at either end of the line; this will continue until some intermediate junction point or the opposite terminus is reached. The line length is seldom an exact multiple of the section length; if the remainder is less than half a section, it is added to the preceding section, or if greater than a half-section, it is made a complete section by itself. In either case the standard section is extended or shortened to suit the requirements.

The treatment of induction between telephone circuits has been by empirical rule rather than theory. It has been determined by experiment, with transmitters and receivers of a given power, how frequently two adjacent circuits should be transposed in order to eliminate cross talk. In two-mile sections transposed at the center, it will be found that the cross talk is distinguishable with transmission sufficiently powerful for 1000-mile service. However, one-half or one-quarter mile sections transposed at the center are satisfactory, where the minimum transposition spacing is one-quarter mile. The existence of cable at each end of the line, to any considerable length, will reduce cross talk, which can be accounted for by the fact that the attenuation in the cable diminishes the strength of the cross talk currents which come from the distant open-wire line.

The first step in developing a standard section is that of devising different types of transposed circuits. The manner in which this is readily accomplished is shown in Fig. 214. It will be observed from

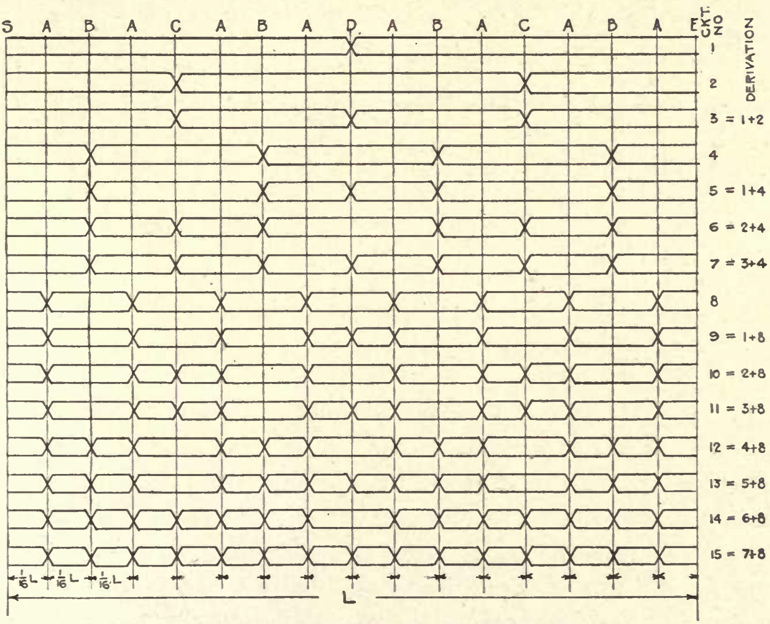

FIG. 214. — Derivations of Standard Transposition Types.

the figure that the exposure of circuit 1 to circuit 2 is one-quarter; of 1 to 3, one-quarter; and that of 2 to 3, one-half. The increased exposure of circuit 2 to circuit 3 is due to the fact that two transpositions on circuit 2 are identical in location with the end transpositions on circuit 3; therefore, these transpositions have no beneficial effect as regards the inductive action between the circuits. It will be further observed that the exposure of circuits 1 to 5, 2 to 6 and 3 to 7 is one-eighth; while that of 2 to 8 and 2 to 9 is one-sixteenth, etc. A complete list of the exposures is given in terms of the length of a transposition section in Table 14.

TABLE 14

CROSS-TALK EXPOSURES IN TERMS OF STANDARD TRANSPOSITION SECTIONS

To	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	¼													
3	¼	½												
4	⅛	⅛	⅛											
5	⅛	⅛	⅛	½										
6	⅛	⅛	⅛	¼	¼									
7	⅛	⅛	⅛	¼	¼	½								
8	1/16	1/16	1/16	1/16	1/16	1/16	1/16							
9	1/16	1/16	1/16	1/16	1/16	1/16	1/16	½						
10	1/16	1/16	1/16	1/16	1/16	1/16	1/16	¼	¼					
11	1/16	1/16	1/16	1/16	1/16	1/16	1/16	¼	¼	½				
12	1/16	1/16	1/16	1/16	1/16	1/16	1/16	⅛	⅛	⅛	⅛			
13	1/16	1/16	1/16	1/16	1/16	1/16	1/16	⅛	⅛	⅛	⅛	½		
14	1/16	1/16	1/16	1/16	1/16	1/16	1/16	⅛	⅛	⅛	⅛	¼	¼	
15	1/16	1/16	1/16	1/16	1/16	1/16	1/16	⅛	⅛	⅛	⅛	¼	¼	½

The derivation of the types is quite simple and is shown at the right in Fig. 214. The first three of these are necessarily obvious. The fourth, as indicated, is obtained by doubling the number of transpositions in the second; the fifth by superimposing the first on the fourth; and the sixth by superimposing the second on the fourth. The absolute length of exposure depends entirely upon the selection of the length of the section. Having given the maximum permissible exposure, the length of section depends upon the number of transposition types required to take care of the ultimate number of circuits on the pole line. For convenience the exposure should be an integral multiple of the span length. A satisfactory standard of exposure between two adjacent horizontal circuits on a ten-pin cross-arm is one-quarter mile between transpositions. If two such adjacent circuits are transposed, with respect to each other, one-quarter mile from one of the terminals and then at each consecutive half-mile to the distant terminal, it will be found that with the standard of transmission now in general use, the cross talk will be entirely negligible under normal conditions. An eight-mile section has been extensively used, but is rather long; a length of four miles is much more convenient. In case there are only a few circuits a two-mile section may be used; a case of this kind would be a ten-wire line on a single cross-arm, as shown in Fig. 215. In the application of a standard section to any line, it is well to remember the general rule, by reason of which any discontinuity in the line is made the junction of two contiguous sections. A discontinuity is established whenever new or branch lines are joined to the main line, or when a number of the main line circuits leave the main route. The same condition of discontinuity arises when all or any of the circuits enter an intermediate or terminal office.

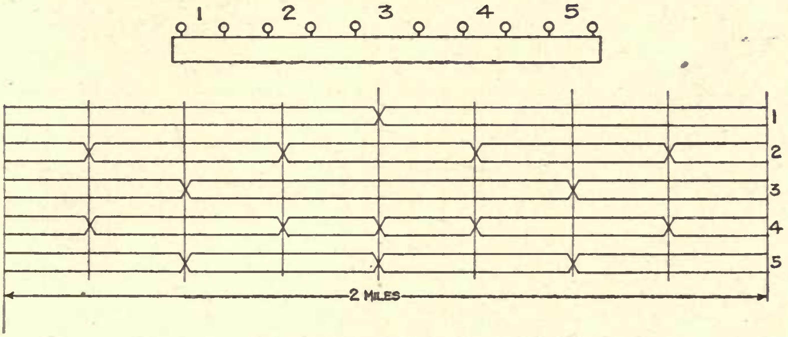

FIG. 215. — Transposition Scheme for a Ten-wire Line.

Transposition poles are generally placed at one-quarter mile intervals, or every ten spans. The standard span is 130 feet and the transposition poles are consequently 1300 feet apart. The general system which has been adopted and used by the American Telephone and Telegraph Company is shown in Figs. 216 and 217. The system indicated in Fig. 216 is arranged for two cross-arms, each of which carries six wires or three circuits. Fig. 217 shows four cross-arms, each of which is equipped with five circuits. In order that proper construction records may be maintained, each pin is numbered. The method of numbering the wires on a ten-pin arm is shown in Fig. 217; for an eight-pin arm the wires 5 and 6 are omitted and the remaining wires are numbered 1 to 10 on the upper and 11 to 20 on the lower cross-arm. The numbering of the wires on a six-pin arm is shown in Fig. 216, which follows the basis of a ten-pin arm. On four-pin arms the wires next to the pole and the two outside wires on each arm are omitted, the numbering being otherwise the same. The system of numbering for four cross-arms is shown in Fig. 217.

Figs, 216 and 217 each show one complete standard section which

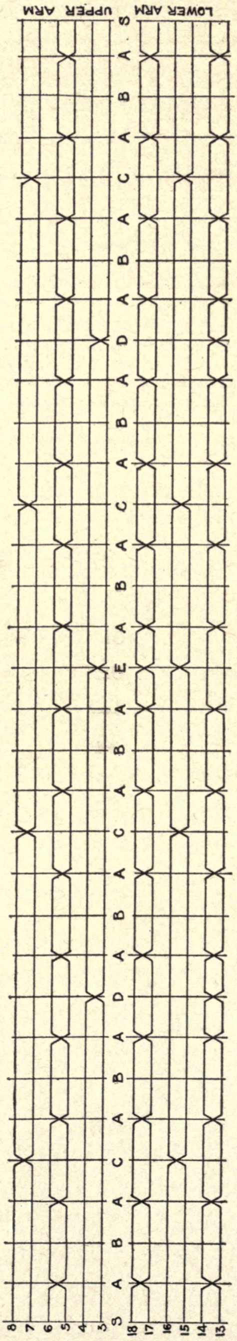

FIG. 216. — Standard Transposition Scheme for Twelve-wire Line.

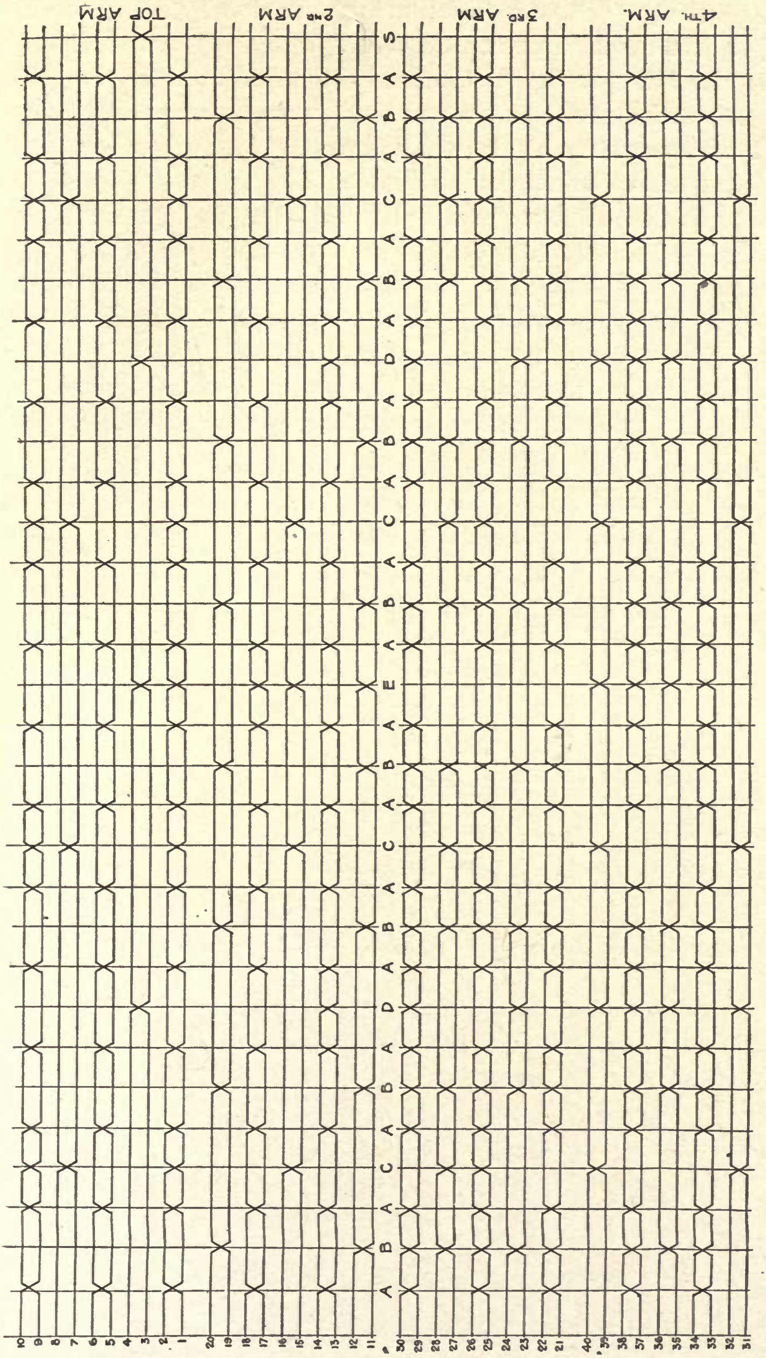

FIG. 217. — Standard Transposition Scheme for Forty-wire Line.

contains thirty-two transposition poles, separated by equal distances of 1300 feet or one-quarter of a mile. Transposition sections may be standard or special. A standard section is 41,600 feet long; but a special section may be anywhere from 21,000 to 62,000 feet long, in which the transposition poles will be spaced at intervals of one thirty-second of the length of the section.

Transposition poles are usually located when the line is measured and the poles are stenciled, proceeding continuously from one end of the line to the other. The end section at a junction, intermediate office, or terminal is treated as before described. The pole lettering follows Figs. 216 and 217.

On all standard sections, as will be observed from Figs. 216 and 217, the distance from the first open-wire fixture to the first *A* pole is 1300 feet; that to the first *B* pole 2600 feet; to the first *C* pole, 5200 feet; to the first *D* pole, 10,400 feet; to the first *E* pole, 20,800 feet; and to the first *S* pole, or the end of the section, 41,600 feet. Counting from the first *A* pole, every alternate transposition pole is an *A* pole. Counting from the first *B* pole, every fourth transposition pole is a *B* pole. Counting from the first *C* pole, every eighth transposition pole is a *C* pole. Counting from the first *D* pole, every sixteenth transposition pole is a *D* pole. Counting from the first *E* pole, every thirty-second transposition pole is an *E* pole. Counting from the first open-wire fixture, every thirty-second transposition pole is an *S* pole.

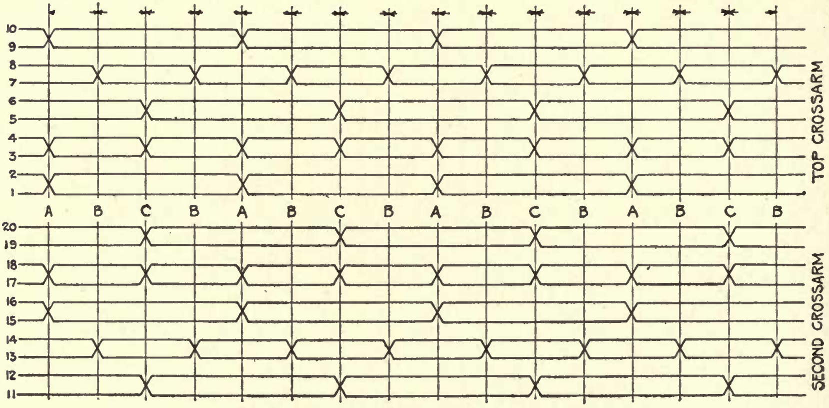

FIG. 218. — A–B–C Transposition System.

The system just described is generally known as the " Standard

System of Transposition." There is, however, another method of transposing which is known as the A–B–C system, illustrated in Fig. 218. This system was used on the original New York-Chicago line, built in 1893. In the A–B–C system the transposition poles are likewise placed 1300 feet apart, but there is no definite section in which the mutual disturbances are balanced and eliminated, as in the standard system. The pole lettering is different and the letters represent different types of transposition poles. All the odd-numbered cross-arms are transposed in a manner similar to the top cross-arm and the even-numbered arms like the second cross-arm.

The methods of making transpositions are quite numerous. Fig. 219 shows the standard method when it is possible to pull up sufficient slack at the transposition pole. For this purpose, six feet of slack should be taken up by means of the blocks and come-alongs shown at *M* in Fig. 219; this should then be cut so as to leave ends projecting 20 inches beyond the cross-arm, on the pole side of the arm. The next step is to slip on the half-sleeves *C* and *D* and dead-end the wires *X* and *Z*, leaving loose ends projecting for the sleeves *G* and *H*. The half-sleeves *E* and *F* should then be slipped on the opposite ends and wires dead-ended, as shown. The next and last step is to put on the half-sleeves *G* and *H*, when the transposition is completed. When pole wires are being transposed, the cross connections should be brought back around the insulator as shown at *O* in Fig. 219; if both wires are on the same side of the pole, the connections should be arranged as at *N*. In making these transpositions, it should be remembered that the transposition insulator shown in Fig. 178, and the transposition pin shown in Fig. 149, must be used.

When slack is not available, the standard transposition should be made as indicated in Fig. 220. Here the line wires should be cut on the pole side of the cross-arm, 20 inches from the pin. The half-sleeves *C* and *D* should then be slipped over the line wires and the circuit dead-ended, while the ends of the wire are allowed to project for the sleeves *G* and *H*. Six feet of slack wire is next cut into the line on the pole side of the circuit by means of the sleeves *A* and *B*. The half-sleeves *E* and *F* are slipped over the slack ends and then the circuit is pulled up and dead-ended, as shown in the figure. The half-sleeves *G* and *H* are used to make the cross connections and the transposition is finally completed. If the transposition is made on pole wires, the connections should be brought back around the insu-

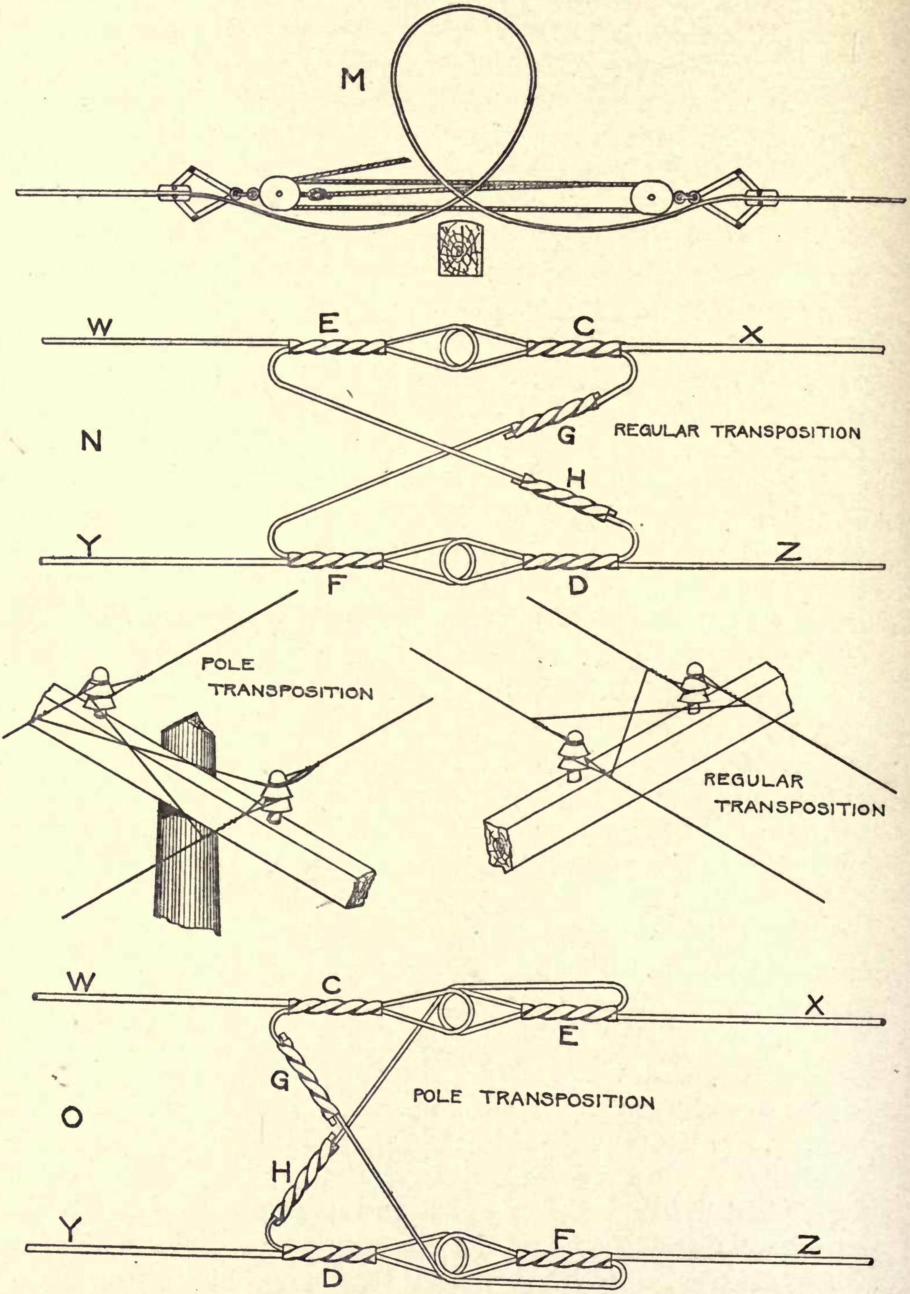

FIG. 219. — Method of Cutting in Transpositions With Slack.

lator as shown at *O*. The cross connections at a transposition afford a very convenient place to insert test connectors, so that the line can be opened for testing purposes without cutting the wires. One of these connectors of the Cook type is shown in Fig. 221. They are sometimes installed as a substitute for a lineman's test station, or at points where testing is occasionally required. Transpositions

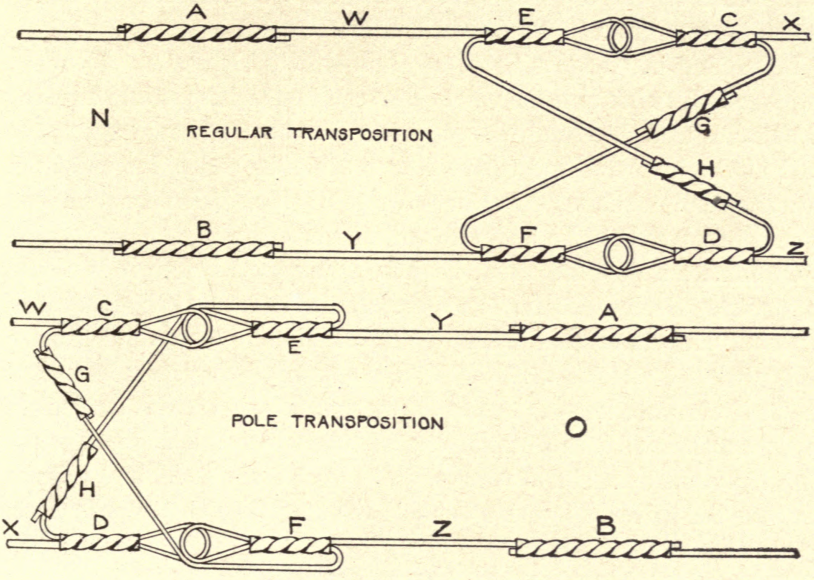

FIG. 220. — Standard Method of Cutting in Transpositions.

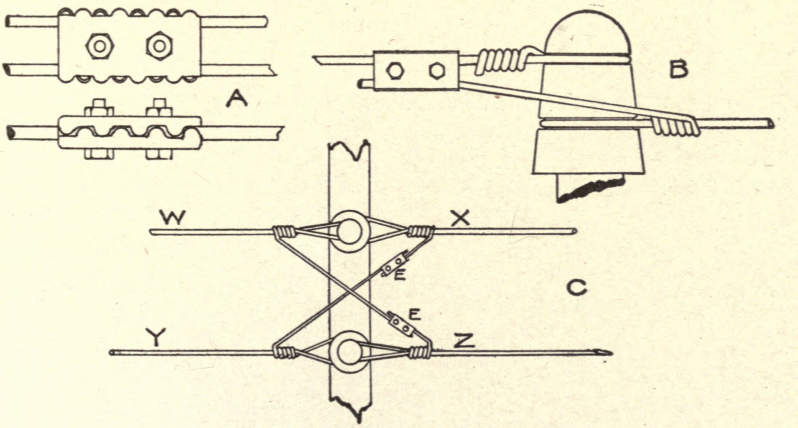

FIG. 221. — Method of Installing Test Connectors.

sometimes introduce cases of trouble caused by crosses between the connections. In order to minimize this, the wires *W* and *Z* should be dead-ended in the top grooves of the insulators and leads *X* and *Y* in the bottom grooves, as shown in Figs. 219 and 221.

In cutting in transpositions, the half-sleeves should be given one and one-half twists and the whole-sleeves three twists; and in twisting the sleeves at a dead-end, the stationary connector should always be held at the insulator end of the sleeve, so as to throw the twist out into the span, while for the sleeves *G* and *H*, the stationary connector should be placed at the line-wire end of the sleeve.

Ordinarily a pole line must be fully transposed before it is placed in service. Sometimes, however, transpositions are cut in afterwards, especially in connection with the installation of phantom circuits. This always interferes with the service slightly, being most serious in the case of morse leases. Another feature, also, is worth mentioning, in connection with the numbering of line wires at the test panels. The insertion of a single transposition, as shown at *E* in Fig. 222, reverses the pair. Confusion is likely to exist while the work is under way, but the numbering system is readily corrected when the work is completed by making the necessary reversals at the main frames.

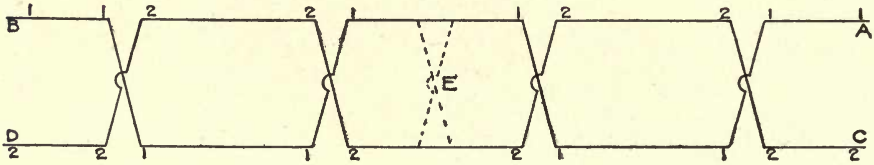

FIG. 222. — Reversal of Line Wires Caused by Cutting in a New Transposition.

Another form of transposition now used very widely is known, because of its construction, as the single-pin transposition. This type is shown in Fig. 223, where *A*, *B* and *C* represent the cross-arms on consecutive poles. Cross-arms *A* and *C* are each equipped with standard insulators in the usual way, while cross-arm *B* has one transposition insulator per circuit. The circuit is transposed by stringing wire number 1 from pin *G* on cross-arm *A* to the lower groove in the transposition insulator, and then to pin *E* on cross-arm *C*. Wire number 2 of the circuit is carried from pin *F* on cross-arm *A* to the upper groove of the transposition insulator and then to pin *D* on cross-arm *C*. This rotates the circuit through 180 degrees, or reverses the relative position of the two line wires. Fig. 224 indicates how this transposition is cut in; slack is needed in only one wire, instead of both.

The relative merits of this type of transposition, as stated by Mr. Fowle in his papers previously referred to, are as follows: "It has the comparative advantages of less first cost and simpler construction. It can be cut in at any time, cut out, or moved several poles at less cost and with much less work than in the case of a square transposition. If transpositions occur frequently, every one-half or one-quarter mile, the line capacity is increased a few per cent and the line inductance diminished, with a consequent slight increase in attenuation. The square transposition has the advantage of concentrating the entire transposition within a very short length and of not altering the plane or the separation of the wires. While the single-pin transposition

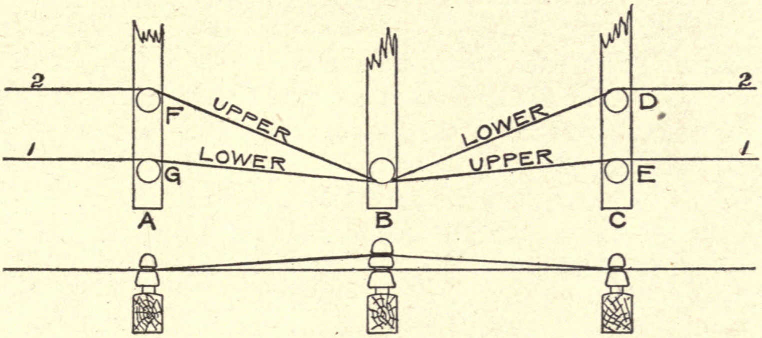

FIG. 223. — Single-pin Transpositions.

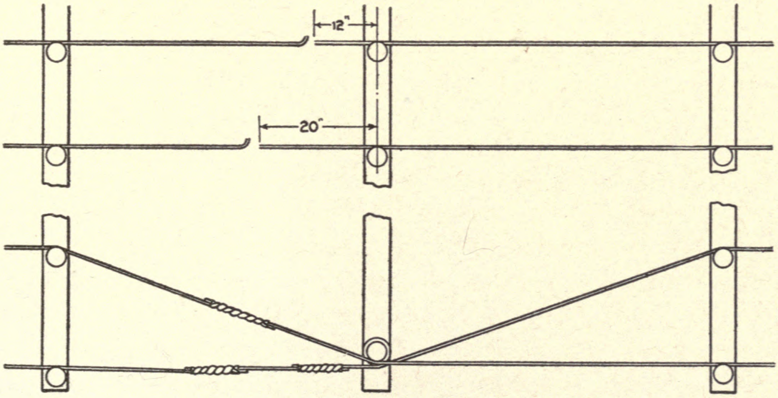

FIG. 224. — Method of Cutting in Single-pin Transposition.

changes the plane of the circuit, the wire separation is greatly reduced, and this is an advantage. Since it requires two spans in which to make this transposition, it is possible to transpose only at every other pole, as a maximum, in case of excessive induction, against every pole for the square transposition."

The practical application of transpositions has been considered, thus far, only with reference to cross talk between physical metallic circuits. The rapid development of phantom circuits during the past few years has added a new and somewhat complicated element to the general problem. Phantom circuits, if not transposed, will cross talk in the same manner as physical circuits. This can be prevented, as before, by a suitable system of transpositions of the physical circuits composing the phantoms.

There are three possible types of phantom circuit transpositions. In the first, shown in Fig. 225, the phantom circuit is transposed, and the two physical circuits, while not transposed with respect to each other, are transposed with respect to all other parallel circuits. The second method, indicated in Fig. 226, causes transpositions of the phantom and one of the physical circuits; and now the two physical circuits are transposed with respect to each other. In this type, also, one of the physical circuits is transposed with respect to all other parallel circuits, whereas the other is not. In the last or third type, shown in Fig. 227, the phantom circuit is transposed but neither one of the physical circuits is transposed with respect to any parallel circuits, although they are transposed with respect to each other. In

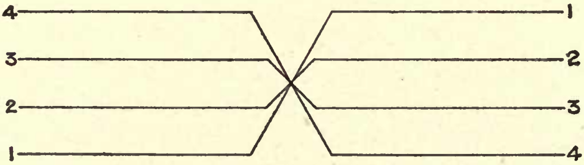

FIG. 225. — First Type of Phantom Transpositions.

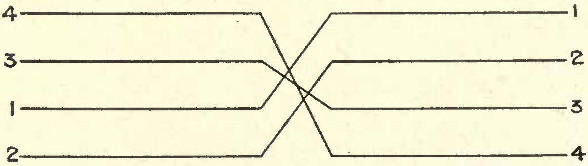

FIG. 226. — Second Type of Phantom Transpositions.

case the regular transposition sections are not too long, the phantom transpositions may be located at the poles forming the junctions between sections, where they will have no effect on the regular sectional system. If placed within a section, however, they will upset the exposures shown in Fig. 213. If many phantom circuits are employed, it is best to lay out a section with only the phantom transpositions and then superimpose the additional transpositions required to eliminate cross talk between the physical circuits. In general, it will be necessary to change the previous systems somewhat, cutting out some of the transpositions and cutting in others. It is general practice to compose the phantom circuits of pairs 1–2 and 3–4, 7–8 and 9–10, and corresponding pairs on the lower cross-arms. The arrangement of the A–B–C system, in this manner, is shown in Fig. 228.

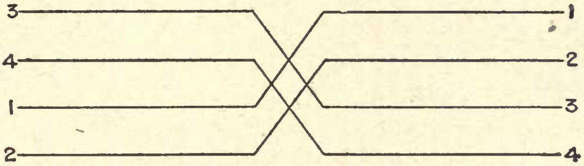

FIG. 227. — Third Type of Phantom Transpositions.

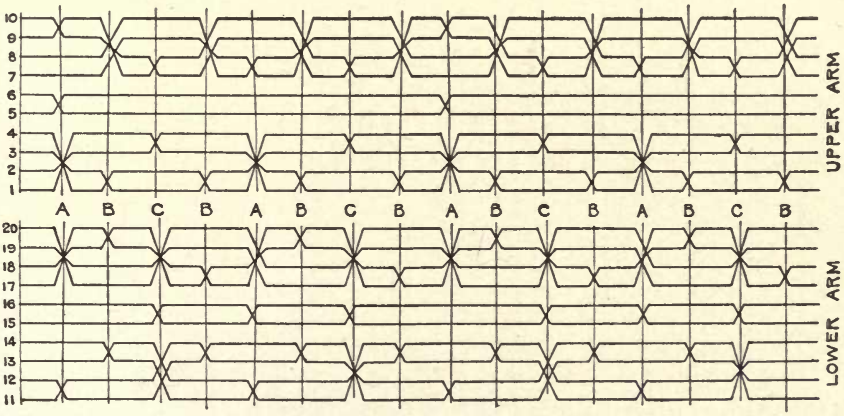

FIG. 228. — Phantom Transposition Applied to the A–B–C System.

Fig. 229 shows a forty-wire line transposed according to the standard system and arranged for eight phantom circuits.

In the transposition layouts shown in Figs. 228 and 229, each of the three types of phantom transpositions shown in Figs. 225, 226 and 227 is used. This makes the work of installation somewhat

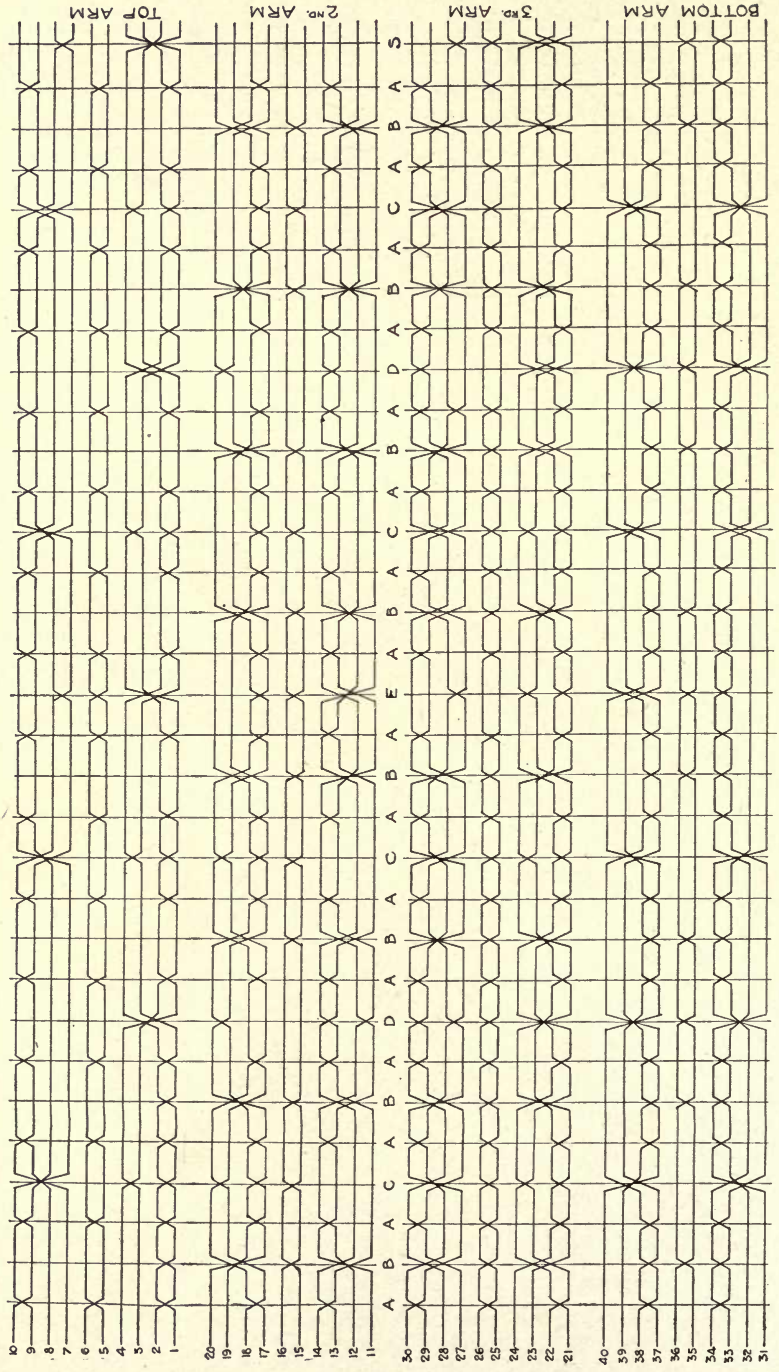

Fig. 229. — Phantom Transpositions Applied to the Standard System.

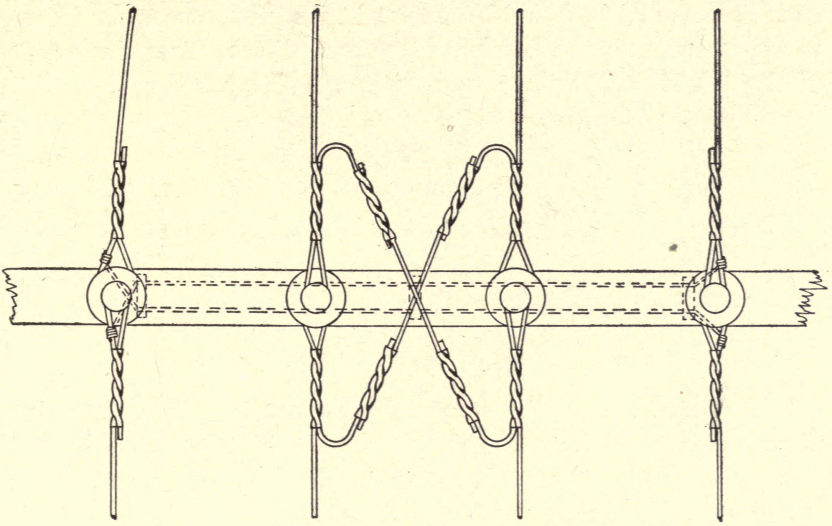

FIG. 230. — Construction of Phantom Transposition; First Type, Standard Method.

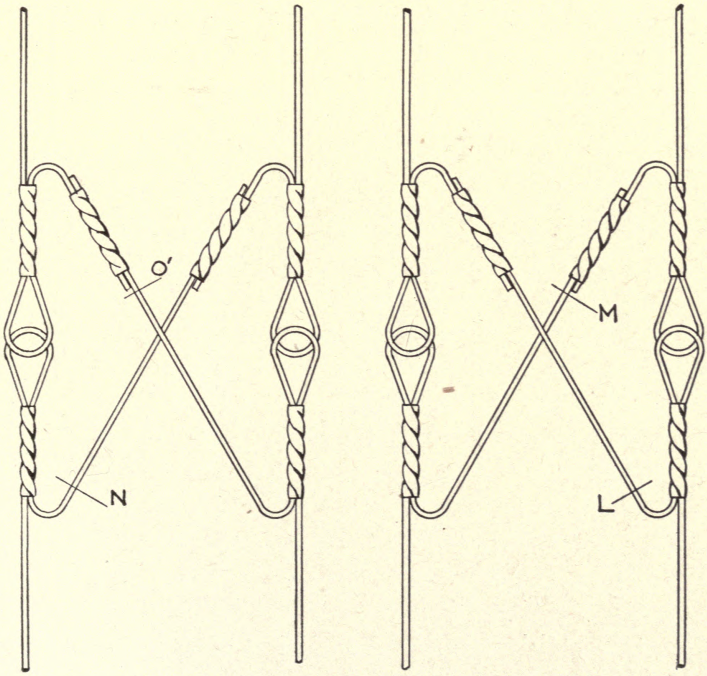

FIG. 231. — Method of Cutting Standard Transpositions to Change to the First Type of Phantom Transposition.

complicated, and it should be executed with great care to avoid confusion and mistakes. The following description outlines the practice of the American Telephone and Telegraph Company.

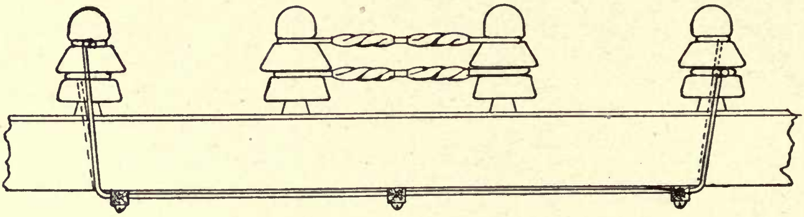

FIG. 232. — Cleat Wiring in First Type of Phantom Transposition.

When both physical circuits are already transposed by the double-pin method, the phantom transposition should be made as shown in Fig. 230. The best way to make the change from the regular to the phantom transposition, is to cut the wires of the old transpositions at *L*, *M*, *N* and *O* as shown in Fig. 231. The sleeves near *M* and *O* should then be cut off. The four connections are then carefully

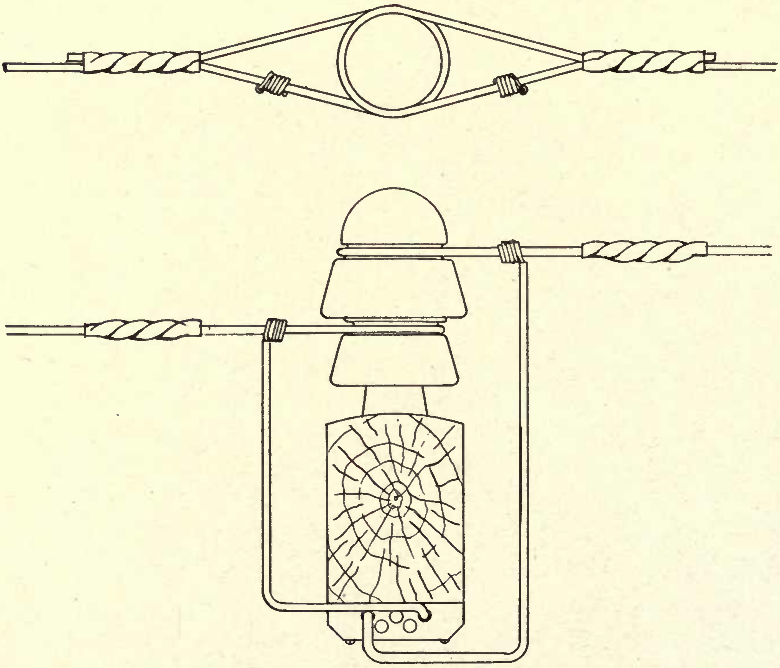

FIG. 233. — End View of Cleat Wiring.

twisted over and connected, by means of two half-sleeves, between the middle wires as shown in Fig. 230. The two outer wires are transposed by means of two pieces of insulated wire about five feet long, which are wired in cross-arm cleats attached to the under side of the cross-arm. These cleats should be fastened just inside of the two outer pin-holes, as shown in Fig. 232. The insulated wire should be run in the outside holes of the cleats, and should be soldered to the line wires between the insulators and the half-sleeves. The insulated wires should cross each other under the pin farthest from the pole, as illustrated in Fig. 233.

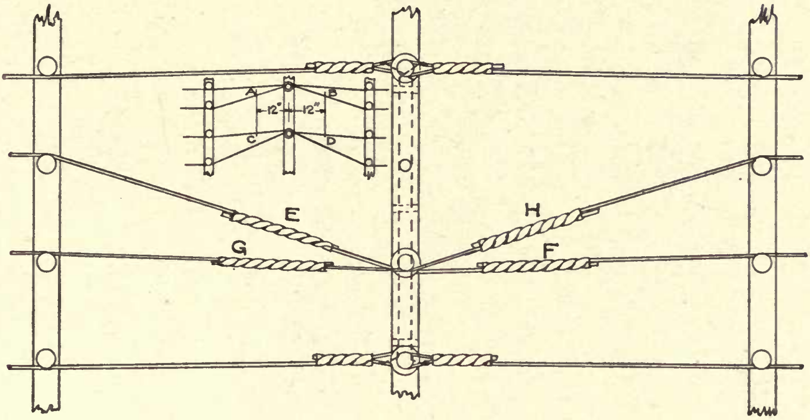

FIG. 234. — Construction of Phantom Transposition; First Type, Single-pin Method.

In case the two physical circuits are already transposed by the single-pin method, the phantom transposition should be made as indicated in Fig. 234. Here the middle wires are cut at *A*, *B*, *C* and *D*, about 12 inches from the insulators. Two pieces of line wire about four feet long are then cut into the two middle wires, by means of the whole sleeves *E*, *F*, *G* and *H*, and a standard single-pin transposition made. The two outer wires are then transposed as before, by means of insulated wire in cleats.

When the two physical circuits are not already transposed, the phantom transposition is made as outlined in Fig. 235. In this case, the middle wires are transposed according to the single-pin method. One of these wires is cut at *D*, 20 inches from the insulator and the other at *C*, 12 inches from the insulator. Into the latter is spliced 30 inches of line wire by means of the whole sleeve *H*, and the free ends of the wires are then connected by means of the sleeves *G* and *J*. The outer wires are cut at *A* and *B* about 12 inches from the insulators, and 30 inches of slack is spliced into two of the ends by means of the sleeves *E* and *F*. The four free ends are then dead-ended by means of half-sleeves in the standard manner and the transposition is completed with rubber-covered wire and cross-arm cleats, as previously described.

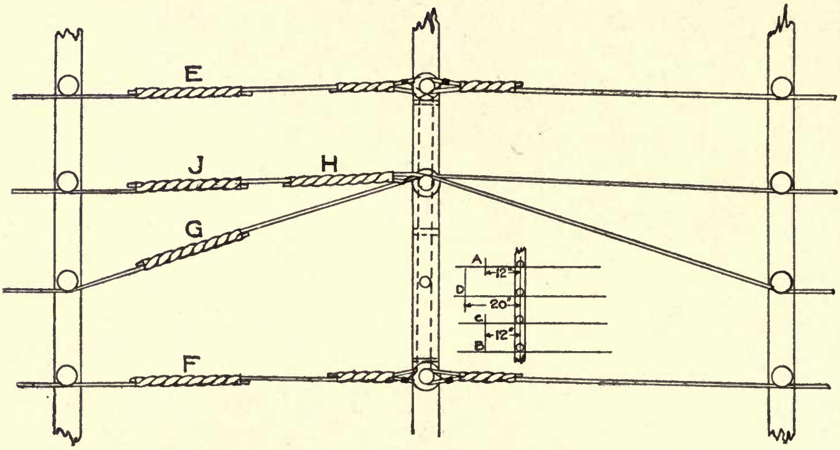

Fig. 235. — Construction of Phantom Transposition; First Type, Where no Previous Transposition Existed.

In the second type of phantom transposition, only one of the physical circuits is transposed. The wires of the circuit which is not transposed are dead-ended on the bottom grooves of the insulators and those of the other circuit on the upper grooves, as illustrated in Fig. 236. The alternate wires on opposite sides of the cross-arm should be cut 20 inches from the insulators, as indicated in the figure, and about seven feet of slack cut into two of the short ends by means of sleeves *A* and *D*, and about six feet in the remaining two with the sleeves *B* and *C*. Before the wires are dead-ended, the half-sleeves *E*, *F*, *H* and *I* should be slipped over proper ends. Then the slack end of wire *A* should be bent around the groove of the insulator and made fast in the half-sleeve *E*, about ten inches from the insulator. The end from *D* is attached to the sleeve *F* in a like manner, while the end from *C* is carried around the insulator and connected to the end from *B* by means of the half-sleeve *G*. In order that the connection from *I* to *H* shall not foul with the other wires of the transposition, a bracket equipped with a standard insulator is attached to the same side of the cross-arm as the sleeve *C*, between the middle pins. This bracket should be so located that the groove of the insulator is at least three inches above the adjacent wires. A six-foot length of wire is then attached to the outside line by means of the half-sleeve *I*; this wire is next carried around the groove of the transposition insulator and thence to the bracket insulator, about which it is given one turn, when it is drawn up as tightly as possible and terminated in the half-sleeve *H*.

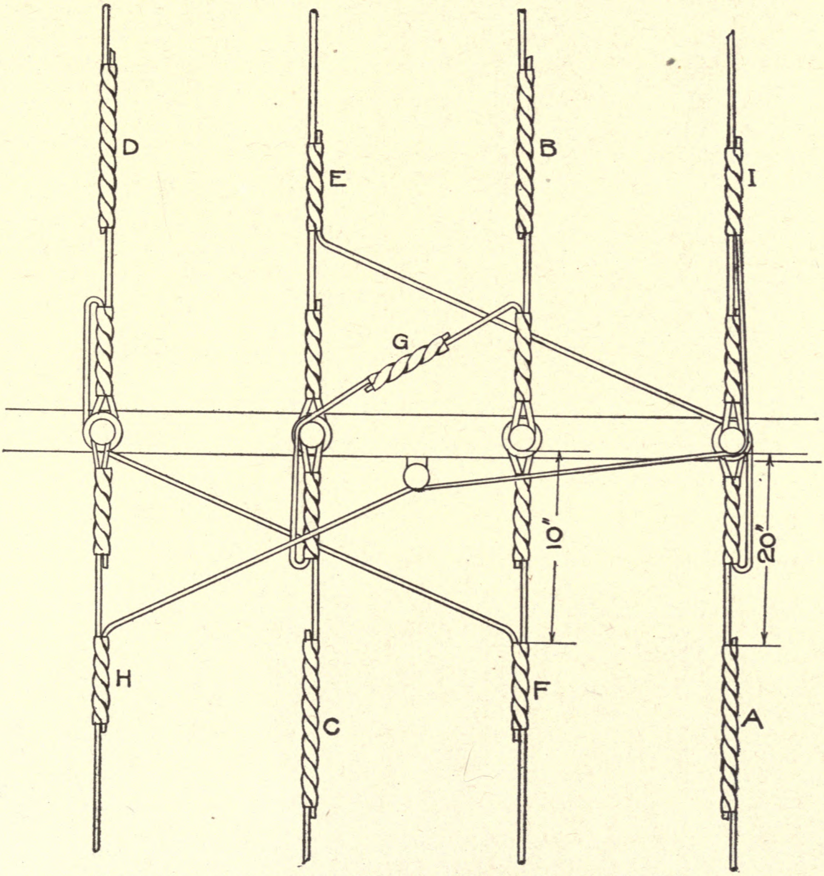

FIG. 236. — Construction of Phantom Transposition; Second Type.

In the third type of phantom transposition, in which neither physical circuit is transposed, the alternate wires on opposite sides of the cross-arm are cut about 20 inches from the insulator and seven feet of slack is cut into the short ends by means of the sleeves *A*, *B*, *C* and *D*, as indicated in Fig. 237. The half-sleeves *E*, *F*, *G* and *H* are then slipped over the proper ends, before the wires are dead-ended. The wires which constitute a continuous circuit are dead-ended in similar grooves of the insulators. The ends from sleeves *A* and *D* are then bent back around the insulator grooves and attached to the half-sleeves *E* and *F*, respectively, ten inches from the insulators. These wires must be drawn taut before the sleeves are twisted. The ends from *B* and *C* are then bent around the insulator grooves and fastened to the half-sleeves *H* and *G*, respectively.

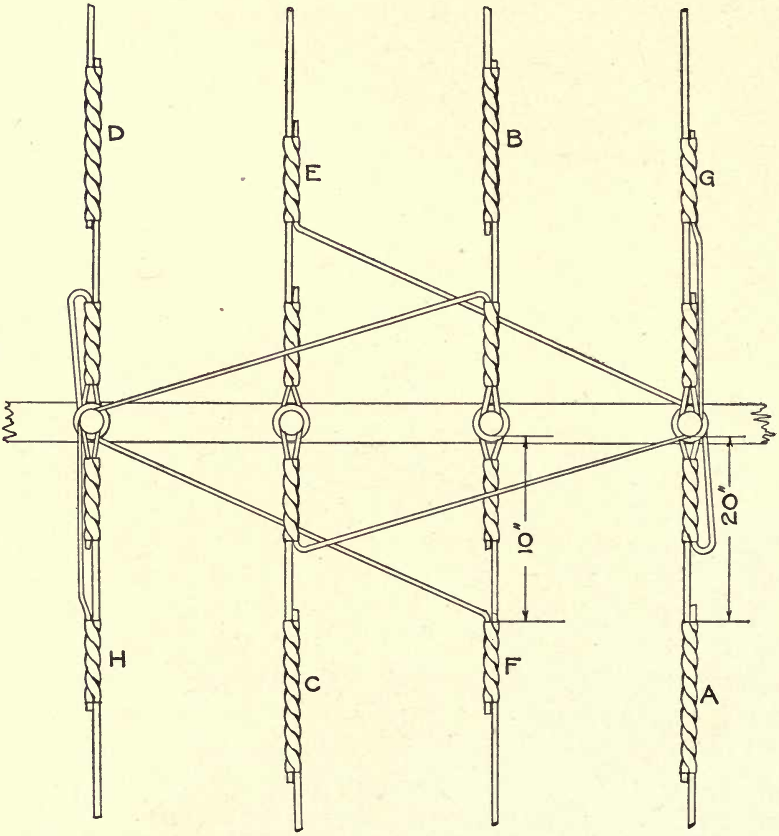

FIG. 237. — Construction of Phantom Transposition; Third Type.

The transposition methods employed in dealing with disturbances from power circuits comprise the remaining phase of the subject. Mr. F. F. Fowle in his paper before the American Institute of Electrical

Engineers, previously referred to, treated this subject quite extensively, and what follows is largely abstracted from that source.

When telephone lines are paralleled by power lines the transposition problem naturally becomes more complicated, and the development of high-tension transmission is increasing so rapidly that this branch of the subject of transposition is exceedingly important. In this case it is necessary to recognize not only the manner in which the load is distributed in the disturbing circuits, producing abrupt changes in line pressure or line current, but also any changes in the wire spacing. Thus, if the length *L* of the circuits shown in Fig. 238 is not very great there will be practically no mutual interference. The per cent of pressure drop in the power circuit must be so small that the total induced charges on the portion *AB* are sensibly equal and opposite to those on *BC*; likewise, the per cent of current loss in the power circuit must be so small that the induced E.M.F. in the portion *AB* is equal and opposite to that in *BC*. However, if a transformer or a branch circuit be connected to the power circuit within the portion *AC*, the transposition will no longer neutralize the induction. If the transformer were placed at *B*, the transposition would have the least effect, for the point *B* on the telephone circuit is, as it were, a neutral point. Should the power circuit be a constant-current circuit, any arc lamp which is cut into the line will have the same effect as regards the efficiency of the transposition. Any change in the wire spacing of the power circuit will also modify the effect of the transposition.

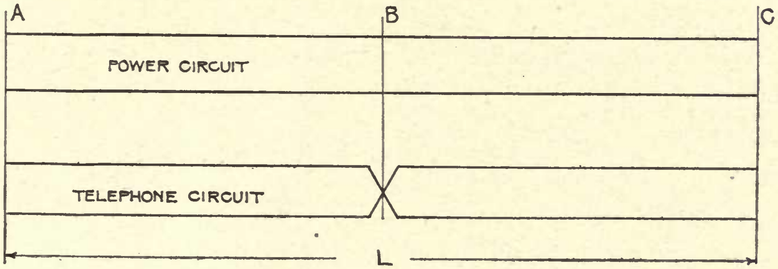

FIG. 238. — Single Exposure of Telephone Circuit to Power Circuit.

Therefore that portion of the disturbing line within which the E.M.F. and the current are both constant as to magnitude and phase, should be treated as a unit section and all the telephone circuits should be transposed opposite its center. If the total external exposure to the power line involves several consecutive sections, the cross-talk transpositions should be placed opposite the junctions of the sections, where the disturbing current and pressure change in magnitude or phase.

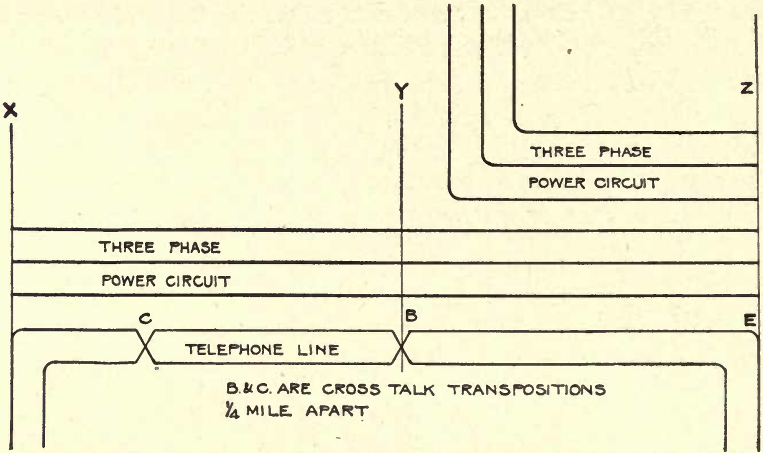

FIG. 239. — Unbalanced Exposure of Telephone Line to Power Lines.

This may be illustrated by a reference to Figs. 239 and 240. These show a telephone line paralleled by two three-phase circuits. Fig. 239 shows the transpositions as they were before the power lines were

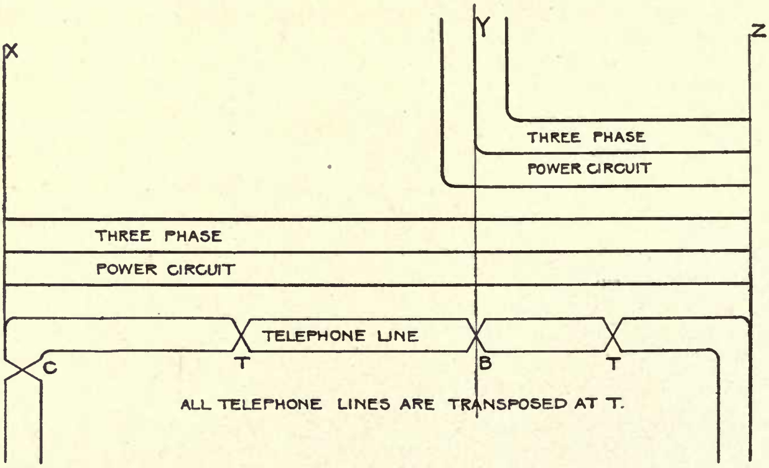

FIG. 240. — Method of Balancing the Exposures Shown in Fig. 239.

built; after these lines were placed in service there was considerable induction. The layout which eliminated the induction entirely is shown in Fig. 240, in which *XY* and *YZ* are each treated as unit sections with a transposition *T* at the center, where all telephone circuits are transposed. To simplify the drawing only one telephone circuit is shown in the figures. The cross-talk transpositions for this circuit remain the same in both figures, and this is naturally true of all the others. A more general case, depicted in Fig. 241, further illustrates the method of selecting the proper sections and the locations of the transpositions *T* which eliminate the induction from the power circuit.

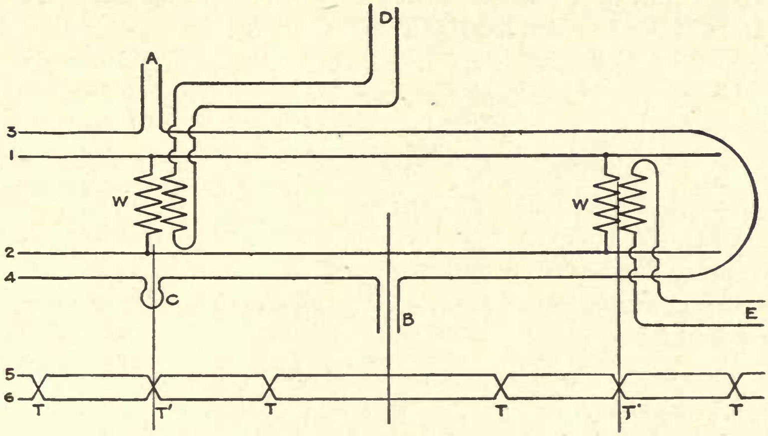

FIG. 241. — General Type of Balanced Exposure.

The general scheme just outlined is exceedingly efficient, until the character of the exposure becomes very complicated. Then the transpositions may become so frequent as to be impractical, or the physical limitations may be such as to prevent their proper location. Thus, if the connected load on the power circuit is developing rapidly, the exposures will be changing frequently, due to new customers. A remedy for this would be twisted pairs or a cable; but, as previously shown, either of these would impair the transmission. A study of the power wires should be made with a view of ascertaining whether they are not separated, with respect to one another, further than is necessary with the pressure employed, or whether the separations are uniform. Thus there are cases in which the reduction of the separation from several feet to less than two feet has so reduced the field of the power circuit as to allow the cross-talk transpositions to practically eliminate the induction.

Where telephone lines have paralleled transmission lines along highways, separated by 15 or 20 feet, or the width of the highway, the following practice has been employed; all the telephone circuits are transposed at every tenth pole, midway between the regular transpositions, thus having no effect upon the cross-talk exposures. This method is of course a makeshift, but is sometimes the only alternative when the exposure between the lines varies considerably, on account of the character of the right of way.

Frequently high-tension systems are transposed for their own benefit. When telephone circuits are run on such pole lines, the transpositions in the power circuits may sometimes be used to reduce the induction; but in general it is best, regardless of the location of the telephone circuits, to treat such transpositions as neutral points or junctions of contiguous sections. In general, the induction from a three-phase line is slightly greater than from a single-phase line having the same wire spacing and current per wire, and a pressure equal to the delta pressure.

A three-wire, three-phase line will have two transpositions within a section as shown in Fig. 242, in which two complete sections are shown. It seems to be fairly general practice to transpose high-pressure systems, but the length of the sections is usually several miles. On this account, it is difficult to make use of the power-line transpositions in transposing the telephone line, and hence it is usually necessary to treat them as the junction point between adjacent sections. On account of the very low frequency and the high ratio of pressure to current customary in high-tension practice, there is usually little inductive interference if the power circuit is separated from the telephone line by the width of the road or highway, or say 30 or 40 feet, because the regular cross-talk transpositions are sufficient for all practical purposes. Fig. 242 illustrates the method of transposing any circuit containing three wires, which may be considered as part of a distribution line on the Edison three-wire system, or a three-phase

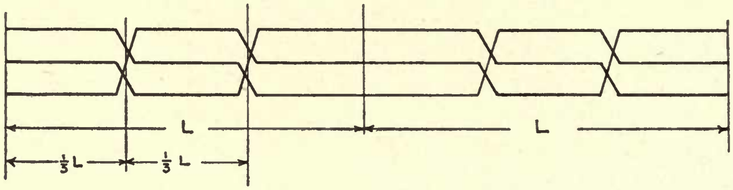

FIG. 242. — Transposition of Three-wire Three-phase Line.

transmission line, or a three-wire two-phase line. If the three wires are spaced equilaterally, each transposition amounts to a revolution of the line through 120 degrees. Thus the telephone line is exposed to three consecutive sections of the three-wire line in such a manner that the total induced electromotive force neutralizes itself.

In general, the transposition of a circuit having n wires will require $n - 1$ transpositions, the distance from one end of the section of exposure to the first transposition being $\frac{1}{n}$th of the total length of the section; successive transpositions will occur at regular intervals of $\frac{1}{n}$th of the section.

CHAPTER XX

METHODS OF TESTING

Chapter XI describes the equipment commonly required by a toll wire chief to make the line tests necessary in determining the nature and location of the various sorts of trouble ordinarily met in everyday toll service, and the present chapter deals with the use of this equipment. The proper testing instruments and apparatus are readily procured, but their proper use requires both some theoretical knowledge and considerable experience in manipulation. In addition to this, an understanding of elementary algebra is often of considerable value. This is required in the derivation of formulæ, only, and is not absolutely essential; for the use of formulæ, when once derived, requires only plain arithmetic.

Similar to many other branches of telephony, the greater part of the knowledge of testing is acquired by actual experience. It is often a comparatively simple matter to determine theoretically just how a certain test should be made, but it usually requires some time and patience to become proficient in securing reliable and accurate results. Frequent repetition, however, soon overcomes this deficiency and makes one so familiar with the various procedures that they become almost second nature. Then again, one man finds some given method of testing extremely easy and efficient, whereas the next man experiences great difficulty in pursuing that method, but obtains results that are just as accurate by an entirely different procedure. There are frequently several methods of testing for a certain case of trouble that are available to a resourceful wire chief, the result from any of which will lead to an accurate conclusion, but there is seldom, if ever, more than one " best way." However, it may be well to add that after making the test with the best method, it is often advisable to check results by another; and a careful tester will always follow this plan. Very often this " best method " requires testing equipment that is not commonly found at small toll stations; then a less accurate substitute must be employed, unless some office not too far away is fully equipped. The prime requisite of a good tester is a thorough understanding of the theory and applications of the instruments used, for in this, as in all other work, a substantial knowledge of the tools with which one is working is essential to the best results.

It is fortunate that a very simple test will often determine the nature of a case of trouble, for in small toll stations the testing equipment usually consists merely of a lineman's test set and possibly a voltmeter. This apparatus placed in the hands of a man skilled in testing, will give results that could hardly be expected; and since this apparatus has the greatest amount of application, owing to the fact that the small toll stations greatly outnumber the larger ones, it will be discussed first.

The first step in locating a case of trouble is to determine accurately its nature, and for this reason it is necessary to understand thoroughly the different classes of trouble to which a telephone line is subject. Line faults may be divided into four general groups as follows: grounds, crosses, opens and foreign currents. The first of these four divisions probably covers the most troublesome class of faults, because an unbroken line wire may have a ground connection with or without any resistance between the wire and ground. If the ground exists without resistance it is termed a " dead " ground; but if it has an appreciable resistance, it is known as a high-resistance ground. These two types of grounds are more easily located and rectified, comparatively speaking, than the swinging or intermittent ground. The difficulty in the latter case is that the trouble can be observed for very short intervals only, since the ground appears and disappears without any apparent cause, and frequently it is not of sufficient duration to allow the completion of a satisfactory test.

The second class of trouble, namely, crosses, may be of several kinds. Thus one of the line wires may be crossed with its mate, or with a wire of another line. If the cross is of the first variety and without resistance, it is known as a " dead short " or merely a short circuit, whereas if it introduces resistance, it is known as a high-resistance cross. As in the case of grounds, there are quite often intermittent crosses.

In the third group of troubles designated as opens, or breaks, a great number of external complications may be encountered, since it rarely happens that the two broken ends of a wire hang clear of the ground or other wires. It is thus obvious that either one of the two classes of trouble previously enumerated may be again encountered. Then it frequently happens, also, that the open is an electrical break and not a mechanical one, such as a corroded joint, which quite frequently results in intermittent trouble and is extremely annoying.

In considering the last group, or foreign current troubles, it should be remembered that they are sometimes the most formidable of all. This trouble is brought about by the existence of a difference of potential on the line wires, which causes a flow of current in the telephone circuit, usually of fluctuating character. This trouble may be brought about by a cross, by static discharge, or by electrostatic or electromagnetic induction. The static discharges are often met in the northwestern part of the country, where they are caused by the chaff of the wheat during the threshing season, and the extreme winds driving the snow in winter.

In order to present a clearer analysis of the several classes of trouble, they have been recapitulated in tabular form as follows:

1. *Grounds.*
    - (*a*) Dead ground.
    - (*b*) High-resistance ground or leak.
    - (*c*) Swinging or intermittent ground.
2. *Crosses.*
    - (*a*) Short circuit.
    - (*b*) High-resistance cross.
    - (*c*) Intermittent cross.
3. *Opens or breaks.*
    - (*a*) Broken ends insulated.
    - (*b*) Broken ends grounded.
    - (*c*) Broken ends crossed with other wires.
    - (*d*) Intermittent opens.
4. *Foreign currents.*
    - (*a*) Crosses.
    - (*b*) Static.
    - (*c*) Electrostatic induction.
    - (*d*) Electromagnetic induction.

The wire chief, upon receiving a report that a line is in trouble, should first convince himself that the trouble actually exists on the line; for it often occurs that a line is reported in trouble when the fault really exists in a cord or some other part of the switchboard equipment. When he has assured himself that the trouble actually exists, his next step is to determine whether the trouble is inside or outside, *i.e.*, in the part of the line from the arresters to the switchboard, or on the outside line. In case the trouble is outside, the office end of the circuit should be disconnected; then, by means of the magneto test set, the tester can determine whether either side of the line is grounded. This is accomplished by connecting one terminal of the test set to one of the line wires and the other to ground. This test will give an indication of whether either line is grounded. If both lines test clear, the test set should be bridged across the line, to test for a cross. In case this test also indicates a clear line, then the natural conclusion is that the line is open; this can be verified by attempting to ring through to the next office.

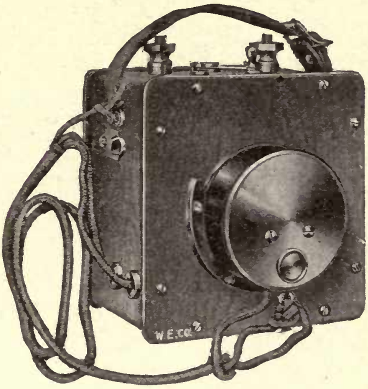

FIG. 243. — Magneto Test Set.

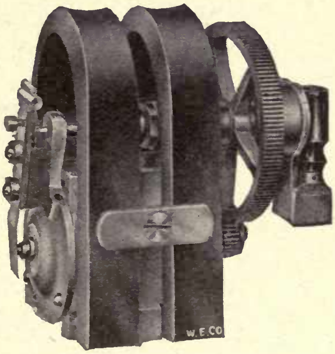

FIG. 244. — Test Set Generator.

It may be well in this connection to give a description of the type of lineman's test set (Fig. 243) best suited for toll work. This set should be as light as possible without sacrificing its efficiency, because it must be readily portable for long distances. The set should contain a generator (Fig. 244) capable of ringing a polarized bell through 20,000 to 25,000 ohms resistance, while the ringer should be of a small type; an alternating-current buzzer (Fig. 245) has been used for this purpose with good results. A watchcase receiver, substantially built so as to withstand considerable abuse,

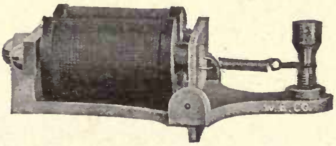

FIG. 245. — Alternating-current Buzzer.

should be used for talking and receiving. The proper method of connecting the apparatus is shown in Fig. 246. When testing, the switch rests on contact *a*, and is switched to contact *b* for talking purposes. This equipment, when placed in a small box and provided with a carrying strap, makes an extremely light and compact testing set. A set of this kind will serve as the means of detecting faults with quite a considerable degree of accuracy, by noting the pull on the generator and the sound of the bell. On long toll lines, the use of a test set becomes unreliable, due to the fact that the large amount of distributed capacity is often great enough to permit a flow of current sufficient to operate the bell.

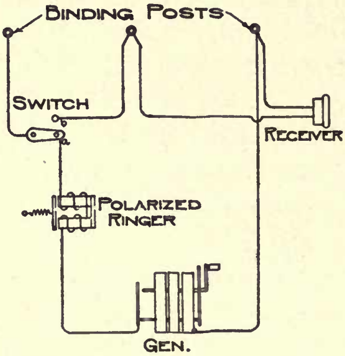

FIG. 246. — Wiring of Lineman's Test Set.

While a lineman's test set is of value in determining the existence of certain troubles on the line, it is not intended that it should give more than a rough idea as to their location. However, in many small toll stations, this is the only equipment provided for making tests, and therefore the results must be relied upon as a basis for trouble hunting. Since the cost of electrical testing instruments is decreasing each year, and as there are some on the market to-day that can be procured for a very nominal figure, no telephone exchange of any consequence should be without a voltmeter. The cost of instruments of this class is as low as ten dollars and some of these cheaper instruments are made so as to be quite reliable. The results that can be obtained with them certainly warrant the investment, to say the least, because they do so much to reduce the cost of clearing trouble. The higher-priced portable type of instrument is naturally more desirable, but there are many cases in which their cost is not justified. In selecting a voltmeter, one with a double scale should be chosen, so that small as well as large voltages may be accurately measured. One with a low scale of 0 to 30 and a high scale of 0 to 300 has been found to be well adapted for general work.

The voltmeter can be used not only for determining the nature of troubles, but also for locating them, in many instances. Its indications are far more reliable than those of a test set. In making tests with this instrument it is only necessary to connect it in series with a battery and proceed as in the case of a test set.

The location of the trouble may be found in some cases by measuring the resistance of the line between the testing point and the fault. Thus, if the preliminary test indicates a ground, the resistance of the line out to and through the ground can be obtained in two general ways by means of a voltmeter. Both of these methods depend on the electrical law that when two resistances are connected in series, the fall of potential in one is to the fall of potential in the other, as the resistance of the first is to the resistance of the second. Therefore, to determine where this ground exists, the first step is to take a reading across the testing battery, which we shall call V; then a reading should be taken with the voltmeter, battery and defective wire all in series, the first terminal of the battery being grounded. Then, if we call this second reading V', the resistance of the line X and the resistance of the voltmeter R, we have, according to the law referred to above,

$$V - V' : V' :: R : X$$

or

$$V'R = X(V - V'),$$

which gives the formula,

$$X = R\left(\frac{V'}{V - V'}\right). \qquad \text{(1)}$$

This method will give reliable results only when the resistance out to ground is rather high, because of the fact that the resistance of the voltmeter is usually very high, running up to 30,000 ohms. Therefore, if the external resistance is low, the fall of potential around this resistance will also be low; consequently a slight error in the reading of the instrument will introduce a much larger error in the result. It is generally advisable to use the method described in the following, because the line resistance is seldom high enough to insure good results with the first method. In this case the testing battery, a variable resistance, and the faulty wire are all connected in series as before. The voltmeter is then shunted around the standard resistance as shown in Fig. 247 and readings are taken as previously described. The variable resistance should then be regulated until the deflection of the voltmeter is about one-half of the battery voltage. The formula used with this method is the same as that derived for the first case; but in this instance, R is equal to the adjusted resistance of the variable box when the final reading is taken. To get the best results with this test, it is essential to keep V' approximately one-half the value of V.

After the resistance of the wire from the testing station to the fault has been obtained, it is necessary to divide it by the resistance per mile to obtain the distance. The resistance per mile may be taken from standard tables; but the best method is to have on record the total resistance and the resistance per mile, from actual measurement, of each line leading out of the station.

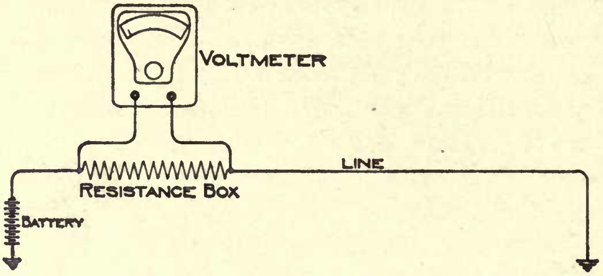

FIG. 247. — Voltmeter Connections for Measuring Line Resistance.

In the following table is given the resistance per mile for the various kinds and sizes of wire used in toll-line construction. The size of the iron and steel wire is given in B. W. G., while the copper is given in B. & S. gauge; this is the general practice in this country.

TABLE 15

RESISTANCE PER MILE OF IRON AND COPPER LINE WIRE AT 68° F.

Gauge.	Iron Wire.			Hard-drawn Copper.
	EBB.	BB.	Steel.	
6	8.21	9.6	11.35	2.129
7	10.44	12.21	14.43	2.685
8	12.42	14.53	17.18	3.386
9	15.44	18.06	21.35	4.277
10	18.83	22.04	26.04	5.385
11	23.48	27.48	32.47	6.787
12	28.46	33.3	39.36	8.564
13	37.48	43.45	51.82	10.794
14	49.08	57.44	67.88	13.612

To determine the distance to a cross between two wires, the procedure is the same as in the test for a grounded line; but instead of connecting the battery to ground, it is attached to the other wire. The result obtained by this test is the resistance of the loop, or the two wires in series, to the cross. The total resistance divided by the loop resistance per mile will give the distance to the fault.

In the tests thus far described, it is assumed that the ground connection, or the cross between the two wires, has a negligible resistance. This very seldom is the case, however, and it is always a good plan to make tests from each end of a defective line whenever possible. Then by comparing the two results, a more reliable conclusion may be reached.

To obtain results that can be absolutely relied upon, the tests must be made with an accurate Wheatstone bridge of the form shown in Fig. 248. The type of bridge best suited for telephone work should comply in general with the following specifications. The ratio arms should be so arranged as to permit of an adjustment for any convenient ratio to each other, from $\frac{1}{100}$ to $\frac{100}{1}$, while the rheostat arm should be so made that any resistance from 1 to 11,000 ohms can be obtained. The galvanometer should be made a part of the set and should be fairly sensitive; at the same time it should be constructed to stand the rough usage received in portable work. It is also very convenient to have the battery included as part of the set. A bridge following these specifications will measure any resistance between 1 and 100,000 ohms, in which the error should not exceed one-quarter of one per cent.

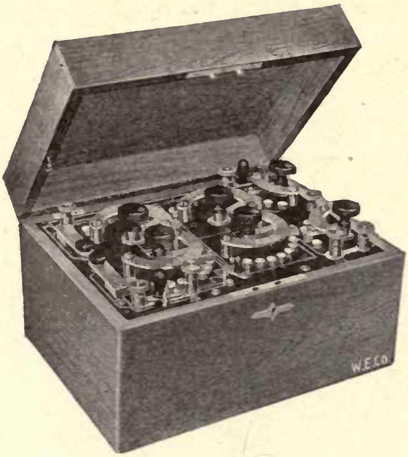

FIG. 248. — Bridge.

There are two general types of bridges, one of which uses plugs while the other makes use of a dial rheostat. The plug type is considered the most reliable, although some telephone companies prefer the second because it is so easily adjusted. Before attempting to show how the bridge is used in practice, its theory will be given briefly.

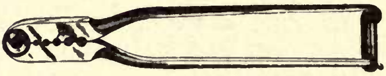

FIG. 249. — Wire Connectors.

The operation of the bridge is based upon the principle that the drop of potential in a conductor, when the current remains constant, is proportional to the resistance. Thus, suppose that V and V' are the potentials of two points A and B on a conductor. Then it follows from Ohm's law that

$$V - V' = RI, \qquad \ldots \ldots \ldots \quad (2)$$

in which R is the resistance of that part of the conductor on which the potential reading was taken and I is the current flowing. It is obvious from this equation that the potential difference between any two points on a conductor in which a constant current is flowing, is proportional to the resistance between these points, provided of course that the conductor is not the seat of an electromotive force. Thus take a point X so situated between A and B that the resistance between X and A is one-half that between A and B, then the potential difference between X and A is likewise one-half the potential between A and B.

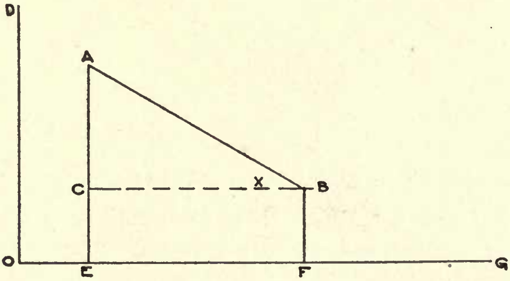

FIG. 250.

In Fig. 250 is represented graphically what has just been stated. Thus, let the distances measured along OG represent resistance and those along OD potentials. It will then be evident from what has been said that *EA* equals *V* and *FB* equals *V′*; also that *EF* represents the resistance *R* between the points *A* and *B* on the conductor. Now, if we join points *A* and *B* and draw *BC* parallel to *OG*, then it will be evident that *AC* is equal to $V - V'$, the potential difference between *A* and *B*. Therefore the slope of the line *AB* represents the rate at which the potential drops along the resistance *R*. Then solving triangle *ABC*, it is found that the tangent of angle *CBA* equals

$$\frac{AC}{BC}=\frac{E}{R}=I, \quad \ldots\ldots\ldots \quad (3)$$

which proves that the tangent of the angle of slope is equal to the strength of the current. It will be noted that the principle just demonstrated was made use of in the voltmeter tests previously described, and it is one of almost universal application in telephone testing. The Wheatstone bridge utilizes this principle, the bridge consisting of six conductors which connect four points, one of the conductors contains the battery and another the galvanometer. This is illustrated in Fig. 251, where the letters *Y*, *Z*, *S* and *T* represent the four points, *B′* the battery and *G* the galvanometer. Then as the fall of potential between the points *Y* and *S* is the same by either path, *YZS* or *YTS*, there must be a point *Z* on the former which has the same potential as *T* on the latter. Then since the circuit through the galvanometer connects these two equipotential points, it will receive no current. Thus, if *I* is the current flowing through *A*, it will also be the current flowing through *R*, since none flows through the galvanometer. Further, let *I′* represent the current flowing through the branch *YTS*. Now, since the potential difference between *Y* and *T* is the same as between *Y* and *Z*, we have by Ohm's law that

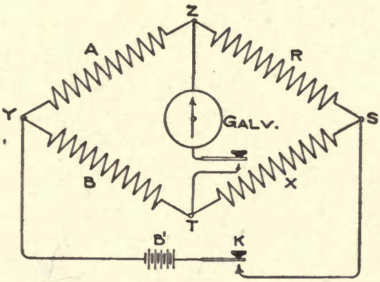

FIG. 251. — Wheatstone Bridge Circuit.

$$AI = BI', \quad \ldots\ldots\ldots \quad (4)$$

and similarly,

$$RI = XI'. \quad \ldots\ldots\ldots \quad (5)$$

And then by dividing equation (4) by (5) we have

$$\frac{AI}{RI}=\frac{BI'}{XI'}, \text{ or } \frac{A}{R}=\frac{B}{X}, \quad \ldots\ldots \quad (6)$$

which can be stated in the proportion

$$A : R :: B : X. \qquad (7)$$

Consequently, when the four resistances are so adjusted that no current flows through the galvanometer, the proportion stated above always holds. In practice, three of the resistances are fixed and the adjustment for a balance is made by varying the fourth. Thus, in equation (6), X represents the unknown, while A and B represent the ratio arms and R the rheostat or variable arm. Therefore, it is only necessary to know the ratio $\frac{B}{A}$, for then the equation gives the relation between R and X, or $X = R\frac{B}{A}\cdot$

In making a test to ascertain the resistance of a line, the terminals are connected to binding posts marked X and thus the line furnishes the unknown resistance arm of the bridge. The test should be commenced with 100 ohms in each of the ratio arms, and then the rheostat arm should be adjusted until a balance is obtained, when the resistance of the line X may be ascertained by substituting the proper values in the equation $X = R\frac{B}{A}\cdot$

This measurement may be considered as final, if X is below 6000 ohms; but if not, the ratio arms A and B should be readjusted to conform with the following table.

TABLE 16

BRIDGE ARM RATIOS

If X is below	1.5	ohms makes	$A=1$;	$B=10{,}000$.
“ “ “ between	1.5–11	“ “	$A=1$;	$B=100$.
“ “ “ “	11–75	“ “	$A=10$;	$B=100$.
“ “ “ “	78–1100	“ “	$A=100$;	$B=1000$.
“ “ “ “	1100–6100	“ “	$A=100$;	$B=100$.
“ “ “ “	6100–110,000	“ “	$A=1000$;	$B=100$.
“ “ “ “	110,000–1,110,000	“ “	$A=1000$;	$B=10$.

This table is given on the assumption that a bridge conforming with the preceding specifications is being used.

To ascertain the resistance of a wire between any two points when a second wire is not available, the only method that can be followed is to connect the far end to earth, being sure that a good connection is made. In this test the bridge should be connected as shown in

Fig. 252 and a balance taken. The resistance so obtained, however, cannot be relied upon as being accurate, due to the possibility of resistance in the ground connection.

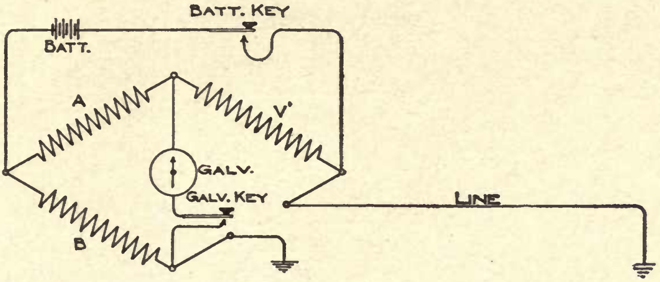

FIG. 252. — Wheatstone Bridge Connection for Measuring Resistance of Single Line Wire.

If three wires extend between two toll stations, then the resistance of each wire can be accurately ascertained. Let X, Y and Z represent the respective resistances of the three wires. Then if the far ends of any two are connected as in Fig. 253, the loop resistance R thus obtained will be

$$X + Y = R. \qquad (8)$$

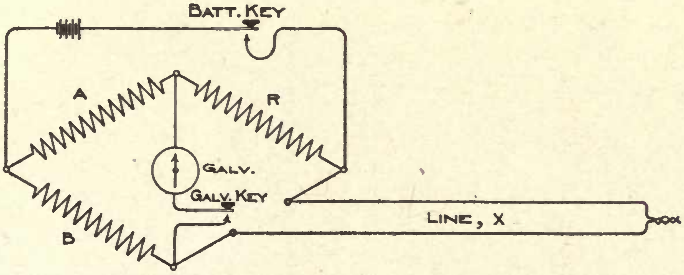

FIG. 253. — Bridge Connection for Measuring Line Loop Resistance.

If we now connect the far ends of wires X and Z and measure this loop in the same way, the resistance R' will be

$$X + Z = R'. \qquad (9)$$

Lastly by connecting the far ends of Y and Z, and letting the resistance of this loop equal R'', the result will be

$$Y + Z = R''. \qquad (10)$$

With these three equations (8), (9) and (10), the values of X, Y and Z can be found as follows.

First, subtract equation (10) from (9),

$$X - Y = R' - R'', \quad \ldots\ldots \quad (11)$$

then add (11) to (8) and eliminate Y, or

$$2X = R + R' - R'',$$

which gives

$$X = \frac{R + R' - R''}{2}. \quad \ldots\ldots \quad (12)$$

Similarly Y and Z can be found; and

$$Y = \frac{R + R'' - R'}{2}. \quad \ldots\ldots \quad (13)$$

$$Z = \frac{R' + R'' - R}{2}. \quad \ldots\ldots \quad (14)$$

If there are but two wires between the stations, the ground can be used as the third conductor, and then the procedure is the same as described above for three wires. First make the measurement of the two wires in series, next of each one connected to ground, and then the calculations will follow, as in the preceding paragraph. The ground return resistance should be very small, measuring not more than ten ohms if proper earth connections are made.

In the method just described, trouble may be encountered in the form of earth potentials, and this is especially true if the line parallels an electric railway. Where the earth potentials are smaller than the testing voltage and relatively steady, an additional measurement should be made in each case with the terminals of the battery reversed, and a mean of the two results should be used in the calculations. Earth currents may be readily detected by a milliammeter connected between one end of the line and ground, when the far end is also grounded.

The most important use made of the bridge is the location of such faults as grounds and crosses. The accurate location of these faults is extremely essential, so that proper directions may be given to the linemen to clear the trouble with as little delay to the service as possible.

When the trouble consists of a simple ground and a second wire is available, the location of the fault is comparatively easy. The procedure in this case is known as the Varley loop test. In making this test, the first step is to connect the far end of the faulty wire to its mate, or any other clear wire, and measure the loop with the connections set up as shown in Fig. 254. Then if the loop resistance be represented by R, we have

$$R = X + Y. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (15)$$

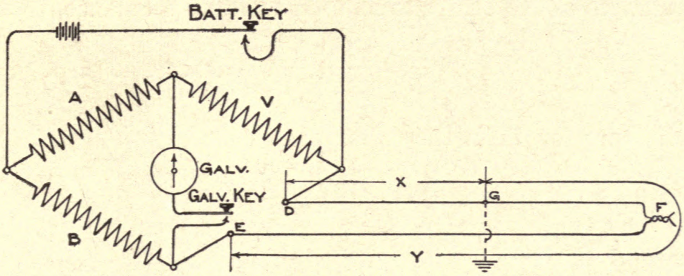

FIG. 254. — Connection for First Measurement in Varley Loop Test.

Now, without changing the line connections on the bridge, one terminal of the battery should be switched to ground, as shown in Fig. 255, and another balance obtained; the following conditions will then exist.

$$\frac{A}{B} = \frac{r' + X}{Y}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (16)$$

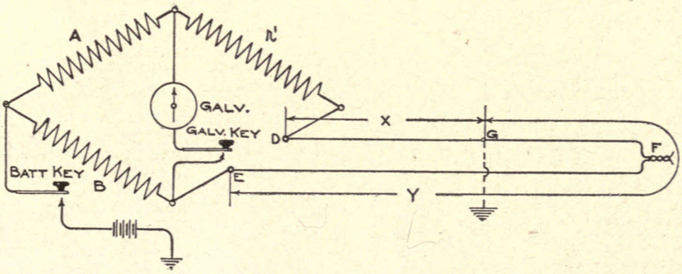

FIG. 255. — Connection for Second Measurement in Varley Loop Test.

By substituting in (16) the value of Y obtained from (15),

$$\frac{A}{B} = \frac{r' + X}{R - X}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (17)$$

and clearing of fractions,

$$AR - AX = Br' + BX,$$

or

$$AX + BX = AR - Br'$$

which gives

$$X = \frac{AR - Br'}{A + B}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (18)$$

In the above equations r' is the resistance of the rheostat arm. One more test is usually made before the result is accepted, merely to serve as a check. The connections are the same as shown in Fig. 255, but with the line connections reversed at D and E. Now if R' and r'' are the resistances of the bridge arms used to reach a balance, then

$$\frac{A}{B}=\frac{r''+Y'}{X'}. \qquad (19)$$

Substituting for Y' in the terms of X',

$$\frac{A}{B}=\frac{r''+R'-X'}{X'},$$

and clearing of fractions,

$$AX'+BX'=Br''+BR'.$$

Then solving for X',

$$X'=\frac{B(r''+R')}{A+B}. \qquad (20)$$

The average of the results obtained in these two tests will give a more accurate location than either one alone; but one result should check the other very closely if the measurements have been made with due care. To obtain the distance to the fault, divide the result thus obtained by the resistance per mile of the faulty conductor.

Another method of obtaining the same results, known as the Murray loop test, can be used to advantage either as a check on the preceding method or for direct location. Here, as in the previous test, the far end of the faulty wire is connected to a good wire and the loop measured, giving the resistance

$$R=X+Y.$$

The bridge is then connected as shown in Fig. 256, and it will be noted that in this case there are only two adjustable arms, since A and r now constitute a single arm. X and Y constitute the other two arms of the bridge, with the ground as the junction. If a balance is now obtained,

$$\frac{A+r'}{B}=\frac{Y}{X}. \qquad (21)$$

And by substituting $R-X$ for Y,

$$X=\frac{BR}{A+r'+B}. \qquad (22)$$

This result may be checked by reversing the line wires as in the Varley test. Some bridges are not arranged for switching the galvanometer terminal to the point *D* for making this kind of test; but the standard forms that are made expressly for telephone work are usually so constructed. In case a bridge is not available, or the one at hand is not arranged so that this change in the connections can be made, the test may still be accomplished if two adjustable resistance boxes can be procured and the loop resistance is known. In this event it is necessary only to substitute the resistance boxes for the two arms, while any galvanometer or a sensitive telephone receiver may be used in place of the instrument usually mounted in the bridge. The connections should be set up as shown in Fig. 257, and it will be noted that they are the equivalent of those in Fig. 256.

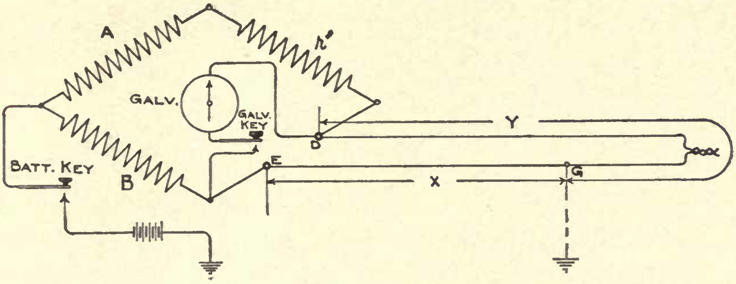

FIG. 256. — Connection for Second Measurement in Murray Loop Test.

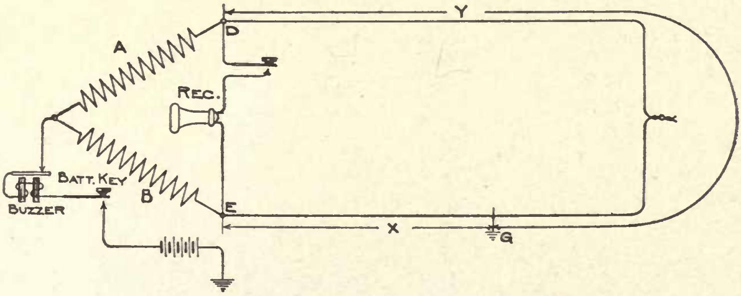

FIG. 257. — Murray Loop Test, Using Resistance Boxes.

In both the Murray and the Varley loop tests, the resistance of the fault and the presence of earth currents have no effect on the accuracy of the results. The reason for this is found in the fact that the resistance of the fault lies outside of the neutral point *G* and forms part of the battery circuit. It might be well to add that in case considerable resistance is introduced by the leads used in connecting the line wires to the bridge, it should be deducted from the value of X before computing the distance to the fault. However, in most cases this resistance is so small as to be negligible.

When no clear wire is available for making a loop test, the following method may be used with a high degree of accuracy, in case the resistance of the fault is constant. For this test the bridge should be connected as shown in Fig. 258 and the usual balance obtained. The result thus obtained is the resistance of $X + Z$. Let this be represented by

$$R' = X + Z. \qquad (23)$$

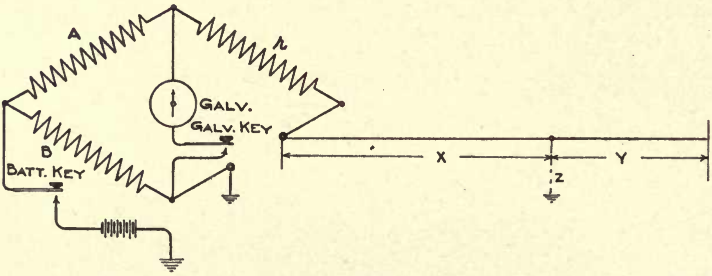

FIG. 258. — Connection for Measurement When Resistance of Fault is Constant.

Then the same test from the opposite end of the line should be made giving

$$R'' = Y + Z. \qquad (24)$$

The total resistance of the line — either previously determined or computed from its size, length and temperature — may be represented by

$$R = X + Y. \qquad (25)$$

Then by subtracting equation (24) from (23),

$$R' - R'' = X - Y. \qquad (26)$$

Then substituting the value of $Y = R - X$, and solving for X,

$$X = \frac{R + R' - R''}{2}. \qquad (27)$$

Now since the resistance to the fault and the resistance per mile of wire are known, it is an easy matter to determine the location.

In making tests for the location of crosses, the procedure is similar to that already given for the location of grounds. In the first place, it is not always safe to assume that the resistance of the fault is negligible, although it may be so in many instances. It is safer to assume that the fault has a perceptible resistance and make all tests accordingly. All such tests for location of crosses require two measurements, or more. The Varley loop method is one of the simplest and best, and the results obtained can be relied upon where the resistance of the fault is constant. In making this test the bridge connections should be set up as shown in Fig. 259, and the resistance of the loop measured. Let the resistance be called *R*. Then

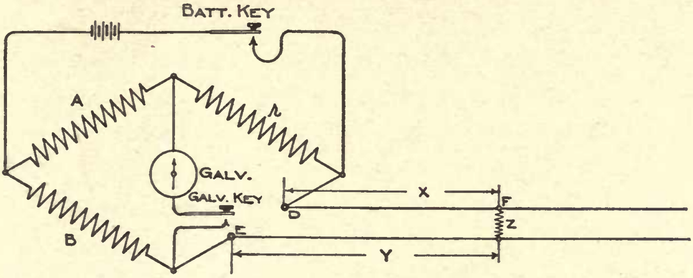

FIG. 259. — First Connection in Varley Loop Measurement for Crosses.

$$R = X + Y + Z. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (28)$$

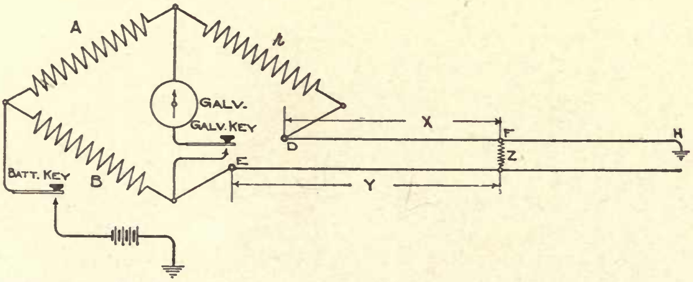

FIG. 260. — Second Connection in Varley Loop Measurement for Crosses.

Either of the crossed wires is next connected to ground at any point beyond the fault. This is readily accomplished at the next toll station, and the bridge is then connected as shown in Fig. 260. It follows from the second balance that

$$\frac{A}{B} = \frac{r + X}{Y + Z}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (29)$$

Then from equation (28),

$$Y + Z = R - X. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (30)$$

Substituting this value for $(Y + Z)$ in (29),

$$\frac{A}{B} = \frac{r + X}{R - X}, \quad \dots\dots\dots \quad (31)$$

and by clearing of fractions and solving for X,

$$X = \frac{AR - Br}{A + B}, \quad \dots\dots\dots \quad (32)$$

and by dividing by the resistance per mile of wire, the distance to the fault is obtained. This test may be checked by reversing the two wires at D and E, or by placing the ground H on the other wire.

It is sometimes advisable to check the result by a different method, if possible. The following test can be used in some instances. The first measurement is made as in the preceding test, while the second is made with the connections shown in Fig. 261. This determines the resistance of the wire ES, which will be termed R'. Then

$$R' = X + W. \quad \dots\dots \quad (33)$$

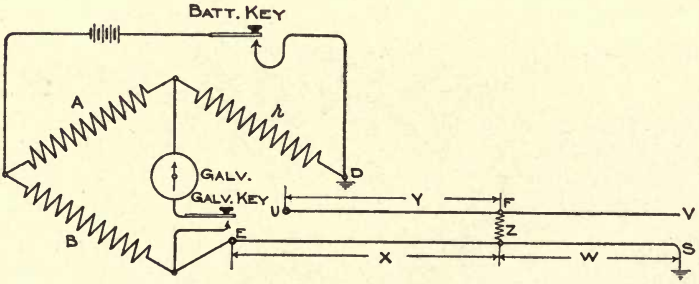

FIG. 261. — Second Connection in Varley Loop Test for Locating High-resistance Crosses.

Next disconnect the wire ES from the bridge and substitute UV, thus measuring the resistance of the portion between the testing station and the fault, the fault itself and the part ES beyond the fault all in series. Let this resistance be denoted by R''. Then

$$R'' = Y + Z + W. \quad \dots\dots\dots \quad (34)$$

Next adding equations (28) and (33),

$$R + R' = 2X + Y + Z + W, \quad \dots\dots \quad (35)$$

and by subtracting (34) from (35),

$$X = \frac{R + R' - R''}{2}. \quad \dots\dots\dots \quad (36)$$

This is the resistance of the wire from the bridge to the fault; the distance being obtained as already explained in the other cases. This test, like the previous one, is reliable only when the resistance of the fault is constant.

Difficulty in keeping the bridge balanced during a test may be caused by varying resistance at the fault. The following test will sometimes obviate this difficulty. The first measurement is made with the bridge connected as shown in Fig. 261. Then

$$R = X + W. \quad \ldots\ldots\ldots \quad (37)$$

The bridge should then be connected as indicated in Fig. 262, from which it will be observed that the three arms have been reconnected to form but two, namely, B and $A + r$. The galvanometer is not connected directly across the arms in the bridge, but through Y and Z to the point F, which forms the junction of X and W. The other two arms of the combination are furnished by the resistances X and W. Now, since the resistance Z is in the galvanometer circuit, it need not be constant, because no current will flow through it when a balance is obtained. Then

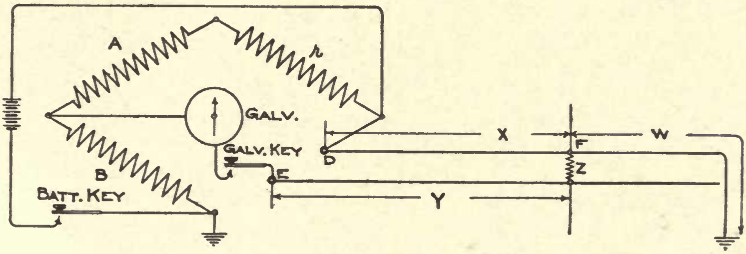

FIG. 262. — Connection for Second Measurement of Variable-resistance Crosses.

$$\frac{A + r}{B} = \frac{X}{W}, \quad \ldots\ldots\ldots \quad (38)$$

and by substituting the value of W as obtained from (37), and solving,

$$X = \frac{(A + r)\,R}{A + B + r}. \quad \ldots\ldots\ldots \quad (39)$$

This is the resistance to the fault, from which the distance is obtained in the usual manner. In order to get a close balance, where Y and Z are of considerable resistance, it is sometimes necessary to use a higher voltage than usual.

In the tests described thus far, nothing has been said regarding the location of open conductors or breaks. In describing the tests for this purpose, only those faults in which the broken ends are insulated from the ground or other wires will be considered, as all others can be located by the methods already given. Faults of this class cannot be located as a whole with the same accuracy as grounds or crosses; but the usual limits of accuracy are sufficient for lines in cable, and of some help in the case of open wires.

The theory is briefly as follows: Referring to Fig. 263, let the potential of point E be represented by V_1, and that of H by V_3. Then when a balance is reached, *i.e.*, when no current flows through the galvanometer on the make and break of the battery key, the potential of points D and F must be equal, and may be represented by V_2. Therefore, if Q_1 and Q_2 represent the quantities of electricity flowing into the condensers of capacities C_1 and C_2, through the resistances A and B, respectively, it follows, since C_1 and C_2 are charged to the same potential $(V_3 - V_2)$, that

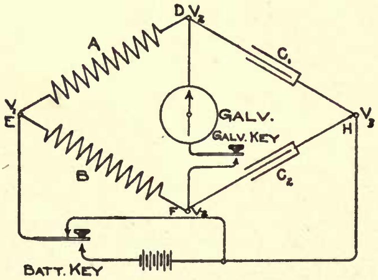

FIG. 263. — Theoretical Connection for Capacity Test.

$$Q_1 = C_1 (V_3 - V_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

and

$$Q_2 = C_2 (V_3 - V_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

Dividing equation (40) by (41) we have

$$\frac{Q_1}{Q_2} = \frac{C_1}{C_2} \cdot \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

But when a condenser is charged through a resistance from a source of constant E.M.F., or when it is afterward discharged through a resistance, the instantaneous value of the current flowing is

$$i = \frac{Q}{RC} \; {}^{-\frac{t}{RC}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

where Q is the final charge, or the initial charge, as the case may be, and R is the resistance, C the capacity and t the time from the moment of commencing the charge or discharge. But $Q = CE$ and so (43) becomes

$$i = \frac{E}{R}\epsilon^{-\frac{t}{RC}}, \quad . \; . \; . \; . \; . \; . \; . \; . \quad (44)$$

and the fall of potential through the resistance at any instant is

$$Ri = E\epsilon^{-\frac{t}{RC}}. \quad . \; . \; . \; . \; . \; . \; . \; . \quad (45)$$

But in Fig. 263, if no current flows through the galvanometer, the potentials $(V_1 - V_2)$, or the drop through A and B respectively, must be alike at any instant. But it is evident that such equality, referring to (45), depends upon the exponential term and RC must be the same in each case. Therefore

$$AC_1 = BC_2, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (46)$$

or

$$\frac{C_1}{C_2} = \frac{B}{A}, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (47)$$

which supplies the means of comparing one capacity with another, or with a known standard.

Now if it is desired to locate a break in a wire, the bridge should be connected as shown in Fig. 264. A and B in this figure represent the two resistance arms shown in Fig. 262, and at least one of these must be adjusted in order to obtain a balance. If desired, two resistance boxes may be used in place of the bridge. Then with the connections set up as shown in the circuit, Fig. 264, the far end of the faulty wire should be connected to a good wire of the same size, and the resistances A and B adjusted so that when the key K is operated and released, the galvanometer needle will not be deflected. A balance of this kind will indicate that the potentials at D and E are equal. In this

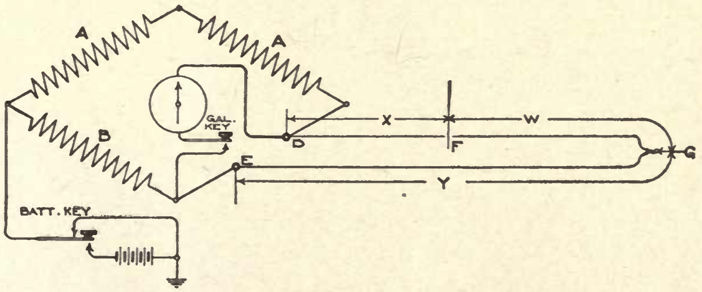

FIG. 264. — Connection for Locating Break in Line Wire by Capacity Test.

test the line wire DF forms one plate of the condenser and the earth the other, while the wire EGF is one plate and the earth the other of the second condenser. Then since the capacity of a wire is proportional to its length,

$$\frac{A}{B} = \frac{Y + W}{X},$$

and since

$$W = Y - X,$$

then

$$X = \frac{2\,BY}{A + B},$$

in which X and Y may be expressed in miles or feet as desired. Then if the length of the wire Y be substituted in the above formula, one will have the distance to the fault in feet or miles according to the units substituted.

In making the above test, it may be convenient to use a telephone receiver in the place of the galvanometer, and a high-frequency interrupter instead of the key; before a balance is reached, sufficient current will flow through the receiver to produce an audible sound.

The measurement of insulation resistance at periodic intervals is very essential in proper maintenance of toll lines. The voltmeter method is simple and rapid, and very generally used. It requires simply a battery, of perhaps 100 cells, and a voltmeter. Let E be the battery voltage, V the reading of the voltmeter, r the resistance of the voltmeter and l the length of the line, when the voltmeter is connected in series with the battery to line, the far end being open, and the other side of the battery grounded. Then the insulation resistance in ohms, per mile of line, is

$$R = lr\left(\frac{E}{V} - 1\right).$$

This method is quite satisfactory unless the line is very long or the insulation resistance is very low, or both. For such cases a method has been given by Mr. F. F. Fowle,[1] which requires the same apparatus, but one additional reading. The first reading is taken as before, with the far end of the line open. The second reading is taken with the same connections, except that the far end of the line is connected directly to ground. Let the second reading of the volt-

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[1] "The Measurement of Distributed Leakage on Transmission Lines"; *Electrical World*, Feb. 6, 1904.

meter be V' and in this case let r' be the line resistance per mile. Then the true insulation resistance per mile is

$$R = \frac{r^2}{r'}\left(\frac{E}{V} - 1\right)\left(\frac{E}{V'} - 1\right).$$

This method should be used when the insulation is low, if accurate results are desired. In many cases the voltmeter readings will not be alike if the battery is reversed and a check reading taken; in such cases the average reading should be used, and as a rule this procedure should be followed.

In dry clear weather a line in good physical condition ought to measure at least ten megohms per mile, but during a heavy rainfall it may diminish to a fraction of a megohm per mile. The minimum value depends on the type of insulator employed, the number per mile and the amount of dirt and soot normally present in the atmosphere. An average minimum of one-quarter of a megohm per mile is as low as the insulation ought to fall and a higher value should be obtained if possible. Careful attention to maintenance is most essential in securing high insulation, especially in the matter of trimming foliage and replacing broken insulators.

Regarding the last classification of troubles, *i.e.*, foreign currents, as given in the table, these can sometimes be detected by bridging a suitable current detector across the line, or from each line wire to ground, on which this trouble exists. If the trouble arises from a cross with a direct-current source, it can be easily verified by means of a direct-current voltmeter, or an alternating-current instrument when the source is alternating. The only method of locating this trouble, after it has been positively identified, is to inspect the line. In the case of induced currents from foreign sources, the best remedy is always to relocate the telephone line beyond the zone of influence. This is not always necessary, however, and the usual remedies have been discussed in Chapter XIX.

It should be noted that loaded circuits contain an additional element which must be considered in all resistance measurements. Each loading coil introduces in the circuit a certain definite resistance, usually 1.25 ohms, and unless this is accounted for in the final calculation, the result will be in error. It is necessary to determine, from the known spacing of the coils, how much resistance each coil adds per mile of wire, which should be added to the wire resistance per mile.

CHAPTER XXI

TOLL-LINE MAINTENANCE

THE design and initial installation of a toll line is a problem that requires a high class of engineering skill. Likewise, the task of keeping the line in good working condition after it has been completed is an undertaking that requires not only reasoning ability and careful observation, but also a knowledge of working conditions, which can be attained only by practical experience. The importance of maintenance in its relation to good service can hardly be underestimated. The form of organization required is simple, but essential. The lines are divided into sections and one or more sections assigned to a resident lineman, who is made responsible for the condition of his territory. His work consists of clearing line trouble and making all ordinary repairs; he is also required to make periodical inspections, which ought not to be more than three months apart. The linemen are ordinarily under the authority of the wire chief, who directs all of their work.

In order that the maintenance may be systematized, each wire chief should be provided with a complete record of every line in his territory. This record should cover the kind and gauge of the wire, the pin number, test poles and test stations to the limits of the territory. There are various methods of keeping such records. One of the most satisfactory, where many lines are to be considered, is by means of card files. In this case, a card file is prepared for each route, giving the position of each wire on every pole and the corresponding jacks at the test stations. While this appears cumbersome at first sight, it is not so in fact and the value of the record amply repays its cost. The first essential is a printed card, showing the requisite number — or better, the ultimate number — of cross-arms, with sufficient room for making any desired notations. In Fig. 265 is shown such a card for a four-arm pole line. It will be noted that all the information needed by the wire chief is given, including the circuit number, pin number and the gauge and resistance of the wire from the wire chief's test board to the pole in question. A card of this kind is filled out for each pole at which any change in the arrangement of the wires takes place. For example, suppose that one card shows pole No. 13,340 and the next card in the file is 13,373. This would indicate that all intervening poles are duplicates of No. 13,340 in so far as the arrangement of the line wires is concerned, and that at pole No. 13,373, some change has taken place which can be readily observed by comparing the cards. In Fig. 266 is shown a card which indicates a method

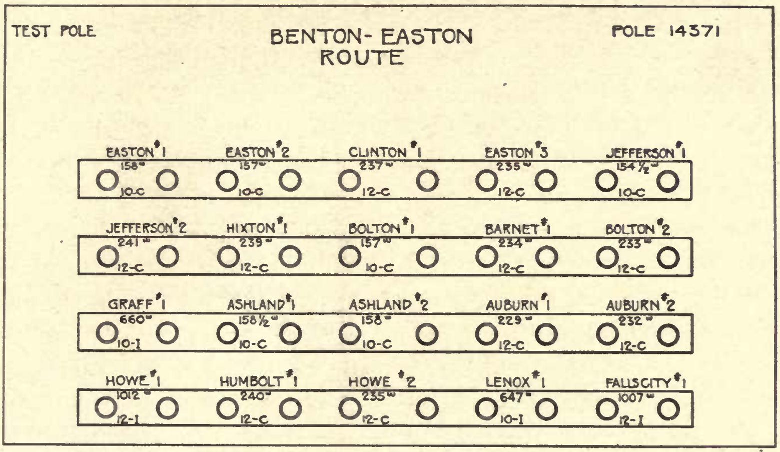

FIG. 265. — Form of Pole-line Record.

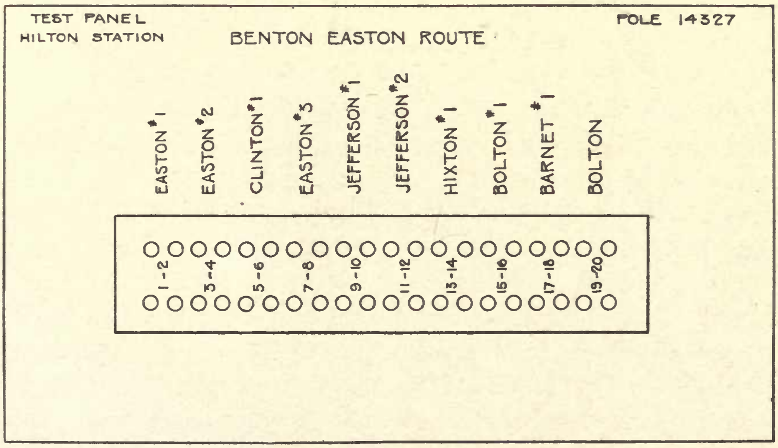

FIG. 266. — Form of Test-panel Record.

of keeping test panel records. These cards should be filed in their proper places, according to location, among the pole-line cards.

When a record of each route is kept in the above form, the wire chief has at hand all of the desired information pertaining to any line; and consequently, when a lineman calls in and reports that he is at a certain pole number, the wire chief can immediately turn to the card for this particular pole and obtain any necessary information. Each lineman's station should be provided with a test panel, of the type described fully in Chapter XVI. This panel should be located as near the center of the section as convenient, and is often placed in the local exchange, or sometimes in the lineman's home.

The location and number of these testing stations on a toll route depends, for the most part, on physical and climatic conditions. For example, in the southwestern part of the country where the climate is dry and warm throughout the entire year and storms are of infrequent occurrence, the facilities for testing need not be very elaborate. The testing stations can be safely located at long intervals and linemen's sections can correspond. In regions such as the middle and northern states, where opposite conditions prevail, the testing stations must be located correspondingly closer together. Under the latter conditions, maintenance is more difficult, particularly in mountainous regions. Under average conditions, each lineman's section should be about 75 to 100 miles long, with the station as near the center as possible, in order to minimize the distance traveled in clearing trouble. The transportation facilities naturally play an important part in determining the sections.

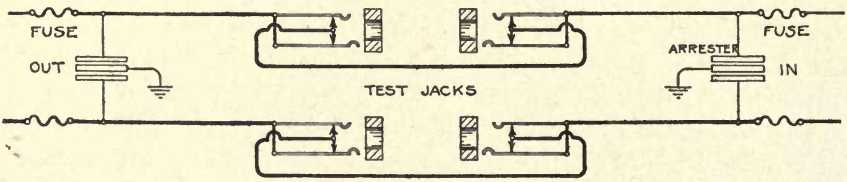

FIG. 267. — Test-panel Wiring.

The method of wiring the lines through the test panels is shown in Fig. 267. The panels should be so located that as little wire as possible will be needed in looping the lines through them. In making the connections from the line to the jacks, rubber-covered cable or a good grade of twisted pair wire, whose gauge is not smaller than No. 16

B. & S., should be used. The lines, both " in " and " out," should pass through suitable fuses, preferably of the tubular type, and carbon block arresters. Each test station should be provided with a standard telephone set, normally connected to some particular line by means of a key or a double-pole, double-throw knife switch. The method of wiring this equipment is given in Fig. 268. This shows the key in its normal position with the telephone set connected to the line. It will be noted, however, that by throwing the key to the opposite position, the twin plug will be connected to the set, which permits connection with any line in the panel. The lineman's set is normally connected to a toll line, which is in service; in order that the wire chief may call him, a code signal is prearranged.

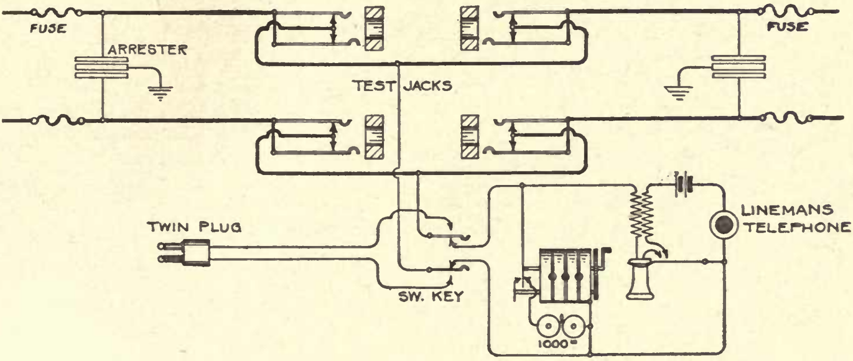

FIG. 268. — Wiring of Lineman's Telephone Set at Test Station.

The test station should also be provided with patching cords, plugs and a ground connection for making the usual simple tests and for patching lines in emergencies. Each of the patching cords consists of a short cord with a single-conductor plug attached to each end, and is used to make up clear circuits when part of the lines are in trouble. For instance, all the circuits between two particular points might be in trouble, while it would still be possible to make up a through circuit by patching the clear portions together at the test stations. This is always done, if possible, in the case of general trouble; the patches are always made under the order of the wire chief. The diagram in Fig. 269 gives a concrete example of what may be accomplished by patching. The crosses in the figure represent the locations of the faults; the rectangles *A* and *F* at each end represent the toll stations at which wire-chief's test boards are located, and the rectangles

B–C–D–E, the linemen's test stations. It will be observed that five out of six lines are in trouble at different points between *A* and *F*, but by means of patches at the several linemen's stations, all except one of the lines are made serviceable.

In case the lines are operated on a simplex or composite basis, a morse schedule or layout, with which each lineman should be thoroughly familiar, must be maintained. This schedule gives the hours and circuits used for these purposes, so that the lineman will not cut in with his telephone or open any of these circuits at the test panel, as this would open the morse. This schedule should read, for example, as follows: 1 and 2 are composited; 3 and 4, 5 and 6 are phantomed; 7 and 8 are simplexed; 9 and 10 are straight, etc. The lineman should be acquainted with the hours during which this service is maintained.

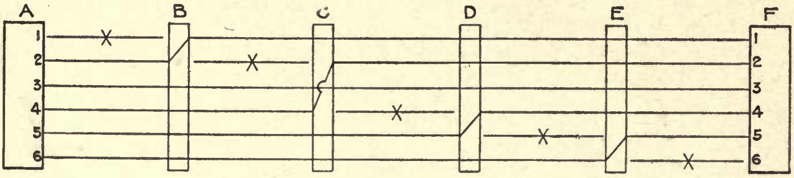

FIG. 269. — Illustration of the Use of Patches.

The duties of a lineman are more than those of a mere trouble-hunter, a fact that may well be emphasized. He ought to inspect his line periodically and at every available opportunity, making all light repairs as he proceeds; there are frequent opportunities for this in connection with his trips to clear line troubles. The replacing of occasional poles is work which he can readily handle with a few men hired as needed. He can also replace the cross-arms, when such general replacement becomes necessary. The heavy replacement work on the pole line itself is usually assigned to the construction department.

The company's right-of-way privileges should also be thoroughly understood by the lineman, so that he may be governed accordingly in his relations with the owners of abutting property. This applies often to the matter of trimming rights. The lineman may act in the capacity of a right-of-way agent in minor matters.

CHAPTER XXII

THE TELEPHONE REPEATER

TELEPHONE currents in long-toll circuits become very much attenuated by the effects of resistance, leakage and capacity, as already shown. The rate of attenuation can be reduced materially by means of artificial inductance loading, but even this is expensive, comparatively, so that a device for relaying these weak currents and increasing their energy is very desirable if it can be obtained. There has existed a demand for a successful two-way telephone relay or repeater ever since the advent of long-distance telephony and, as a consequence, the experimental and research work in this field has been incessant. The various ideas and schemes that have been developed are so numerous that a description of all, or even a few of them, is beyond the present scope. Then again, but one of all of these devices is used commercially, so that the study of the others possesses only a scientific interest and would be of value merely in tracing the gradual evolution from the simple one-way experimental repeater to the practical Shreeve two-way repeater now in use.

The steps in this evolution may be readily outlined, however, without giving a detailed description or making direct reference to the many experimental repeaters that have been tried. It is in this manner that the development will be briefly traced, in order to bring out some of the peculiar and interesting difficulties encountered.

The first attempts in the construction of a telephone repeater were guided, in a measure, by what seems an analogous case, the telegraph repeater. This, however, was a fallacious conception, inasmuch as the telegraph repeater responds merely to single impulses; whereas a telephone repeater must reproduce the entire frequency range of the human voice. In other words, it must deal with very complex alternating currents.

[1] The early inventors who attacked the problem naturally thought of the simple device of applying a microphonic contact immediately to the vibrating diaphragm of a telephone, hoping to repeat the almost infinitesimal vibrations of this dia-

[1] Abstract from an article by Professor John Trowbridge in the *Philosophical Magazine.*

phragm, and to give them an increase of energy by a local battery. This attempt is an application, pure and simple, of the principle of the telegraph relay and, therefore, marks no progress in the art; for it was not new in principle and furthermore did not work. The application of the microphonic contact loaded the diaphragm at its most sensitive point and thus prevented the vibrations which one sought to repeat; moreover, the vibrations of the diaphragm are too minute to cause a sufficient agitation of the microphonic contact.

The next step, in the mind of the inventor, was to endeavor to increase the vibrations of the center of the diaphragm by a lever. This arrangement was found to be inoperative, for the short arm of the lever exercised a prejudicial pressure on the vibrating diaphragm; moreover, the fundamental vibrations of the lever were superposed on the vibrations of the diaphragm, thus completely confusing the speech.

It must be remembered that the telephone is, after all, an imperfect instrument and its wonderful adaptiveness is greatly aided by the human brain, which catches at the connection of thought. This can be seen if individual words are transmitted without context. Moreover, the amount of energy utilized in the telephone is extremely small; most of the energy of the currents which actuate it and transmit speech is dissipated in heat. Some observers think that less than one per cent of the energy of such current is transformed into sound waves. We see, therefore, that the problem of the telephone relay calls for all our electrical and mechanical aids to preserve and transmit this small percentage.

Since mechanical enlargement of the vibration of the telephonic diaphragm by levers is out of the question, the next more promising step seems to be the bringing in, so to speak, of electromagnetic energy. This method gets rid of mechanical pressure on the vibrating diaphragm of the telephone and substitutes an electric pressure without any visible connections between the circuits. This method also is ineffective. It has, however, a certain analogy to another and more successful attempt to utilize an invisible and intangible magnetic effect without bringing a mechanical pressure on the telephonic diaphragm; this method consists in causing the telephone currents to disturb a piece of iron, a balance magnet, or a suspended coil in a strong magnetic field such as is found at the center of an electromagnet or between the poles of a strong permanent magnet.

The principle of this method is that of the siphon recorder, the invention of Lord Kelvin, which is used on ocean cables. Since the current on the cable is very feeble, and cannot work ordinary telegraph instruments, some method must be used to magnify or record the signals. The method adopted by Lord Kelvin was that of a delicately suspended coil so placed between the poles of a powerful magnet that, when the feeble currents passed through this coil, it oscillated; for the feeble currents animated the coil making it an electromagnet, the poles of which sought the poles of the powerful stationary magnet. Thus a very feeble current could be detected by the powerful magnetic influence to which it was subjected. Here we have a mechanical movement of a vibrating system, produced without the intermediation of visible connecting parts. The same principle has been adopted in many forms of instruments for detecting and measuring electrical currents both in laboratories and in commercial electrical installations. It has, therefore, occurred to many that by the use of this principle of magnifying the vibrations of moving parts by the reaction between the feeble currents in such parts and the environment about these parts, one should be able to strengthen vibrations. The mechanical difficulties, however, are very great if one endeavors to apply this principle to the problem of the telephone relay. A delicate suspension, such as that used in the siphon recorder or the D'Arsonval galvanometer, is out of the question; and a rigid suspension prevents the turning movement, or the seeking of the poles of the powerful magnet by the coil which conveys the feeble currents. A certain measure of success, however, can be obtained by careful adjustments in the laboratory, but the utilization of the turning movement of a coil in a magnetic field has not yet proved of commercial use in telephony.

We are apparently brought back to some modification of the simple principle of the disturbance of a powerful magnetic field by the effect of feeble currents circulating around coils placed in such fields. Suppose, for instance, that we have a hollow electromagnet with another electromagnet suspended above it, the iron core of the suspended magnet forming a part of the core of the stationary and more powerful magnet. The system, evidently, can be balanced in various ways; for instance, the suspended magnetic core can be maintained in a definite position by connection with a telephone diaphragm, and when a feeble current circulates through the coil of such a suspended electromagnet, its position with respect to the stationary coil will change. Instead of the diaphragm of a telephone, it is evident that a diaphragm connected to a microphonic contact may be employed. This idea can be found in the efforts of many inventors to construct a relay. Professor Dolbear has described a telephone which works upon this principle; a non-magnetic diaphragm placed close to the pole of a permanent magnet carries a small electromagnet which is balanced under the influence of the elasticity of the diaphragm and the magnetism of the permanent magnet. When the voice causes the diaphragm to vibrate, the movements of the electromagnet disturb the magnetic field, producing feeble currents of induction in the moving coil, which transmits speech to a similar piece of apparatus. If this similar piece of apparatus had been employed to modify a microphonic contact, it would have been the precursor of many subsequent inventions.

Instead, therefore, of the turning or torsional effect relied upon to actuate Lord Kelvin's siphon recorder — called " siphon " because a siphonic pen records the oscillations of the vibrating coil — we have efforts to utilize the to-and-fro thrust of a vibrating core of an electromagnet, whose position in a powerful field is modified by the strength of the feeble currents which circulate around its core.

At first sight, it would seem that the inertia of the suspended electromagnet, or that of its core or plunger if the coil of the electromagnet is fixed, would be so great that the motion of the microphonic contacts would be seriously impeded. It is true that the weight of the vibrating parts in this form of relay must be small and there must not be any subsidiary vibrations of the moving parts which might be superposed upon the vibrations due to the telephonic currents. It is evident that such subsidiary vibrations can arise if the moving parts are long and of considerable size. With a loaded microphonic contact we obtain either feeble effects, or roaring sounds resembling in effect the results obtainable if the membrane of the ear is loaded by an obstruction.

In this form of telephone relay, therefore, we have a microphonic contact connected with what may be called an iron plunger, whose position in a magnetic field is modified by changes in its magnetism produced by feeble telephonic currents. The only mechanical connection is that of the moving plunger with the microphonic contact.

The magnetic portion of a relay embodying these ideas can be suitably constructed so as to perform its part with a commercial degree of perfection. The principal imperfections of the relay arise from its microphonic element. Among such imperfections the most notable one is the roaring of the microphone when a strong battery is used to get the greatest degree of sensitiveness from it. This noise, which arises in great part from crepitations produced by heat, can completely overpower telephonic transmission of speech. This crepitation is greatly enhanced by the direct connection of the plunger or moving electromagnetic coil with the microphonic contact; for the movements in the magnetic field and the crepitation in the microphone get into synchronism, mutually aiding each other. This mutual action is one of the greatest barriers to the perfection of a telephone relay in which a close connection exists between the parts moving in the magnetic field and the microphonic contacts. To overcome this defect would be a great service to the art of telephony.

The design of the commercial repeater used by the American Telephone and Telegraph Company, the invention of Mr. H. E. Shreeve, is a development of the type in which a powerful stationary field and a movable coil are employed. Particular attention has been given to the radiation of the heat generated, so that continuous operation is possible. The best understanding of this apparatus can be obtained from the specification of Mr. Shreeve's fundamental patent, which is quoted in what follows.

"In carrying out my invention I employ and adapt for connection at any point between transmitting and receiving stations of a telephone-circuit or series or sequence of circuits an organization comprising a variable receiving-magnet responsive to the talking-currents of such transmitting-station and a variable-resistance medium mounted in operative relation to the said receiving-magnet to be acted upon thereby and arranged to forward the talking-currents with renewed energy and without impairment of their quality characteristics to such receiving-station for the more perfect operation of the receiving instrument there.

In the development of this invention it has been found important (keeping in mind the character, delicacy, and minuteness of the forces engaged, the smallness of the motion, and the functions to be exercised) that the inertia of the moving parts shall be as small as possible, that the magnetizing and magnetization-varying forces shall be so organized and disposed that the maximum effect of the latter upon the former shall occur at the strongest part of the common field, that the maximum effect of both may be concentrated directly upon the active or movable member of the transmitting medium, and preferably upon the most sensitively mobile part or point thereof, and that provision shall be made to facilitate the expeditious dissipation of the heat developed in and by the operation of the transmitting medium. These principles are exemplified by the present invention and in its receiving and transmitting elements, which are closely associated in a single instrument.

The receiving factor comprises a magnet constituting the required initial magnetic field, a magnetization-varying coil to be connected with the main circuit of the original transmitter to receive the talking-current thereof and encompassing the end of the magnet, which thus serves as a fixed core or pole-piece entering said coil to have its magnetization varied thereby, and a short and light piece of iron which forms a movable pole-piece whose end is closely adjacent to that of the fixed pole-piece in the magnetic field. The transmitting factor closely confronting the said coil is a variable-resistance microphone and has a movable contact or electrode, which instead of being actuated by a vibratory diaphragm in the usual manner is attached directly to the light movable pole-piece of the receiving part of the apparatus, which thus constitutes a direct magnetic connection between the receiving-magnet and the transmitting medium, and by this arrangement the diaphragm is dispensed with, the inertia of the moving parts reduced to a minimum, and the requisite motion imparted to the movable electrode of the transmitting medium directly from the variable field and preferably from the center of the varying-coil, and therefore from the most effective part of said field.

The magnet establishing the initial field may be either an electromagnet of any construction or form excited by a separate magnetizing-coil in a special local circuit or a permanent magnet such as that of the ordinary and standard telephone-receiver. An electromagnet is, however, to be preferred for this purpose, since in association with it an adjustable resistance may be included in its local circuit to regulate the strength of its current, and thereby the strength of the magnet, and thus of the initial field, to any desired degree. Furthermore, I find it of distinct advantage to provide that the electromagnet shall be of tubular form, having an iron shell, with the magnetizing and varying coils arranged concentrically therein, to surround the fixed core or pole-piece, the said magnetizing-coil being preferably outermost and the iron shell or casing arranged to entirely inclose both coils except at their front center, where an opening or perforation is provided to receive the movable pole-piece attached to the transmitter-electrode, which, passing through said opening into the varying-coil, constitutes a portion of the magnetic circuit of the receiving-magnet. For the avoidance of eddy-currents the iron shell may be slit longitudinally down one side and to the center of its front plate.

The variable-resistance-transmitting medium is of the " Hunnings " and " solid-back " types, wherein a mass of granular carbon is held inclosed in a flat chamber or hollow button between rigid and vibratory conducting-disks (usually of carbon), which respectively constitute contact members or electrodes, one of which is vibratory or movable, the mechanical connection of the latter with the light movable pole-piece of the receiving-magnet being made at its center, that being the point or part most sensitive and most readily mobile and having the widest range of motion.

By inclosing the working parts of the apparatus and particularly the transmitting element thereof in a metal casing possessing, or in connection with, considerable mass and radiating-surface and with which such working parts are in heat-conducting relation an effectual means is provided for the prompt and continuous removal and dissipation of the heat, which during the operation of the

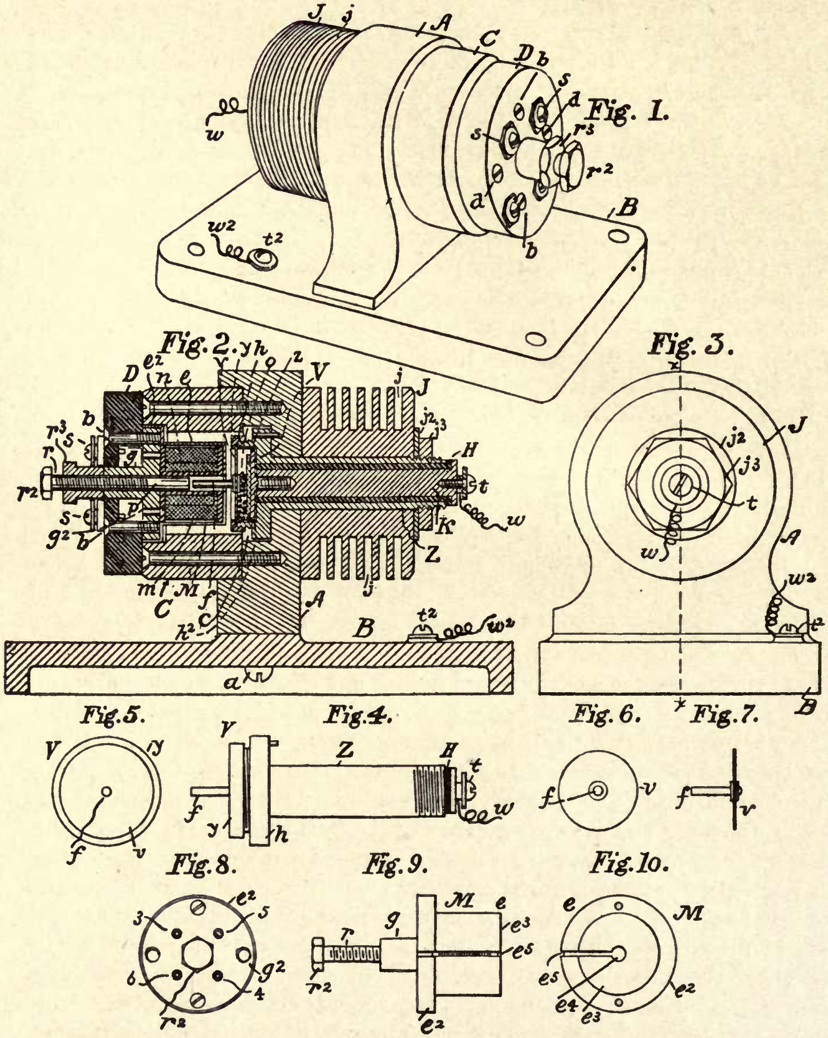

FIG. 270. — Construction of Shreeve Repeater.

instrument is generated in the transmitter-button by the passage of the local-circuit current through the variable-resistance material and which if retained and permitted to accumulate acts to deprive the carbon granules of their microphonic property, and thus seriously impairs the operation of the transmitting medium.

In the drawings accompanying this specification, Fig. 1 is a perspective view showing the external appearance of a form of apparatus embodying the invention which has been made and successfully used. Fig. 2 is a vertical longitudinal section of Fig. 1, taken on the line *x x* of Fig. 3, showing the preferred construction and arrangement of the parts. Fig. 3 is an end view of the apparatus shown by Figs. 1 and 2. Fig. 4 illustrates the mounting of the transmitting medium with the movable core of the receiving-magnet attached to its movable electrode, Figs. 5, 6, and 7 showing, respectively, the end view of the said medium and its mounting and separate side and front views of the said electrode and the core attached thereto. Figs. 8, 9, and 10 show in detail rear, side, and front views of the tubular magnet preferably employed in the receiving medium. Fig. 11 is a diagram showing the electrical connections of the renewer or reinforcing apparatus when associated with a telephone-circuit at an intermediate point thereof. Fig. 12 illustrates a modified arrangement for establishing the initial field of the receiving medium and an alternative circuit arrangement for the apparatus as a whole. Fig. 13 illustrates still another mode of constituting the initial magnetic field of force, and Fig. 14 is a diagram of the manner of supplying the initial field for the form of electromagnet illustrated by Figs. 1 and 2.

Referring to the drawings, and for the present more particularly to Figs. 1 to 10 and 14, the working parts are inclosed in a cylindrical metal casing *C*, screwed or bolted to a chambered and centrally-bored metal standard *A*, which in turn is mounted upon a metallic base *B*, to which it is secured in any desired way, as by screws *a*, which pass through said base and into the lower edge of the standard. The outer end of the casing-cylinder *C* is closed by a disk *D*, of hard rubber or like material, secured to its edge by screws *d*. *M* is the variable magnet constituting the receiving factor or medium of the instrument, and *V* the variable-resistance-transmitting medium. The former (illustrated by Figs. 2, 8, 9, 10, and 14) is in this instance an electromagnet of the tubular or iron-clad type, having a fixed iron core or pole-piece *p*, a movable iron pole-piece *f*, an inclosing iron shell *e*, a magnetizing or exciting coil *m*, and a magnetization-varying coil *n*. It is attached as a whole by screws *b* to the insulating-disk *D*, which has binding-screws *s* to serve as terminals for the said coils and is centrally perforated to receive a threaded iron socket *g*, through which passes the shank *r* of the fixed core *p*. The magnetizing-coil *m* and varying-coil *n* are concentrically disposed within the iron shell *e*, the said magnetizing-coil being preferably outermost. The shell itself is closed in front by the plate e^3, which, however, may, as shown, be an extension of the substance of the shell spun or struck up from the cylindrical part thereof and has for a heel-plate the thick disk-formed base g^2 of the socket *g*, being provided rearwardly with a flange e^2, overlapping and closely clasping the edge of said base-plate, so that both coils are entirely inclosed by the said shell with the exceptions of a small opening or aperture e^4 at the center of the front plate, forming a passage for the movable pole-piece *f*, and a longitudinal slit e^5, extending from the said aperture and down the side of the shell to prevent the development and circulation of eddy-currents and consequent waste of energy. The fixed core *p* may, as shown, be fitted at its outer end with a bolt-head r^2 and jam-nut r^3 or other means for turning it and holding it in place, and its shank *r* is threaded to correspond with the internal thread of its socket *g*. Entering the coils through said socket, it passes to or nearly to the center thereof, and being magnetized by the coil *m*, which receives energy from the battery *S* in the local circuit 7, Fig. 14, it acts to establish the initial magnetic field. *R* is a rheostat or adjustable resistance connected in the local circuit 7 to regulate the strength of the magnetizing-current, and by thus providing the receiving medium of the apparatus with an electromagnet separately excited by a special source in local circuit and with such means of current regulation the magnet may readily be regulated to produce the desired power. The movable iron core or pole-piece *f* is a short piece of small-sized iron rod and is attached at one end to a movable part of the associated transmitting medium in a manner presently to be explained, and being thereby elastically supported it passes loosely through the aperture e^4 and, as best shown in Fig. 2, into the forward end of the inclosed coils *m* and *n*, extending to a point about the center thereof, so that its inner end nearly reaches but does not touch that of the fixed core *p* in the concentrated field at the center of said coils. The distance between the ends of the fixed and movable cores may, it is evident, be accurately adjusted by turning the former in its threaded socket *g*. The magnetic system of the receiving agency when constructed as shown and described constitutes, it will be seen, an approximately complete magnetic circuit having fixed and movable or vibratory pole-pieces at the center of exciting and varying coils, and thus at the point of highest magnetizing power and at the most effective part of the magnetization-varying field and whose only substantial gap in the continuity of its iron is that which is formed by the space between said poles. The magnetization-varying coil *n* is designed to be connected with the main circuit or circuit-section *E* and to be excited by the voice-currents flowing therein and proceeding from the original transmitting-station of such circuit. It encompasses both pole-pieces and is adapted to vary the initial magnetization and mutual attraction of both, and consequently to throw the movable core or pole-piece into vibrations corresponding to such attraction variations and to the electrical variations or voice-currents of the circuit. The ends of the windings of the coils *m* and *n* pass through insulated apertures 3, 4, 5, and 6 in the socket-plate g^2 and then to the terminal binding-screws *s* on the exterior of the non-conducting disk *D*, whereby they may be attached to the local and main circuit conductors, respectively. The transmitting medium *V*, closely confronting the forward end of the magnet *M*, is suitably mounted within the casing *C*, the metal standard *A*, which closes one end of said casing, being recessed at *c* for its reception. It mainly consists of a metal chamber or hollow button *h*, in type and form substantially identical with that employed in standard telephone-transmitters having a non-conducting internal periphery h^2 and forward and back contact members or electrodes *v* and *z*, with granular carbon *o* inclosed between them. The electrodes are insulated from each other at their edges by the said peripheral non-conductor, and the metal-containing case has an elongated stud or sleeve *Z*, passing through the central bore of the standard *A* to form its support and containing a rod *k*, insulated by a non-conducting bushing *H* and terminating externally in a binding-screw connection *t*. The back electrode *z* is a carbon plate fixed to the end within the chamber *h* of the insulated rod *k* and is itself insulated from the metal case or its attached stud. Its connection with the primary circuit

N of the transmitting medium is formed through the said insulated rod k and by means of the conductor w, attached thereto. The forward and movable electrode v, also preferably carbon, is a thin plate held in place to close the chamber h on its side toward the magnet by the ordinary clamping-ring y, which screws over the threaded exterior of the said chamber h. This electrode having considerable elasticity is readily vibratory and is in electrical connection with the said primary circuit N through the metal chamber-casing, the stud Z, the standard A, and the base B, to which the conductor w^2 of said circuit is attached at the screw t^2. As indicated by the diagram, Fig. 11, the local circuit N includes the source of renewed energy S^2 and the primary winding of the induction coil or coils I. The movable electrode v is rigidly attached at its center to the outer end of the movable pole-piece f, and thus forms the external elastic support of the said pole-piece and receives motion therefrom without the intervention of any diaphragm. In an apparatus of this class sensitiveness to slight moving forces and celerity of action is more important than a relatively wide range of motion, such as would be produced by a vibratory diaphragm or armature interposed between the receiving and transmitting media, and I have found that by dispensing with the diaphragm and by securing the light movable pole-piece f of the magnetic system directly to the center of the light and thin movable electrode v of the transmitting medium the requisite sensitiveness and celerity of action is attained, while, moreover, the actuating forces being imparted to the pole-piece f, and as a consequence to the movable electrode, directly from the varying field are enabled to exercise maximum effect. J is a radiating block or mounting centrally bored to slide over the projecting end of the elongated stud Z of the transmitter-case, having considerable mass and scored or ridged, as at j, to increase its surface. It is held in place upon said stud by the washer j^2 and nut j^3, and being in metallic contact with the said stud and also with the heavy metal standard A, base B, and casing C it coöperates with these parts to conduct away from the variable-resistance button the heat generated therein during operation and to dissipate the same by radiation.

In telephone current renewing and retransmitting apparatus constructed in accordance with the foregoing description and with which good practical results have been attained the magnetizing or local-circuit coil was formed of two hundred turns of No. 36 wire, while the main line or varying coil wound next to the cores consisted of fourteen hundred turns of No. 40 wire.

The current-renewing apparatus may be associated with telephone main circuits in various ways. One circuit arrangement with which it has been successfully connected and employed is that represented by Fig. 11 and so far as concerns its receiving factor alone by Fig. 14 also. In this arrangement the apparatus is shown as being placed at the middle of a long circuit and between the sections EE^2 thereof, so that it is adapted to be operated indifferently and reciprocally from either end of the line and to renew the transmission according to its direction from either section of the line to the other.

KK^2 represent keys or switches which when in the position shown maintain the direct connection of the circuit through the section E^3 thereof, the renewing or reinforcing apparatus being disconnected. In this position the circuit-conductor L is traceable between the section-conductors 20 and 22 by way of the restingcontacts 14 and 16 of keys *K* and K^2 and their uniting-conductor 21, while circuit conductor L^2 in like manner extends between its sections 23 and 25 through intermediate conductor 24 and its terminal contacts 15 and 17.

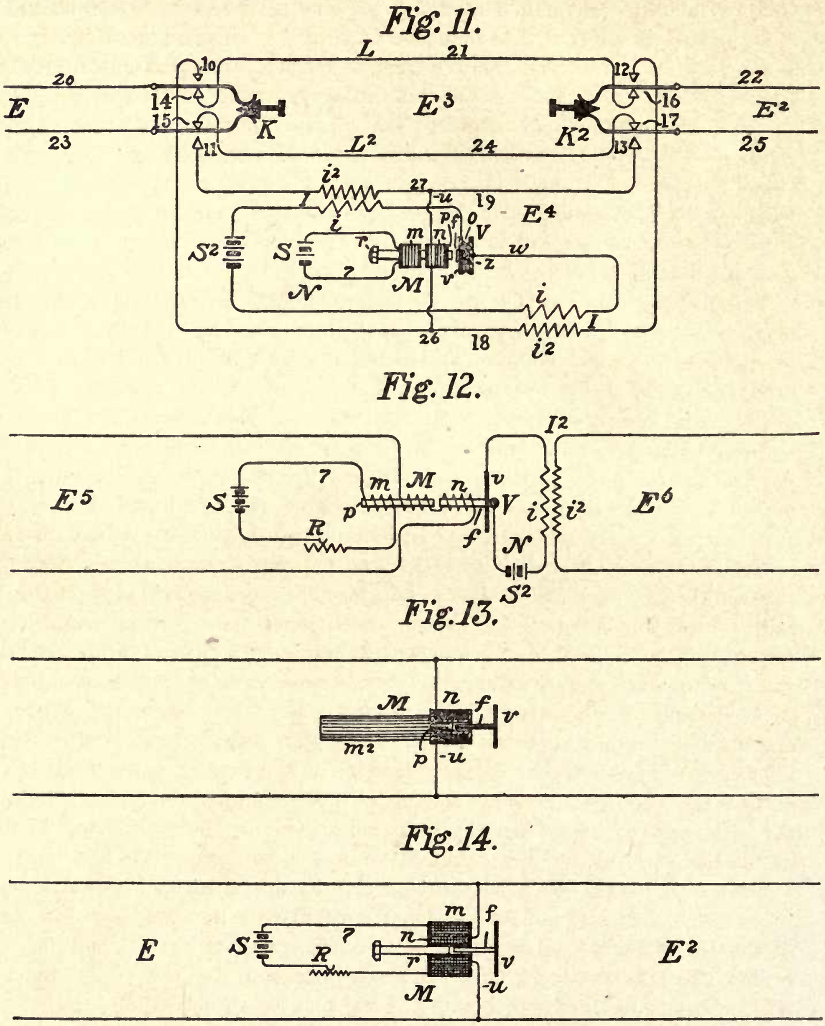

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

FIG. 271. — Circuits of Shreeve Repeater.

By moving the keys or switches *K* K^2 to their alternative position the conductors 20 23 of circuit-section *E* are transferred from contacts 14 15 to contacts 10 11 and the conductors 22 25 of section E^2 from contacts 16 17 to contacts 12 13, so that the intermediate section E^4 is substituted for E^3. The magnetization-varying coil *n* of the renewing-apparatus receiving-magnet is connected in a bridge *u* between points 26 27 of the main conductors 18 and 19 of the said intermediate section E^4 and is thus made common to both of the main sections EE^2 to be operated by the distant transmitter of either one — that is, of the terminal station of either section — according to the direction of transmission at any particular moment of time. The initial magnetic field of the receiving medium may be established by either one of the several plans indicated by Figs. 12, 13, or 14, respectively, but, as hereinbefore stated, preferably by that of Fig. 14. The transmitting medium (indicated conventionally) is included in the local circuit *N* and is adapted to have the resistance between its electrodes *v* and *z* varied by the strength variations of the magnet *M*, produced by the voice-currents in the varying-coil *n*. The primary circuit *N* also contains the primary windings *i* of induction-coils *I*, whose secondary windings i^2 are connected one on either side of the bridge *u* and in the conductors 18 19, respectively, so that one winding is in main section *E* and the other in main section E^2 of the through-circuit.

It is to be understood that the drawings represent the electrical arrangement only and that in practice a single primary winding and two secondaries may be wound over a single core and into a single induction-coil. A coil having a single primary winding of five hundred turns of No. 20 wire with a resistance of about one ohm and two secondaries wound in parallel of twelve hundred and fifty turns and thirty ohms resistance each of No. 29 wire has been found to answer well, as has also a varying-coil for the receiving-magnet formed of fourteen hundred turns of No. 40 wire having a resistance of about one hundred and thirty ohms.

If desired, the apparatus may be employed, as in Fig. 12, in enabling one line-circuit E^5 to retransmit over a second and entirely separate circuit E^6. Thus engaged the varying-coil *n* of the receiving factor or agency *M* is connected in the said transmitting-circuit E^5 and its transmitting medium *V* in the primary local circuit *N* of the battery S^2, together with the primary winding *i* of an induction-coil I^2, whose secondary winding i^2 is wholly connected in the second circuit E^6.

As hereinbefore indicated, while a compound magnet constructed as thus far described has certain advantages it is not essential, and other modes of constructing in accordance with the foregoing principles the magnet system, which constitutes the receiving and retransmitting part of the apparatus, and of producing the initial and varying fields may be adopted without any departure from the spirit of the main invention. For example, while the arrangement of the fixed and movable pole-pieces, which has been specifically described, has in practice been found convenient and effective and has particularly commended itself as being productive of highly-satisfactory results and average ordinary conditions it is evident that the relative length of the fixed and movable pole-pieces and their relation to one another and the varying-coil may be varied within limits of considerable width to suit varying conditions of service, provided always that the latter pole-piece shall in every case be in direct connection with the transmitting medium and that the two poles shall closely confront each other without contact, so that the attraction exercised by each upon the other may readily be varied by the operation of the varying-coil. Such modifications in construction and arrangement are illustrated in Figs. 12, 13, and 11. Fig. 12 illustrates a modification wherein the magnetizing-coil *m* is wound over the hinder part of the fixed core *p*, while the magnetization-varying coil *n* alone is, as in the forms, placed over the adjacent confronting poles of said core and the adjacent movable core *f*, the said poles thus, in this instance also, being close to one another in the center of the varying field. Fig. 13 illustrates another modification of this feature. Here the initial field of the magnetic system *M* is provided by a permanent magnet m^2, the fixed pole-piece *p* being secured thereto and being magnetized thereby in a well-understood manner. This arrangement requires one coil only — viz., the line or magnetization-varying coil *n*, which encompasses the confronting poles of the fixed and movable cores *p* and *f*, which approach one another at its center, or thereabout. In Fig. 11 the magnetic receiving medium is represented as having the fixed pole-piece *p* extended clear through the bridged varying-coil *n* and to a point flush with or a little beyond the forward end thereof, while the movable soft-iron pole-piece *f* is made very short, but is yet directly attached to and supported solely by the movable contact member of the transmitting member. It may here be mentioned that the said movable contact member or vibratory electrode should be very thin and elastic and that I have found a carbon disk about .01 of an inch thick to answer admirably and to be both strong and flexible. In all cases, however, the magnetic system *M* of the renewing apparatus may properly be regarded both as a receiving and a retransmitting medium, for by its varying-coil it receives and makes use of the voice-currents of the distant transmitter, and by its movable or vibratory pole-piece set in motion by said coil under the influence of such voice-currents it actuates the transmitting medium to bring a new source of energy into service."

This repeater has been used with fair success on the New York-Chicago circuits, situated at Pittsburg, approximately halfway between terminals. It is far from perfect, however, because the transmitting element is crowded to the limit of its capacity and severe heating is an unavoidable result. The efficiency also tends to fall rapidly after the repeater has been in service a short time. For this reason, these repeaters are usually mounted in pairs and connected to a double-throw switch, for alternate service.

INDEX

[The figures refer to page numbers.]

Jevkw
3.50 mvw