TEXT BOOK ON RADIO

By JAMES R. CAMERON

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By

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"Radio for Beginners," "Radio Dictionary," "Motors and Motor Generators," "Electricity for Projectionists," "Motion Picture Projection," "Pocket Reference Book for Projectionists," Etc.

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RADIO

To the oft asked question: "What is wireless and how is it possible for one to hear signs, speech or music from a source several miles away, without any apparent connection and certainly without any mechanical connection?" We are at first inclined to use the little boy's expression on seeing the giraffe at the circus for the first time—"There ain't no such animal," but today this answer would immediately be ridiculed by the vast army of radio fans throughout the country who daily "listen-in" to the numerous musical selections and speeches broad-casted from the various broadcasting stations.

If we stop for a moment and think back to our elementary teachings regarding the nature and transmission of sound and light, we find that much of the mystery of wireless becomes very much matter-of-fact. Sound is merely some material body in motion.

The vibrating of a piano or violin string or of the prongs of a tuning fork gives off a musical sound which can be heard by the human ear within a reasonable distance. We easily hear the strains of a brass band playing some few blocks away while seated at home with the doors and windows closed, the discharge of a big gun or an explosion (which is merely violent motion of matter) can be heard many miles away. When matter is set in motion it sets up a series of waves and it is on these waves that sound travels to our ears, the loudness or intensity of the sounds received by the ear depends upon the energy of the initial disturbance, and the distance the disturbance is from the ear.

The discharge of the big gun several miles away sets up a series of oscillations or waves in the ether, and these waves carry the sound of the explosion to us at the rate of 1090 feet per second. When these waves reach the drum of our ear they produce the sensation we call sound. Much the same thing happens in radio.

A series of waves are set in motion by the creating of a disturbance in the ether by the transmitting aerial. The greater the disturbance, the further the waves will travel. These waves are termed "electro-magnetic waves," and travel at the rate of 186,000 miles per second. These waves produce no sound to our ear on account of their very high frequency. It is to bring down this high frequency that the radio receiving set is necessary and a phone receiver employed to make the sounds audible.

In a broad sense, we claim that wireless telephony is a series of communications carried on between the broadcasting station and the receiving station through the medium of the ether. No one as yet has been able to tell us just what the nature of ether is, though we do know some medium exists throughout space which has the property of transmitting both light and electro-magnetic waves.

Perhaps it would be as well at this point for us to study the question of light waves, as both the light waves and electro-magnetic waves have much in common. For most purposes it is sufficiently accurate to take the velocity of light as 186,000 miles a second, (this is also the speed at which our electro-magnetic waves travel).

A usual hypothesis which was first completely formulated by the great Dutch physicist—Huygens (1629-1695)—regards light like sound as a form of wave motion. This hypothesis met at first with two very serious difficulties; in the first place, light, unlike sound, not only travels with practical readiness through the best vacuum which can be obtained with an air-pump, but it travels without any apparent difficulty through the great interstellar spaces, which are probably infinitely better vacua than can be obtained by artificial means.

If, therefore, light is a wave motion, it must be a wave motion of some medium which fills all space and yet which does not hinder the motion of the stars and planets. Huygens assumed such a medium to exist and called it "ether."

The second difficulty of the wave theory of light, was that it seemed to fail to account for the fact of straight-line propagation. Electro-magnetic waves, sound waves, water waves, and all of the forms of waves with which we are familiar bend readily around corners while light apparently does not. It was this difficulty, chiefly, which led many of the famous philosophers, including Sir Isaac Newton, to reject the wave theory of light. Within the last hundred years, however, this difficulty has been completely removed, and in addition other properties of light have been discovered, for which the wave theory offers the only satisfactory explanation.

If the wave theory is to be accepted, we must conceive with Huygens that all space is filled with the medium called the ether, in which both light and electro-magnetic waves can travel. This medium cannot be like any of the other forms of matter, for if any of these forms existed in interplanetary space, the planets and other heavenly bodies would certainly be retarded in their motion. As a matter of fact, we know that no such retardation has ever been observed. The medium which transmits light and electro-magnetic waves must, therefore, have a density which is infinitely smaller even in comparison with that of our lightest gases. The existence of such a medium is now universally assumed by physicists.

Light waves are disturbances set up in the ether, probably by the vibrations of the minute corpuscles or electrons, of which the atoms of ordinary matter are supposed to be built, while sound waves are disturbances set up in the air by the vibration of bodies of ordinary dimensions. Electro-magnetic waves are the waves used in wireless transmission, the waves being set in motion by the vibrations of the wires making up the aerial at the transmission station. These waves spread out in all directions with equal force, unless the direction of transmission be regulated by the use of directive aerials which would tend to make the wave transmission greater in any desired direction.

We have all stood on the banks of some river or lake, and as the result of having thrown a stone into the water, noticed the ripples on the surface of the water, how they spread out continually in the form of a circle, the ripples gradually becoming less distinct the further they travel from the center. We can liken this to the transmission of wireless; the stone which disturbs the water corresponds to the transmission aerial which disturbs the air. The water of the lake to the ether, which we have already conceived fills all space, and the ripples on the surface of the water to the electro-magnetic waves. Just as the ripples on the water gradually die out the further they travel from the source of the disturbance so do the magnetic waves become gradually weaker the further they travel from the transmission station.

In the case of ripples on the surface of water it is plain to the eye that the waves are transmitted by the passing on of the up-and-down motion of the surface at the source. This is possible because at the surface of the water the particles of the water are held together by forces which resist their displacement. When one particle is displaced its neighbors are dragged with it to some extent. In technical terms the medium of transmission is said to have "elastic" properties and the forces brought into play are said to be elastic forces. The velocity of the waves depends on the nature and amount of these elastic forces.

In the case of sound waves in air we do not ordinarily see the vibrations of the particles of the air. The vibrations are quite small and the waves travel so fast that only under quite unusual conditions can they be made visible. But the mechanism by which the energy is transmitted is found to be of the same kind as in the case of water ripples. By the delicate elastic connections between neighboring portions of the air a vibration at one point is passed on to another. Sound waves are of another type than water waves only because the structure of air is different from that of water. Hence the elastic reaction to displacement is different in the two media. This is the sole cause of the differences between any two types of waves.

In the case of electromagnetic waves, often called "electric waves," the displacements produced are of the kind considered in the section on capacity. The elastic reactions set up by such displacement currents can be found by the same laws which determine the electric and magnetic forces due to any current. It is beyond the scope of this book to show the nature of these electrical elastic forces. It will be sufficient, however, to state that they are such as to produce waves in which (in free space)—

(a) The displacement (and the electric field intensity) are at right angles to the direction of motion of the wave train.

(b) The magnetic field intensity resulting from the displacement current is at right angles to the displacement and to the direction of the wave train.

(c) The variations in the displacement (or the electric field intensity) and the magnetic field intensity are in phase.

(d) The velocity of the waves is 300,000,000 meters per second, the same as the velocity of light (about 186,000 miles per second).

Such waves if started at a point in free space travel in all directions with the same velocity. They may be modified in various ways as they proceed. Thus, if they pass into a region of different dielectric constant, they are in general changed slightly in direction and partly reflected. Their energy is also absorbed to a greater or less extent in their passage through any medium. This absorption is greater for short than for long waves. In a perfect conductor no waves could be transmitted, since in such a medium there is no elastic opposition to the displacement of electricity. A perfectly conducting sheet would reflect all of the wave energy falling on it. However, a conductor parallel to the direction of motion of a wave acts as a guide to the wave, through the action of currents induced in it by the varying magnetic field of the wave. It takes less energy from the waves, the better conductor it is. In the use of electric waves in radio communication all of these modifications occur and serve to explain many of the irregularities of received signals. We can think of the space through which radio signals are sent as being bounded below by a sheet of varying conductivity (the earth's surface) and above—at a distance of from 30 to 50 miles—by another conducting region. This upper region, where the air is much rarefied, is a fairly good conductor, owing to its ionization by radiations from the sun. The region in between these conducting layers is usually a good dielectric. Thus, this region acts more or less as a speaking tube does for sound waves, though its action is much more complicated. The electromagnetic waves are set up near the earth's surface. They are partly transmitted as guided wave trains along the earth's surface, modified by refractions and absorption at its irregularities; another part, however, goes off as space waves, which by reflections at the upper and lower layers of the conducting boundaries may recombine with the guided wave in such a way as either to add or subtract their effects, depending on circumstances. In the daytime the upper conducting boundary will be less definitely marked than at night, on account of partial ionization of the air by the sun's radiations. Hence, there will be less reflection of the space wave in the daytime, and consequently the guided wave will not be assisted materially by any reflected or refracted part of the space wave. In the night, however, when the upper boundary is more sharply defined, there is more reflection of the space wave, and in general signals received at night are stronger than in daytime. Night signals are, however, more variable in intensity, particularly for short waves. This is especially true during the time when the sunset line is passing between two communicating stations. This is in general what we should expect, as the upper boundary would be quite variable under such circumstances. Clouds and other meteorological conditions would cause great variations in the sharpness of this boundary surface, and this may explain the rapid fluctuations in the strength of received signals often observed.

From all these considerations it can be seen that the conditions under which received signals will be most uniform in intensity are:

(a) Transmission using long waves.
(b) Transmission by daylight.
(c) Transmission over short distances.
(d) Transmission over uniform conducting surface of sea water.

It is only under these conditions that the performance of different transmitting stations can be fairly compared.

There are three principal sources encountered in practice which make it difficult to receive readable radio signals: (1) Interference from transmitting stations whose signals it is not desired to receive, (2) strays or static, and (3) the "fading" of the strength of the received signal.

Interference from other transmitting stations can to a large extent be eliminated by selection of frequency (wave length), particularly by the use of transmitting apparatus which will radiate only a single wave length or a narrow band of wave lengths. Laws have been enacted which are designed to minimize interference from other stations. Interference from transmitting stations using even the same wave length as the station which it is desired to receive can also be reduced by directional reception and to some extent by directional transmission, which are discussed later.

Strays are electrical disturbances giving rise to irregular interfering noises heard in the telephone receivers. They are also called "static," "atmospherics," "X's," and other names. Investigations have shown that there are many different causes for these stray waves, but have by no means completely explained their sources. In any particular case the possibility of getting a readable signal depends on the ratio of the strength of the signal to the strength of the static at that time. Experienced operators have stated that it is possible to copy messages when the strays were four times as strong as the signals, but much difficulty is often experienced when the strays are much weaker than this. The most common type of strays produces a grinding noise in the telephones; this type causes the most serious trouble. Another type, which produces a hissing noise, is usually associated with snow or rain. Nearby lightning produces a sharp snap. Another type consists of crashes similar to but stronger than the grinding noises first mentioned. By "stray elimination" is meant methods for increasing the ratio of signal strength to stray strength.

Strays are usually much more serious in the summer than in the winter, and more serious in tropical latitudes than in more temperate latitudes. Radio communication in the Tropics presents many special difficult problems.

Strays are the most serious limitation on radio communication. Transmitting stations of high power can be built, but if the strays are strong at a given time at the receiving station satisfactory communication can not be maintained, at least not with the ordinary types of receiving equipment. A great deal of careful investigation has been done to reduce the effects of strays.

The use in particular ways of the three-electrode electron tube has resulted in considerably reducing the effects of strays as compared with the results obtained with earlier forms of receiving equipment. The use of sharply tuned receiving equipment and the use of a musical note in the transmitted signal will usually somewhat reduce the effect of strays.

If the ordinary elevated type of antenna is used alone, a method for reducing strays which has given fairly satisfactory results has been the use of a receiving circuit having a primary circuit containing considerable inductance and having the circuit containing the telephone receivers tuned to the audio frequency and loaded with considerable inductance.

The most satisfactory results in stray elimination have been obtained by the use of various kinds of directional receiving antennas—that is, antennas which receive most strongly signals which are transmitted from a particular direction. Such antennas are discussed later in this book and include not only particular forms of the ordinary elevated antenna but also the coil antenna. The best results have been obtained by a combination of coil antennas and ground antennas.

"Fading" or "swinging" is a rapid variation of the strength of signals received from a given transmitting station, the same circuit adjustments being used at the transmitting and receiving stations. Fading is not usually observed at short distances from a transmitting station, but usually only at distances from the transmitting station which are at least some 10 or 20 per cent of the normal transmitting range of the station. Fading is observed particularly on short wave lengths, especially under 400 meters, and is therefore most important in amateur communication and in communication with airplanes and other special military applications. A certain transmitting station will be received with normal intensity for a few minutes; then for a minute or two the signals will become much louder; and then rapidly become much fainter and may become so weak as to be unreadable for a short time. Fading is usually observed particularly at night and usually only in transmission over land. Fading variations may be very rapid, with a period of about one second, or very slow, with a period of one hour or more. Transmitting stations located on the seacoast seem to fade more than inland stations. The principal method of avoiding transmission difficulties caused by bad fading is to increase considerably the wave length of the transmitting station, when this is possible. Fluctuations of the received signal resembling fading may sometimes be due to variations in the wave length or intensity of the transmitted wave, caused, for instance, by the position of the transmitting antenna being changed by wind. If the fluctuations are due to wave length variations and are not too rapid, it is possible to vary the tuning adjustments of the receiving set to follow the wave length variations.

Theory of Production and Reception of Electromagnetic Waves

To produce a train of waves of any kind a vibrating body is necessary. The vibrations of this body have next to be communicated to a continuous medium, after which the elastic properties of the medium take care of the transmission of the waves. In the case of electromagnetic waves the vibrating body is an oscillating electric charge in a circuit (the sending antenna circuit), while the means by which these oscillations are communicated to free space can best be described in terms of the motion of the lines of force which, when at rest, are used to picture the field about electric charges.

These lines are to be looked upon as lines along which there is a displacement of electricity against the elastic force of the medium. Thus they can not exist in conductors (in which no such elastic forces exist). Under the action of the elastic forces the displaced electricity is continually urged to return to its position of rest. In other words, there is a tension along the lines of force. In addition there must be a pressure at right angles to the lines of force, otherwise those lines would always be straight and parallel under the action of the tensions. These pressures can be thought of as arising from the repulsion between the displaced charges of the same sign in neighboring lines.

Every alternating current has associated with it a magnetic field which can be considered to be the sum of two components having entirely different characteristics called, respectively, the "induction field" and the "radiation field."

The induction field is the only one of importance in the operation of the apparatus ordinarily used with alternating currents of commercial frequencies, such as 60 cycles. The alternating currents by which the ordinary transformer operates are due to the induction field. The cross talk often noticed between adjacent telephone lines is caused by the induction field. The action of the induction field on near-by circuits is often spoken of as "transformer action." If two coils are placed near together, interruptions in an alternating current passing through one coil will be reproduced in the other by the action of the induction field. The intensity of the induction field, due to a current in such a closed coil, decreases rapidly with the distance from the coil and is inversely proportional to the cube of the distance from the coil. Signals can be transmitted by the induction field, using alternating currents having frequencies from about 300 to 3000 cycles; this is called "induction signaling." One of the applications of induction signaling has been to transmit signals from a submerged cable to a ship almost directly over the cable to aid the ship in finding its course. The induction field due to the ordinary type of elevated antenna is inversely proportional to the square of the distance from the antenna. The induction field is not important in the usual applications of radio communication.

The radiation field is transmitted by wave motion. The intensity of the radiation field falls off with the distance from a transmitting station, but is inversely proportional to the distance, instead of being inversely proportional to the square or the cube of the distance. The induction field due to a current in a coil at a distance of 10 miles from the coil is only one one-thousandth of the strength of the induction field at a distance of 1 mile from the coil. The radiation field due to a current in a coil at a distance of 10 miles from the coil is one-tenth of the strength of the radiation field at a distance of 1 mile from the coil. For communication over any considerable distance, it is therefore necessary to make use of the radiation field.

For the ordinary type of elevated antenna, the intensity of the radiation field is greater than that of the induction field at distances from the transmitting station exceeding the wave length divided by 6.28.

The strength of the radiation field at a given point due to an alternating current in the ordinary type of elevated transmitting antenna is directly proportional to the frequency. When the coil antenna is used for transmitting, the strength of the radiated field is proportional to the square of the frequency. It is therefore necessary to use high frequencies to get a radiation field sufficiently strong to allow successful communication. With the ordinary type of elevated antenna, the radiation field at a given point due to an alternating current having a frequency of 1,500,000 cycles (wave length=200 meters) would be 25,000 times as strong as the radiation field due to an alternating current having a frequency of 60 cycles.

The above statements are for radiation in free space. In actual communication part of the energy of the radiated field is, however, absorbed in the surface of the earth or in the surface of the ocean as the wave travels. This absorption effect is greater for high frequencies. It need not ordinarily be taken into account in short-distance work, but at distances greater than about 100 kilometers it becomes important. For this reason it is not possible to indefinitely increase the strength of the radiated field at a given distance by increasing the frequency.

The statement is sometimes made that a circuit carrying an alternating current of low frequency, such as 60 cycles, does not radiate. This is not really true; radiation does occur, but is of very feeble intensity.

Another statement sometimes made is that an "open" circuit can radiate, while a "closed" circuit can not; this is not true. All circuits are closed.

As it has been shown that the electro-magnetic waves travel in every direction from its source, it is possible that any receiving station within range of the transmitting station will be capable of receiving the messages sent out, providing they are tuned up to the same wave lengths. The length of the electro-magnetic waves can be altered at will by altering the oscillatory circuit, but at present the waves vary in length from 150 to 20,000 meters. Most of the local broadcasting stations are sending out the concerts on a short wave length of 360 meters, while amateurs are restricted by the government to a 200 meter wave length for transmission.

That part of the wireless set that creates the electro-magnetic waves at the transmission station is called the transmitter. To be able to fully understand the working principles of the transmitter and its connections, it will be necessary to have at least an elementary knowledge of electricity.

ELECTRICITY

No one knows exactly what electricity is, we do not even know what it consists of, we do know that electricity and magnetism are one and the same. Electricity is not matter nor yet is it energy, although it is a means of transmitting energy, and we know how to handle this force for this purpose.

It is an undeniable fact that energy cannot be created nor can it be destroyed, but we can convert one kind of energy into energy of another kind. For example, should we light a fire under a vessel containing water we will convert the heat energy from the coals to steam energy in the vessel containing the water, and we could again change this steam energy into mechanical energy, as is done with the locomotive.

It is also possible to convert mechanical energy into electrical energy, so by connecting the mechanical energy created by the steam to a dynamo we would produce electrical energy.

It is also possible to convert electrical energy into mechanical energy. A motor is used for this purpose.

The word dynamo is used to designate a machine which produces direct current as distinguished from the alternator or generator which produces alternating current. A dynamo does not create electricity but produces an induced electric-motive force which causes a current of electricity to flow through a circuit of conductors in much the same manner as a pump causes water to flow through a pipe. The point to be settled in the minds of those taking up electricity is that the dynamo merely sets into motion something already existing, by generating sufficient pressure to overcome the resistance to its movement.

Although we speak of alternating and direct current, it should be clearly understood that it is impossible to get a continuous current with a dynamo. The current is really a pulsating one, but the pulsations are so small and follow each other so quickly that the current is practically continuous.

Electromotive Force. When a difference of electrical potential exists between two points, there is said to exist an *electromotive force,* or tendency to cause a current to flow from one point to the other. This electromotive force is analogous to the *pressure,* caused by a difference in level of two bodies of water connected by a pipe. The pressure tends to force the water through the pipe, and the electromotive forces tends to cause an electric current to flow.

Electromotive force is commonly designated by the letters *E. M. F.* or simply *E.* It is also referred to as *pressure* or *voltage.*

Current. A current of electricity flows when two points, at a difference of potential, are connected by a wire, or when the circuit is otherwise completed. Similarly, water flows from a high level to a lower one, when a path is provided. In either case the flow can take place only when the path exists. Hence to produce a current it is necessary to have an electromotive force and a closed circuit. The current continues to flow only as long as the electromotive force and closed circuit exists.

The strength of a current in a conductor is defined as the quantity of electricity which passes any point in the circuit in a unit of time. Current is designated by the letter *C* or *I*.

Resistance. Resistance is that property of matter, in virtue of which bodies oppose or resist the free flow of electricity. Water passes with difficulty through a small pipe of great length or through a pipe filled with stones or sand, but very readily through a large, clear pipe of short length. Likewise, a small wire of considerable length and made of poor conducting material offers great resistance to the passage of electricity, but a good conductor of short length and large cross-sections offers very little resistance.

Resistance is designated by the letter *R*.

Volt, Ampere and Ohm. The *volt* is the practical unit of electromotive force.

The *ampere* is the practical unit of current.

The *ohm* is the practical unit of electrical resistance. The *microhm* is one millionth of an ohm, and the *megohm* is one million ohms.

The International ohm, as nearly as known, is the resistance of a uniform column of mercury 106.3 centimeters in length by one square millimeter in cross-section at a temperature of zero centigrade.

The ampere is the strength of current which, when passed through a solution of silver nitrate, under suitable conditions, deposits silver at the rate of .001118 gram per second.

The volt is equal to the E. M. F. which, when applied to a conductor having a resistance of one ohm, will produce in it a current of one ampere.

All substances resist the passage of electricity, but the resistance offered by some is very much greater than that offered by others. Metals have by far the least resistance, and of these, silver possesses the least of any. In other words, silver is the best conductor. If the temperature remains the same, the resistance of a conductor is not affected by the current passing through it. A current of ten, twenty or any number of amperes may pass through a circuit, but its resistance will be unchanged with constant temperature. Resistance is affected by the temperature and also by the degree of hardness. Annealing decreases the resistance of a metal.

Conductance is the inverse of resistance; that is, if a conductor has a resistance of R ohms, its conductance is equal to $\frac{1}{R}$.

Resistance Proportional to Length. The resistance of a conductor is directly proportional to its length. Hence, if the length of a conductor is doubled, the resistance is doubled, or if the length is divided, say into three equal parts, then the resistance of each part is one-third the total resistance.

Resistance Inversely Proportional to Cross-Section. The resistance of a conductor is inversely proportional to its cross-sectional area. Hence the greater the cross-section of a wire the less is its resistance. Therefore, if two wires have the same length, but one has a cross-section three times that of the other, the resistance of the former is one-third that of the latter.

As the area of a circle is proportional to the square of its diameter, it follows that the resistances of round conductors are inversely proportional to the squares of their diameters.

Specific Resistance. The specific resistance of a substance is the resistance of a portion of that substance of unit length and unit cross-section at a standard temperature. The units commonly used are the centimeter or the inch, and the temperature that of melting ice. The specific resistance may therefore be said to be the resistance (usually stated in microhms) of a centimeter cube or of an inch cube at the temperature of melting ice. If the specific resistances of two substances are known, then their related resistance is given by the ratio of the specific resistance.

Calculation of Resistance. It is evident that resistance varies directly as the length, inversely as the cross-sectional area, and depends upon the specific resistance of the material.

If a circuit is made up of several different materials joined in series with each other, the resistance of the circuit is equal to the sum of the resistances of its several parts. In calculating the resistance of such a circuit, the resistance of each part should first be calculated, and the sum of these resistances will be the total resistance of the circuit.

Resistance Affected by Heating. The resistance of metals depends upon the temperature, and the resistance is increased by heating. The heating of some substances, among which is carbon, causes a decrease in their resistance. The resistance of the filament of an incandescent lamp when lighted is only about half as great as when cold. All *metals*, however, have their resistance increased by a rise in temperature. The percentage increase in resistance with rise of temperature varies with the different metals, and varies slightly for the same metal at different temperatures. The increase is practically uniform for most metals throughout a considerable range of temperature. The resistance of copper increases about .4 per cent. per degree Centigrade. The percentage increase in resistance for alloys is much less than for the simple metals. Standard resistance coils are therefore made of alloys, as it is desirable that their resistance should be as nearly constant as possible.

Quantity, Energy and Power

Quantity. The strength of a current is determined by the amount of electricity which passes any cross-section of the conductor in a second; that is, current strength expresses the *rate* at which electricity is conducted. The *quantity* of electricity conveyed evidently depends upon the current strength and the time the current continues.

The Coulomb. The coulomb is the unit of quantity and is equal to the amount of electricity which passes any cross-section of the conductor in one second when the current strength is one ampere. If a current of one ampere flows for two seconds, the quantity of electricity delivered is two coulombs, and if two amperes flow for one second the quantity is also two coulombs. With a current of four amperes flowing for three seconds, the quantity delivered is 12 coulombs. The quantity of electricity in coulombs is therefore equal to the current strength in amperes multiplied by the time in seconds.

Energy. Whenever a current flows, a certain amount of energy is expended, and this may be transformed into heat, or mechanical work, or may produce chemical changes. The unit of mechanical energy is the amount of work performed in raising a mass of one pound through a distance of one foot, and is called the foot-pound. The work done in raising any mass through any height is found by multiplying the number of pounds in that mass by the number of feet through which it is lifted. Electrical work may be determined in a corresponding manner by the amount of electricity transferred through a difference of potential.

The Joule. The joule is the unit of electrical energy, and is the work performed in transferring one coulomb through a difference of potential of one volt. That is, the unit of electrical energy is equal to the work performed in transferring a unit of quantity of electricity through a unit of difference of potential. It is evident that if 2 coulombs pass in a circuit and the difference of potential is one volt, the energy expended is 2 joules. Likewise, if 1 coulomb passes and the potential difference is 2 volts, then the energy expended is also 2 joules. Therefore, to find the number of joules expended in a circuit, multiply the quantity of electricity by the potential difference through which it is transferred.

Power. Power is the *rate* of doing work, and expresses the amount of work done in a certain time. The horsepower is the unit of mechanical energy, and is equal to 33,000 foot-pounds per minute, or 550 foot-pounds per second. A certain amount of work may be done in one hour or two hours, and in stating the work done to be so many foot-pounds or so many joules, the rate at which the work is done is not expressed. Power, on the other hand, includes the rate of working.

It is evident that if it is known that a certain amount of work is done in a certain time, the rate at which the work is done, or the power, may be obtained by dividing the work by the time, giving the work done per unit of time.

The Watt. The electrical unit of power is the watt, and is equal to one joule per second; that is, when one joule of work is expended in one second, the power is one watt. If the number of joules expended in a certain time is known, then the power in watts is obtained by dividing the number of joules by the time in seconds.

The power is obtained by multiplying the current by the voltage, or by multiplying the square of the current by the resistance.

The watt is sometimes called the *volt-ampere.*

For large units the *kilowatt* is used, and this is equal to 1,000 watts. The common abbreviation for kilowatt is K. W. The *kilowatt-hour* is a unit of energy, and is the energy expended in one hour when the power is one kilowatt.

Equivalent of Electrical Energy in Mechanical Units. The common unit of mechanical energy is the foot-pound, and from experiment it has been found that one joule is equivalent to .7373 foot-pound; that is, the same amount of heat will be developed by one joule as by .7373 foot-pound of work.

As one horse-power is equal to 550 foot-pounds per second, it follows that this rate of working is equivalent to

$$\frac{550}{.7373} = 746 \text{ joules per second (approx.).}$$

Hence one horse-power is equivalent to 746 watts. Therefore, to find the equivalent of mechanical power in electrical power, multiply the horse-power by 746; and to find the equivalent of electrical power in mechanical power, divide the number of watts by 746.

Ohms Law. Ohms law is merely the fundamental principle on which most of electrical mathematics are worked.

A series of formulas used by electricians in figuring voltage, amperage and resistance:

FORMULA 1

To find the amount of current flowing in a circuit divide the voltage by the resistance, or

$$\text{Current} = \frac{\text{Electric Motive Force}}{\text{Resistance}}$$

For instance, if we have a line voltage of 100 and our circuit has resistance of 5 ohms, then by dividing 100 by 5, we would get our amperage.

```
5 ) 100 ( 20
    100
    ———
```

so we would have 20 amperes.

FORMULA 2

To find the amount of resistance in a circuit, divide the voltage by the amount of amperage drawn, or

$$\text{Resistance} = \frac{\text{Electric Motive Force}}{\text{Current}}$$

For instance, suppose we have a line voltage of 100 and are using 20 amperes, then by dividing the 100 by 20 we would get the amount of resistance we have in our circuit.

```
20 ) 100 ( 5
     100
     ———
```

so we would have 5 ohms resistance in our circuit.

FORMULA 3

To find the voltage of a circuit, multiply the amount of amperes drawn by the amount of resistance, or

Electric Motive Force = Amperes Times Resistance

For example: If we were using 20 amperes and our circuit was offering 5 ohms resistance, then by multiplying 20 by 5 we would get our voltage.

```
 20 amperes
  5 ohms
———
100 volts
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To find Volts. Multiply number of Amperes by amount of Resistance.

To find Resistance. Divide Voltage by Amperage.

To find Amperage. Divide Voltage by Resistance.

To find Watts. Multiply Voltage by Amperage.

To find Amps. Divide Watts by Volts.

To find Volts. Divide Watts by Amperage.

GENERATION OF ELECTRICITY

Everyone is acquainted with the horseshoe magnet and the small pocket compass, and these two articles will serve as an illustration.

Now if one of the legs of the horseshoe magnet be brought near the compass, it will be found that one end of the needle will be attracted to it, whilst if the other leg be presented the other end of the needle is attracted. One leg, at its end, has north polarity, because it attracts the south pole of the compass needle, whilst the other end, having south polarity, attracts the north end of the needle, so that between the ends of the two legs there exists what is known as a "magnetic field," or space wherein magnetic lines of force are present. These lines of force are invisible, but if the magnet be laid on a table, and a piece of paper put over it, and if on the paper be sprinkled some iron filings it will be found, when the paper is tapped by the finger, that these filings group themselves around the ends of the magnet in circles, being closer together at the ends than further away, or higher up towards the bend of the horseshoe. The magnetic field is the most dense between the legs of the magnet at their ends. If a copper wire be passed up and down between the ends of the legs an electric current will be induced in the wire, its direction of flow varying with the upward and downward motion of the wire. In this case the electricity is obtained from the magnet by "induction," this being the elementary principle upon which all dynamos, whether for lighting or power, is based. In the dynamo the horseshoe is replaced by electro-magnets, the large stationary pieces of soft iron surrounded with covered copper wire, whilst the armature, the part which revolves, replaces the thin pieces of copper wire in the above simple experiment. The armature does not touch the magnets, and there is no friction except that in the bearings of the armature shaft, in which it is

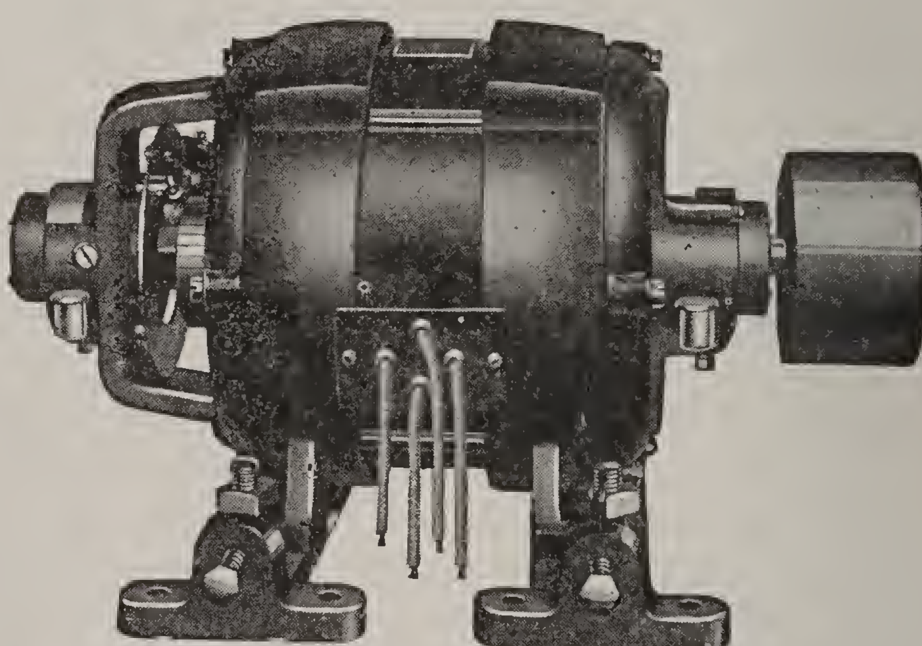


Fig. 1—Generator

necessary to revolve, and which is made as easy as possible by a liberal supply of oil. It will also be seen that the electricity is not pumped from the atmosphere, but is simply the revolution of a bundle of copper wires between the poles of a powerful electro-magnet. The ends of the electro-magnets are thickened out, and each one made semi-circular so that the armature may revolve between the north and south poles and the electro-magnets, consisting of soft iron, are wound round with insulated copper wire, so that a portion of the electricity generated in the armature may be shunted around them and so keep always, whilst the dynamo is in action, as powerful electro-magnets. When the dynamo is stopped, these magnets retain a small amount of magnetism, which is gradually strengthened to its maximum as the armature is started revolving, the dynamo "building up" as it is termed. Anyone who has watched the starting up of a dynamo will have noticed that when running slowly the lamp connected to it as "pilot" gradually

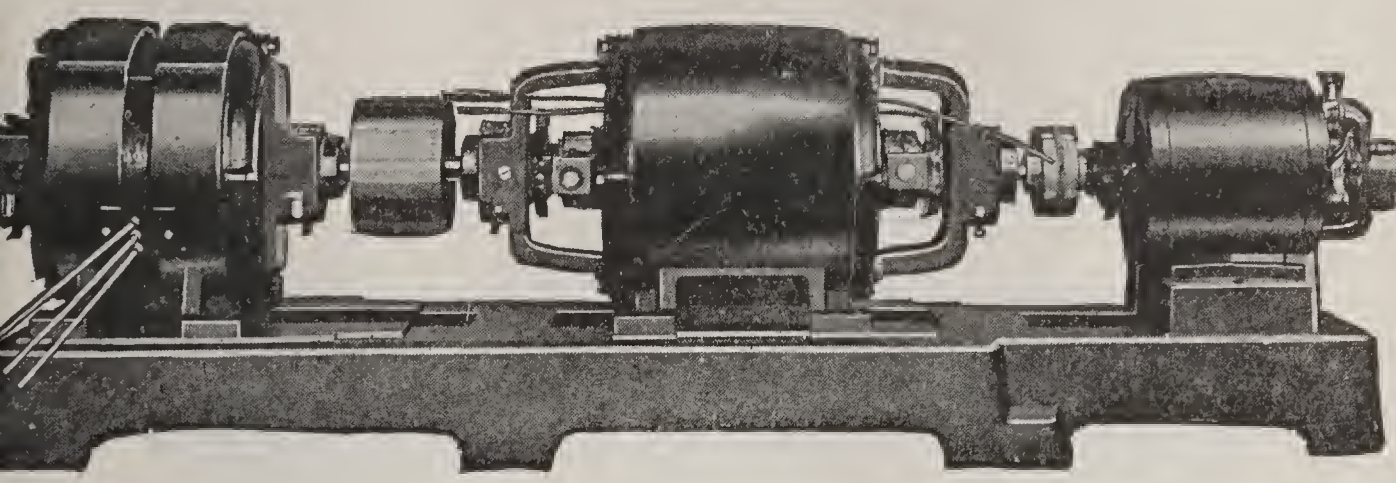
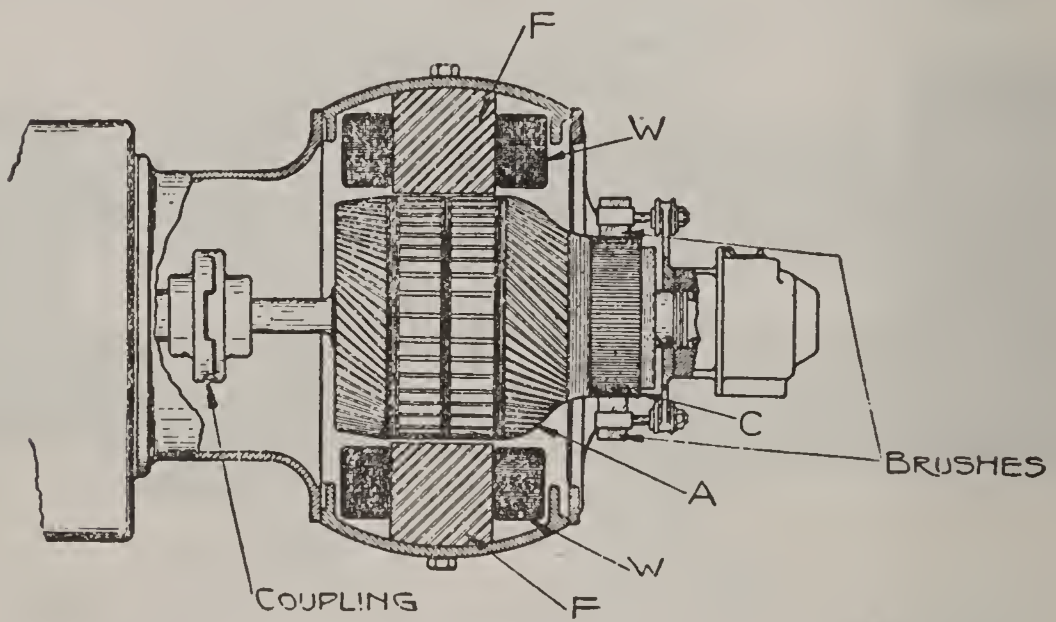


Fig. 2—Three Unit Set

shows a red filament, which becomes brighter, as the revolutions increase, until, when the correct speed is reached for which the dynamo was designed, the right voltage will show on the voltmeter and the pilot lamp attain its full brilliancy.

The armature of the dynamo is the only part which revolves, and this consists of a steel shaft supported in bearings at each end, to which the pulley is attached to receive the belt for transmitting the power from the engine to the dynamo. On the shaft are built up thin sheets of soft iron provided with grooves in which the different sections of insulated copper wire are laid lengthwise, their ends being connected to what is called the "commutator" fastened to the shaft. This consists of bars of copper made into a drum, each bar being insulated from its neighbor by means of strips of mica, and on the commutator rest lightly the carbon or copper brushes to convey the electricity to the lamps or motors.

The number of coils of wire on the armature depends upon the voltage the dynamo is designed to



GENERATOR

Fig. 3

give, and the speed at which it has to run, also upon the strength of the magnetic field of the electro-magnets; and the thickness of these conductors will depend upon whether it has to give a large or small current strength. If the voltage is to be high, and small current strength, many conductors of fine wire are employed; if the voltage required is to be low, and large current strength, a few sections of thick wire are required.

A machine as above described is known as a continuous-current dynamo, to distinguish it from an "alternator," and the current obtained from it flows in a continuous circuit from the positive brush or collector on the commutator, through the lamps or motors, and completes the circuit to the other brush.

The mistaken notion of electricity being obtained by friction has probably arisen from the fact that, resting on the top and bottom of the commutator are carbon or copper brushes, but these are for the purpose of turning the currents, which are generated in the armature as alternating currents, into one direction.

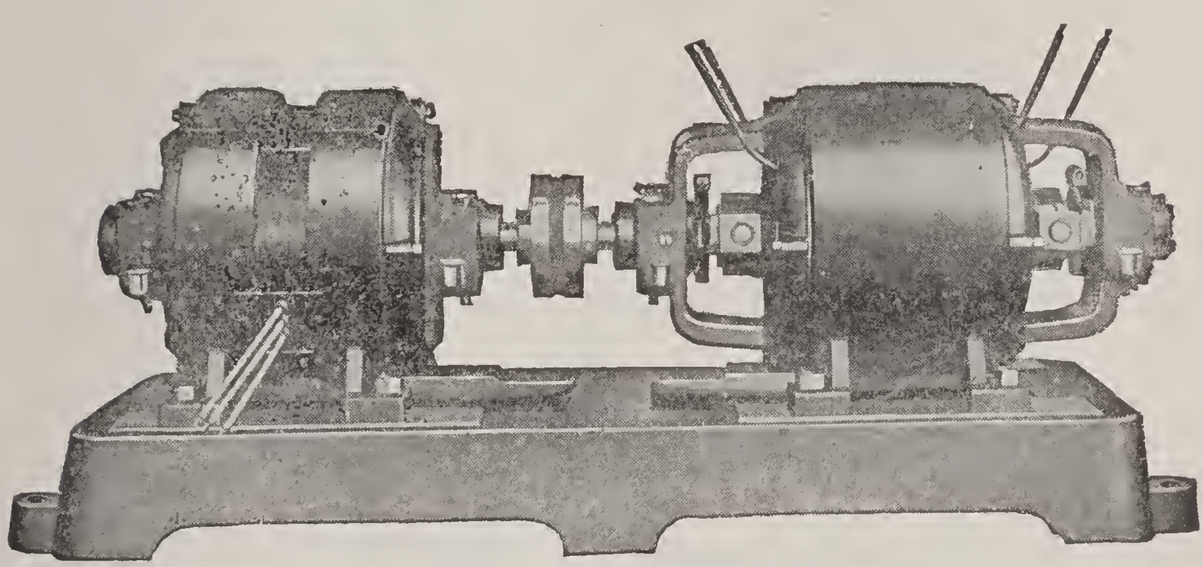


Fig. 4—Four Bearing, Ring-oiled Set

They also act as collectors to convey the electricity to the external circuit for lamps, motors, or other electricity-consuming devices, and do not offer practically any friction, only resting lightly against the surface of the revolving commutator.

For supplying extensive areas such as towns where the demand for electricity is scattered, alternating-current machines or "alternators" are employed which do not require commutators, the high voltage generated, 2,000 volts and upwards, being led to transformer stations, where it is reduced, by means of stationary transformers, to 110 and 220 volts for feeding lamps direct, or for motors and other uses. The field magnets of these alternators are energized by a continuous or direct current supplied from a small dynamo generally fixed on the alternator shaft, and running at the same speed.

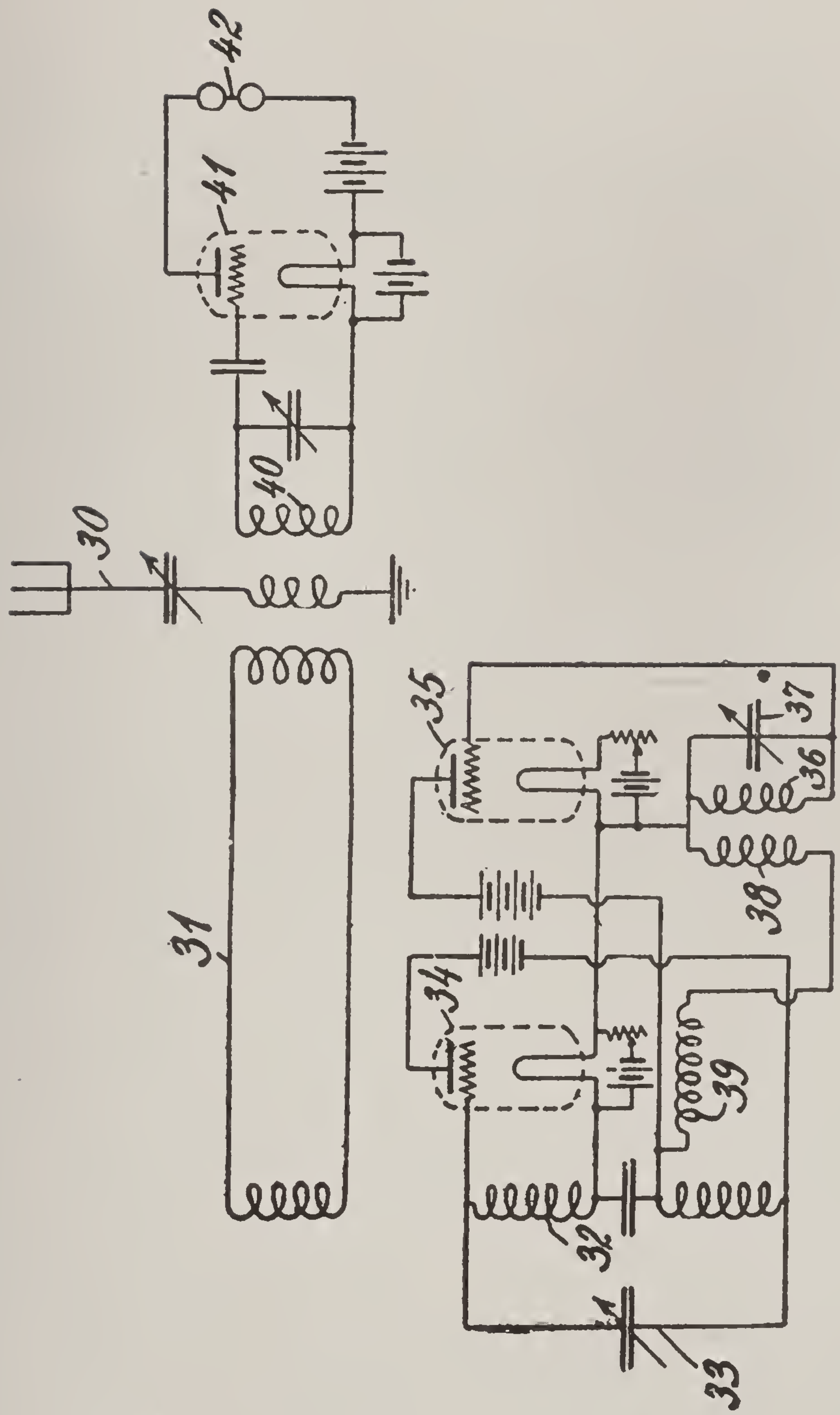


Fig. 5

ALTERNATING CURRENTS

A continuous or direct current is one of uniform strength always flowing in one direction, while an *alternating current* is continually changing both its strength and direction. The various principles and facts concerning direct current distribution apply also to alternating current systems. But in addition to the simple phenomena due to the resistance, which occur with direct currents, there are certain additional factors that must be considered in connection with alternating current transmission.

The flow of a direct current is entirely determined by the ohmic resistance of the various parts of the circuit. The flow of an alternating current depends upon not only the resistance, but also upon any *inductance* (self or mutual) or *capacity* that may be contained in or connected with the circuit. These two factors, inductance and capacity, have no effect upon a direct current after a steady flow has been established, which usually requires only a fraction of a second. In an alternating current circuit either or both of them may be far more important than the resistance and in some cases may entirely control the action of the current. Alternating current problems involving the consideration of three factors are usually more complicated and difficult to solve than those relating to direct currents. By an extension of the principles and methods employed for direct currents, however, alternating current systems can be designed correctly and without great difficulty.

The only reason practically for employing alternating currents for electric lighting and power purposes is the economy effected in the cost of transmission, which is accomplished by the use of high voltages and transformers. The cross section of a wire to convey a given amount of electrical energy in watts with a certain "drop" or loss of potential in volts, is inversely proportional to the square of the voltage supplied; that is, it requires a wire of only one-quarter the cross-section and weight if the initial voltage is doubled. The great advantage thus obtained by the use of high voltages can be realized either by a saving in the weight of wire required or by transmitting the energy to a greater distance with the same weight of copper.

When the alternating current, or emf., has passed from zero, to its maximum value, to zero, in one direction, then from zero, to its maximum value, to zero, in the other direction, the complete set of values passed through repeatedly during that time is called a *cycle*. This cycle of changes constitutes a complete *period*, and since it is repeated indefinitely at each revolution of the armature the currents produced by such an emf. are called *periodic currents*. The number of complete periods in one second is called the *frequency* of the pressure or current.

The term *frequency* is applied to the number of cycles completed in a unit of time—one second. The word *alternations* is sometimes used to express the frequency of an alternator, meaning the number of *alternations per minute*. In practice the frequency is usually expressed in *cycles*. An alternation is half a period or cycle; since the current changes its direction at each half cycle, it follows that the number of alternations or reversals is twice the number of cycles.

If the current from an alternator performed the cycle sixty times a second, it would be said to have a *frequency* of 60 *cycles*, which would mean 120 alternations per second, or 120×60 seconds $= 7200$ alternations per minute.

The frequency of an alternating current is always that of the emf. producing it.

Unless otherwise specified, *frequencies* are in the term of cycles, thus: a frequency of 60 means 60 cycles. The frequency of commercial alternating current depends upon the work it is expected to do. For power a low frequency is desirable, frequencies for this purpose varying from 60 down to 25.

For lighting work frequencies from 60 to 125 are in general use. Very low frequencies cannot be used for lighting owing to the flickering of the lamps. A number of central stations have adopted a frequency of 60 as a standard for lighting and power transmission.

For wireless work the frequency must be very high, amateurs today are using a 1,500,000 cycle current for transmission.

Most of the peculiarities that alternating current exhibits, as compared with direct current, are due more or less to the fact that an alternating current is constantly changing, whereas a continuous current flows uniformly in one direction. When a current flows through a wire it sets up a magnetic field around the wire, and since the current changes continually this magnetic field will also change. Whenever the magnetic field surrounding a wire is made to change, an emf. is set up in the wire, and this induced emf. opposes the current. For example, when the current rises in the positive direction, the magnetism increases, in let us say, the clockwise direction about the conductor; after the current passes the maximum value and begins to decrease, the lines of force commence to collapse, reaching zero value when the current reaches zero; then when the current rises in the negative direction the magnetic lines expand in the counter-clockwise direction, and so on. The result is that the counter emf. of self-induction, instead of being momentary, as when the current is made and broken through a conductor, is continuous, but varies in value like the applied emf. and the current. The value of an induced emf. is proportional to the rapidity with which lines of force are cut by the conductor, and as the lines of force vary most rapidly when passing the zero point (changing from + to —) or *vice versa*, the induced emf. is maximum at the moment.

When the current, and therefore the magnetism, is at the maximum value in either direction, its strength varies very little within a given momentary period of time, and consequently the *induced* emf. is zero at the moment the current and magnetism is at maximum, the emf. of self-induction not rising and falling in unison with the applied emf. and the current, but lagging behind the current exactly a quarter of a cycle.

This property of a wire or coil to act upon itself *inductively* (self-induction) or of one circuit to act inductively on another independent circuit (mutual induction) is termed *Inductance.*

The *Unit or Coefficient* of inductance is called the *henry,* the symbol for which is L.

Many devices met with an alternating current work have this property of inductance. A long transmission line has a certain amount of it, as have induction motors and transformers.

The effect of *inductance* in an alternating current circuit is to oppose the flow of current on account of the counter emf. which is set up. This opposition may be considered as an apparent additional resistance and is called *reactance* to distinguish it from ohmic resistance.

Reactance is expressed in ohms, like resistance, because it constitutes an opposition to the flow of the current. Unlike the resistance, however, this opposition does not entail any loss of energy because it is due to a counter pressure and is not a property analogous to friction. Its effect in practice is to make it necessary to apply a higher emf. to a circuit in order to pass a given current through it than would be required if only the resistance of the circuit opposed the current.

Alternating currents are generated at various frequencies, covering a remarkably wide range. Depending on their application, the frequencies in practical use fall into three well-defined classes:

(a) *Commercial* frequencies, which nowadays generally mean 25 or 60 cycles per second.

(b) *Audio* frequencies, which are usually around 500 to 1000 cycles per second but may extend as high as 10,000 cycles per second.

(c) *Radio* frequencies, usually between 20,000 and 2,000,000, but extending in extreme cases down to perhaps 10,000 and up to three hundred million cycles per second.

Commercial frequencies are used for lighting and power. The great machines in the central stations which supply our cities with current operate at these frequencies.

Audio frequencies are those conveniently heard in the telephone. When alternating currents are sent through a telephone, the diaphragm of the latter vibrates. The vibrations are heard as sound. The more rapid the vibrations, the shriller the tone. Vibrations at the rate of 4,000 or 5,000 per second give a shrill whistle, while the lowest notes of a bass voice have somewhat under 100. If a 500-cycle generator supplies current to a spark gap and the spark jumps once on the positive and once on the negative half-wave, then at the receiving station the signal is heard in the telephone as a musical tone of 1000 vibrations per second.

Radio frequencies occur in the circuits of radio apparatus, for instance, in an antenna. They are too rapid to cause a sound in a telephone which can be heard by the human ear. They may be generated by dynamo-electric machines of highly specialized construction, but are usually produced by other means.

To show how the methods described in the preceding sections are applied in actual generators, a few typical machines used in radio sets will be briefly described. Whether or not these are of the latest design is not important. Changes of detail are constantly being made, but they do not affect the principles used and can be readily understood after the workings of similar machines have been grasped. The examples of machines here given will also illustrate how the form of generator and the auxiliaries used with it are influenced by the source of power available for driving it.

The generator is only one part of a unit for converting energy into the electrical form. The other part depends on the source of energy available; it may be heat derived from coal or gasoline; it may be falling water, moving air, human muscles, or a charged storage battery.

Crank Driven.—The field radio pack set furnishes an example of a self-contained generating unit driven by hand. These sets have been changed somewhat from time to time and can therefore be described only in a general way. The generator is cylindrical in shape and is entirely incased, including the ends, in a metal shell. At one end of it is a flywheel for equalizing the speed. At the other is the train of gears, running in oil and inclosed in a housing, through which power is transmitted from the crank shaft to the generator shaft. The crank shaft is turned by means of a pair of cranks.

The alternator is a 250-watt, 500-cycle machine of the revolving armature type. The exciter is built in with the alternator, so that the two have but one frame and one set of bearings, and the same shaft carries both armatures. Near one end, on opposite sides of the shell, is a pair of holes giving access to the d.c. brushes which bear on the commutator of the exciter and near the other end are similar holes for the a.c. brushes that bear on the collector rings. The crank is turned at the rate of 33 to 50 r.p.m., depending on the machine (that is, the date of the model), and the generators make 3300 to 5000 r.p.m., the cranks being geared to them at a ratio of 1 to 100.

ELECTRICAL RESISTANCE

Electrical resistance is that property of anything in an electric circuit which will resist the flow of current. The effect of resistance is to produce heat.

The unit of electrical resistance is the ohm, and is so named after Dr. G. S. Ohm who gave us the series of formulas now known as Ohm's Law; it will be necessary to thoroughly understand the working of this law to be able to work out any of the numerous problems in electrical resistance. Ohm's Law states that: The current is directly proportional to the voltage and inversely proportional to the resistance. This means that if the voltage of a circuit be increased the current will proportionally increase, and should the resistance of a circuit be increased then the current will be proportionately decreased. Should the voltage be decreased there will be a proportional decrease in the current, if the resistance in the circuit is decreased there will be a proportional increase in current. Expressed mathematically

$$\text{Current} = \frac{\text{Electric Motive Force}}{\text{Resistance}}$$

Current is equal to the Electric Motive Force (Voltage) divided by the Resistance (in ohms) or

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

If by dividing the voltage by the resistance we get the amount of current, then by dividing the voltage by the current we will naturally get the amount of resistance in our circuit, or—

$$R = \frac{E\,M\,F}{C}$$

and so to find the voltage all we have to do is to

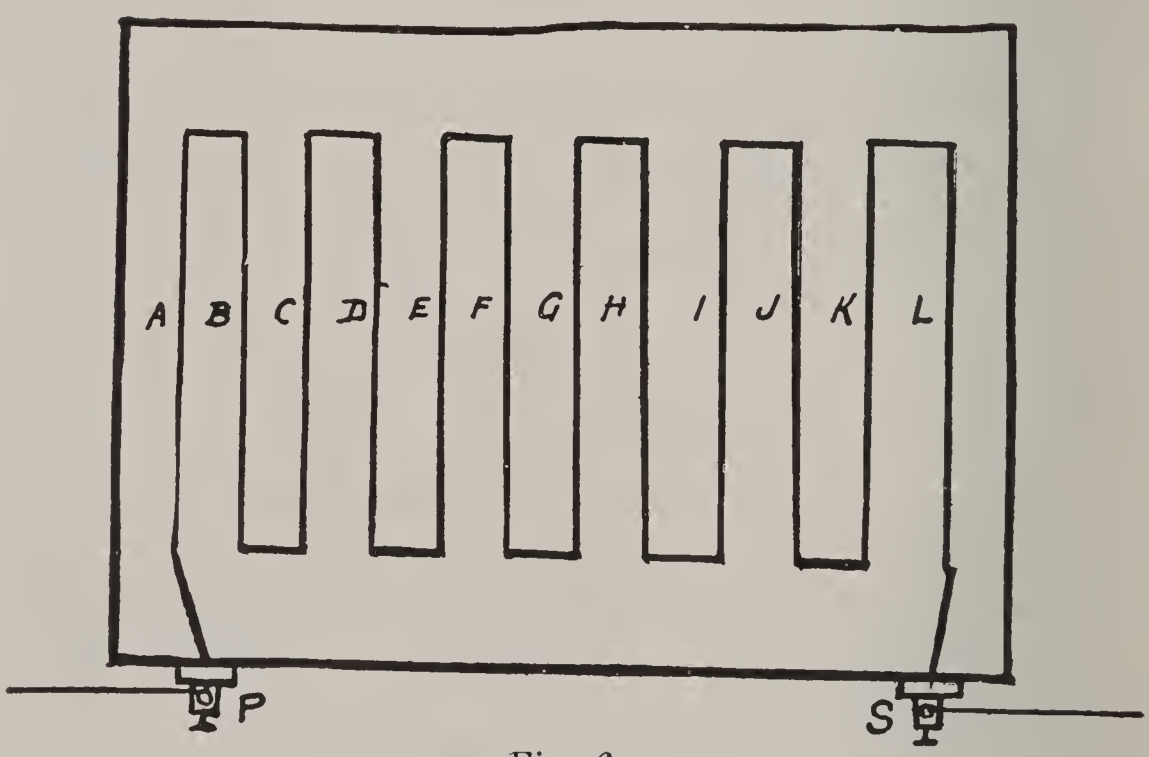


Fig. 6

multiply the current by the amount of resistance in our circuit, or—

$$E\ M\ F = C \times R$$

It will thus be seen that providing we have two known quantities the third unknown quantity can easily be obtained by the use of one of the above formulas; for instance, let us suppose that we have a line voltage of 100 and our circuit has a total resistance of 5 ohms, then by dividing the 100 (volts) by 5 (ohms) we find our current to be 20 (amperes).

Providing we knew there was a line voltage of 100 and we were drawing 20 amps, then by dividing the 100 (volts) by 20 (amperes) we would get the amount of resistance in our circuit, which would be 5 (ohms).

By the foregoing it is evident that the amount of current we will get depends on the emf. and the amount of resistance in our circuit.

Resistance is the inverse to conductivity.

Current encounters resistance when passed over any conductor. Copper, silver and aluminum are good conductors, so offer very little resistance, while

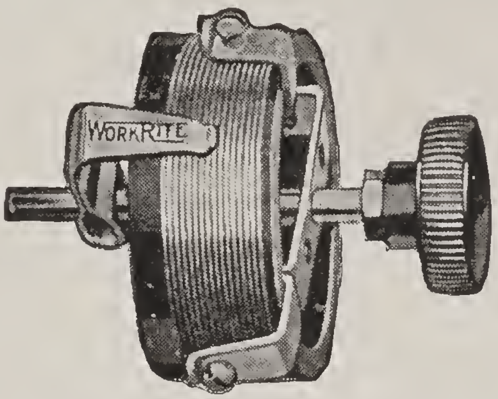
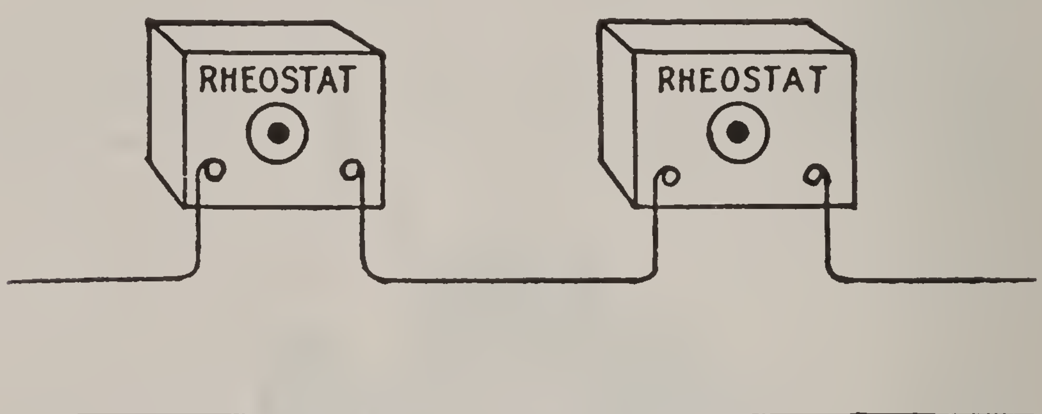


Fig. 7—Vernier Rheostat

metals like iron and German silver are poor conductors and offer a much higher resistance to the flow of current.

The resistance of any conductor increases, as the length of the conductor is increased, as the diameter of the conductor is decreased; or as the temperature of conductor is increased (the resistance of insulating material and carbon decreases with an increase of temperature). To find the resistance of a copper wire, multiply its length in feet by 10.5 and divide the product by its area in circular mills.

A rheostat is constructed of a number of metal coils or grids (these coils or grids are made of some metal offering high resistance to the flow of current over them, generally iron or German silver) connected in series, these coils or grids are mounted on a metal frame from which they are insulated, the whole thing being covered with a perforated metal cover. The



RHEOSTATS IN SERIES

Fig. 8

first and last coil are each connected to a terminal which allows for the connection of the conductors (see Fig. 6). The current enters the rheostat through terminal P, then passes through the coil or grid A to B, then to C and so on till it has passed through each of the coils in turn and leaves the rheostat through terminal S. Most of the rheostats manufactured today are of the adjustable type, so constructed that by the turning of an adjustable lever a number of the coils can be cut in or out of the circuit, thus cutting in or out resistance, thereby lowering or increasing the amperage. Fig. 9 is an elementary drawing showing how this is accomplished. P is the terminal through which the current enters the rheostat, S the terminal through which it leaves after having passed through the series of coils or grids. As will be seen by referring to the diagram (Fig. 9) it depends on which contact points 1, 2, 3, 4 or 5, the adjusting lever N is placed as to the number of coils

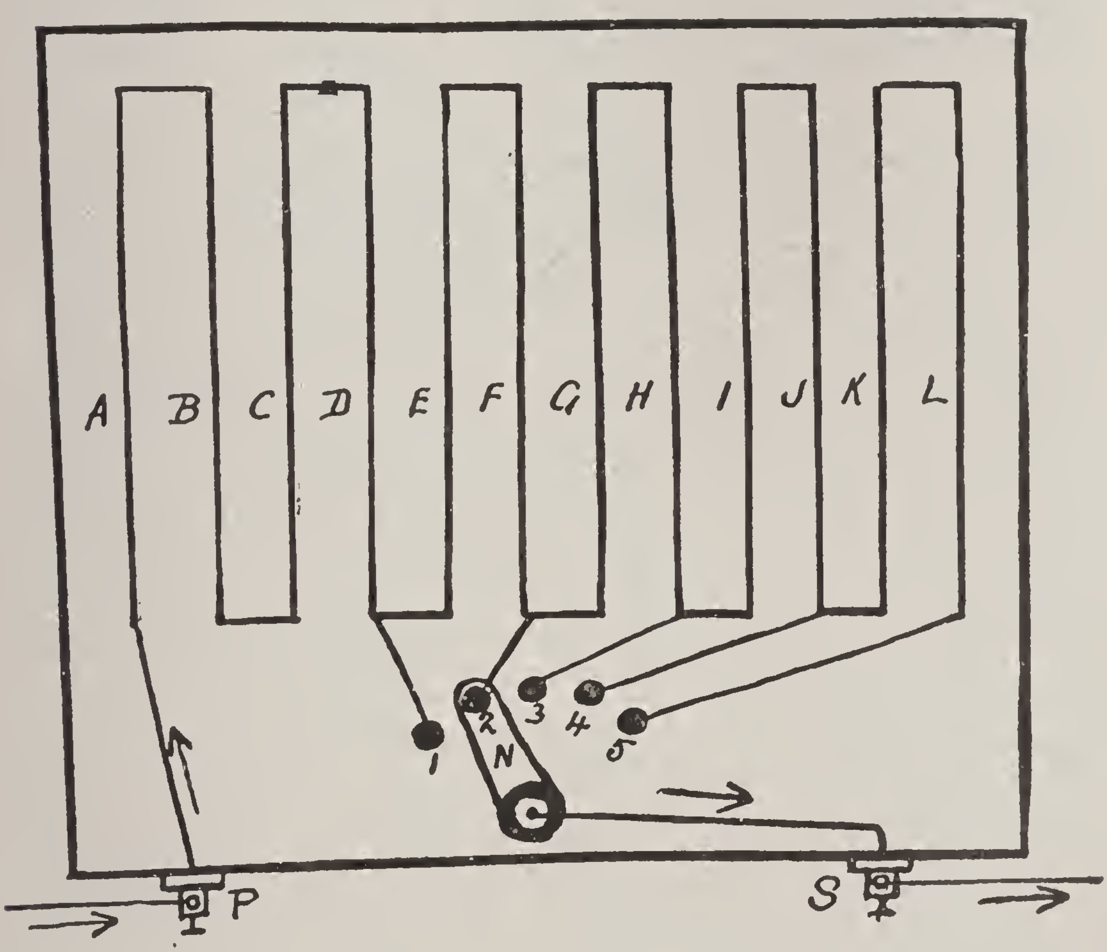
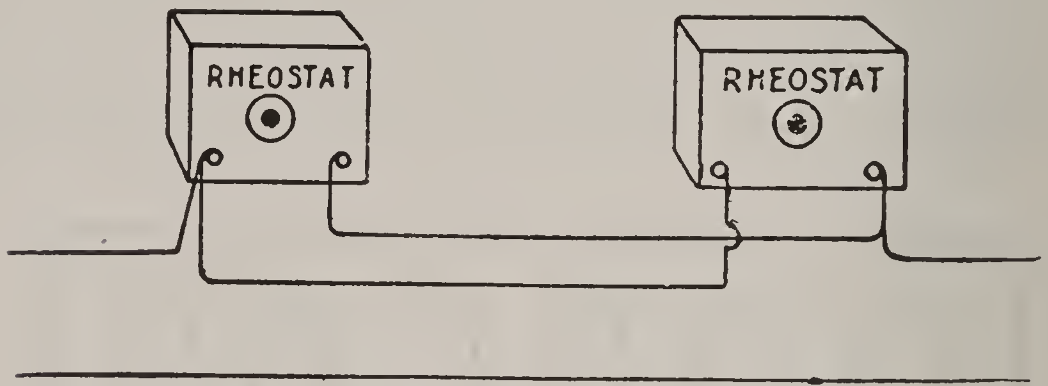


Fig. 9

through which the current will pass. With the lever "N" or contact No. 1 the current will pass through coils A B C D only, by turning the lever to contact

4, two coils K and L will be cut out of the circuit; while if lever is placed on contact 5 the current must pass through all the coils or grids before leaving through terminal S.



RHEOSTATS IN MULTIPLE

Fig. 10

TRANSFORMERS

A transformer is a device for changing the voltage and current of an alternating current circuit.

Transformers are spoken of as Step-up and Step-down transformers.

The three essential parts of a transformer are two copper coils, known as the primary and secondary, and a laminated iron core.

The core of the transformer is made up of a number of thin sheets of annealed iron; these sheets are very thin, generally running to one-hundredth part of an inch in thickness, the exact thickness depending upon the frequency of the circuit the transformer is to be used on. Each of the sheets is given a coat of some insulating compound, so that they are insulated from each other. The sheets are then built one upon the other in the form of a hollow square till a core large enough is obtained, the sheets are then clamped together and are insulated with mica or some other insulating material, so that the two copper coils may be wound around the core without the copper wire of the coils coming in contact with the iron core. Fig. 11 is a diagram of an elementary transformer, showing the primary coil wound around one leg of the core and the secondary coil wound around the opposite leg.

When we close the circuit on the primary side of transformer the current passing through the primary coil magnetizes the iron core, this magnetism in turn induces an a.c. current in the secondary coil. So that while the primary and secondary coil are insulated from the core and from each other, there is a magnetic connection between both coils and core.

If we turn back to the basic principle of induction the working principle of the transformer is made clear.

If an a, c, current is passed through a conductor encircling a bar of soft iron, the iron will become a magnet and remain so just as long as current is passed through the conductor.

If a bar of iron carrying a conductor around it be magnetized in a direction at right angles to the plane of the conductor a momentary emf will be induced in the conductor; if the current be reversed another momentary emf. will be induced in the opposite direction in the conductor.

The pressure induced in the secondary coil depends on the ratio between the number of turns in the primary and secondary coils. Suppose the primary coil has 100 turns of wire and is connected to a 100 volt line, and draws ten amperes, and the secondary coil has 50,000 turns of wire, the voltage on the secondary side of the transformer will be 50,000 but the amperage will be one-fiftieth of an ampere. So we see that the wattage on the primary is equal to the wattage on the secondary, assuming that there is no loss in transformation.

We know that there are two forms of losses in all transformers, the iron or core loss and the copper or coil loss.

All of the magnetic flux due to the current flowing in one winding and linked with that winding is not also linked with the other winding. The path of a certain part of the flux is through the air, outside of the core. This part of the flux due to one winding which is not linked with the other winding is called its "leakage" flux. In well-designed transformers this leakage flux is quite small. The leakage flux obviously is not effective in transferring energy from

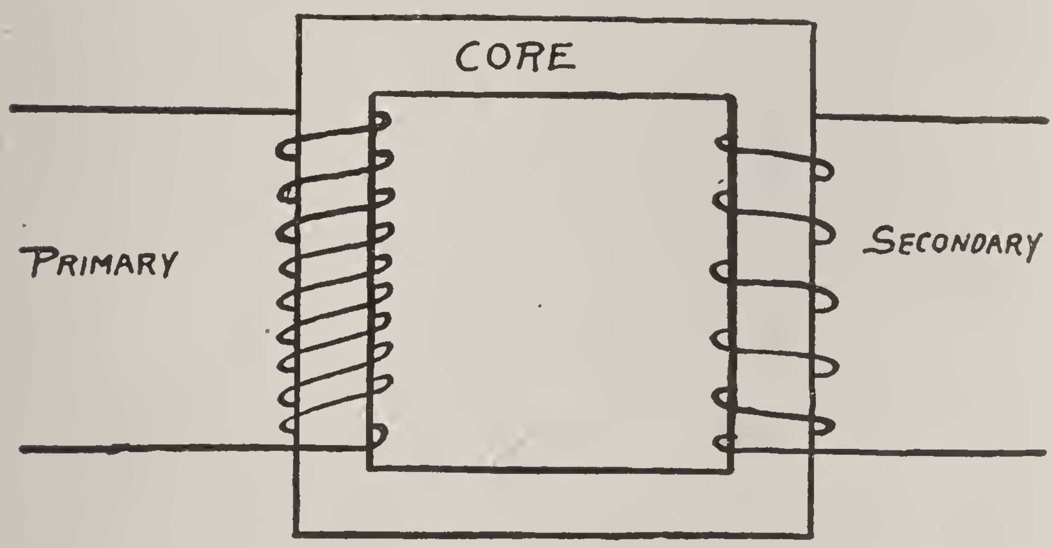


Fig. 11

one winding to the other. Leakage may be reduced by offering to the magnetic flux a complete path of high permeability. One way to do this is to use a closed core, so that the path of the magnetic flux is entirely through iron; in the open-core transformer part of the path of the magnetic flux is through air, and considerable leakage necessarily results. Another way is to use a core of large cross-section, so that the iron is worked at low flux densities. Leakage is also reduced by bringing the coils close together and making them approach coincidence. This may be done by winding one winding right on top of the other; very little magnetic flux can then be linked with one winding and not with the other.

The transformer is one of the most efficient kinds of electrical apparatus. The efficiency of well-designed transformers is usually from about 94 to 98 per cent, according to size, the larger units being the more efficient. There are "copper" losses in primary and secondary windings, equal to the resistance times the square of the current. There are "eddy current" losses due to the currents induced in the iron core. If the iron core were solid, currents would be set up in the whole cross section of the core in the same plane as the plane of a turn of winding. By using thin sheets of iron the path of the eddy currents is reduced, and hence the eddy-current loss. At comparatively low frequencies the eddy-current loss is proportional to the square of the frequency and also to the square of the thickness of the sheets or laminations. At radio frequencies other effects must be taken into consideration, and these relations do not hold. At high frequencies it is important to have the laminations as thin as possible. In transformers for commercial frequencies the thickness of the laminations is usually between 0.010 inch and 0.030 inch. If a solid core were used in a transformer for handling any considerable amount of power, enough heat might be quickly evolved by the eddy currents in the core to destroy the unit. There is also another loss in the iron, called the "hysteresis" loss. Hysteresis losses are caused by reversals of the magnetism of the core and represent the energy required to change the positions of the molecules of the iron core. At comparatively low frequencies hysteresis losses are directly proportional to the frequency and are greater the higher the flux density at which the iron is worked. The sum of the eddy-current losses and the hysteresis losses is known as the "core losses" or "iron losses."

The core losses occur as long as a voltage is applied to the primary and are nearly the same whether the secondary is delivering a load current or not. The current taken by the primary when the secondary circuit is open supplies these losses in the iron. It is therefore very important to design transformers so that the eddy-current losses and hysteresis losses are small. This is particularly important in transformers which are connected to the line all the time but supply a load during only a small part of the day, as transformers on electric-light systems, and is less important on transformers supplying full load secondary current all day, as transformers in a power house.

The cores of most transformers and other apparatus for alternating currents are now made of silicon steel instead of soft iron or a mild steel. One advantage of silicon steel is that when subjected to heat it does not age appreciably; that is, its permeability does not decrease with use. Ordinary soft iron will age rapidly with heat. Therefore a transformer with core of silicon steel can be operated at a higher temperature than a transformer with soft-iron core. Another important advantage of silicon steel is that its ohmic resistivity for electric currents is much higher than soft iron, and therefore in a given transformer the eddy-current losses will be less with a silicon-steel core than with a soft-iron core. The permeability of silicon steel is about the same as the permeability of the soft iron which has been used for transformers. Practically all core transformers used for radio apparatus, for either transmitting or receiving, have cores made of silicon steel.

The losses represent electrical energy converted into heat. Some means must be provided for dissipating this heat, or the temperature of the transformer may rise until it is destroyed. Small sizes, including most of those found in radio stations of moderate size, may be cooled by simply being exposed to the air. The exposed surface of the windings must be sufficient to dissipate the heat. In larger sizes an air blast may be blown through the transformer. Large transformers are also cooled by immersing the windings in oil, which is kept cool by circulation.

If a tap is brought out from an intermediate point of the winding of an inductance coil, a part of the

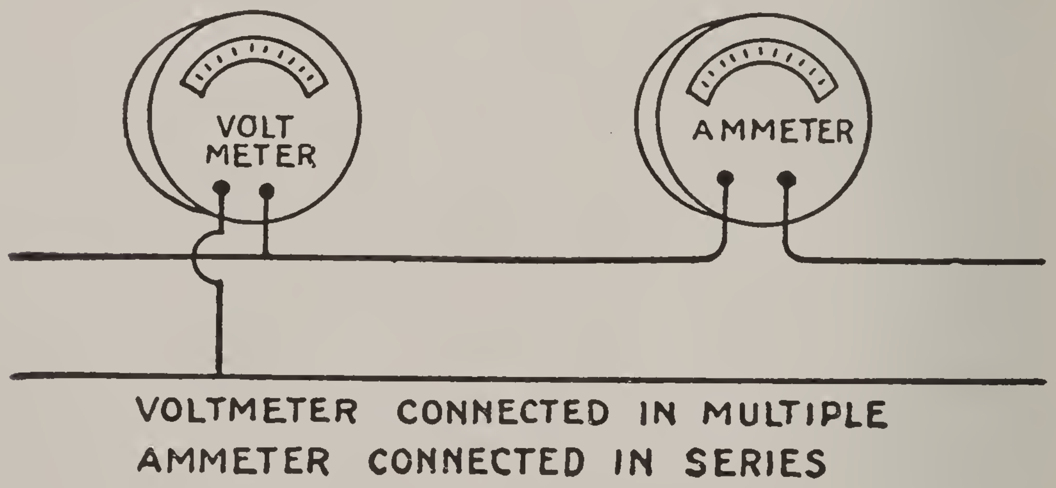


Fig 12

voltage applied at the terminals may be tapped off between one terminal and the intermediate tap. This can be considered to be a transformer in which one winding serves as both primary and secondary. It is simple and cheap, but has the disadvantage that the two windings are not insulated and the voltage to ground of the high-voltage winding also exists in the low-voltage circuit. Its use is confined for the most part to small sizes. This device is often called an "auto-transformer."

In radio apparatus the load on the secondary of a transformer usually includes a capacity. It may become desirable to adjust the system consisting of the a.c. generator, transformer, and secondary condenser so that the impedance of the primary circuit is a minimum; that is, so that the condition of "resonance" exists. This arrangement is called a "resonance transformer." With such an arrangement it is possible to obtain very high voltages. One type of transformer employing resonant circuits is sometimes called a "Tesla coil" and may be made to produce spectacular high-voltage effects.

On closing the primary switch when a transformer is first connected to the line a relatively very large current may flow for an instant, its magnitude depending on the state of magnetization in which the iron was left when the transformer was last disconnected from the line. This momentary current obtained on closing the primary line switch may in some cases be perhaps 10 times the primary rated full-load current and may blow the fuses in the primary line.

Transformers used for alternating currents of radio frequencies usually have air cores; that is, no iron is employed, as has been stated. If an iron core is used, very thin laminations are employed. At radio frequencies, the effectiveness of iron in increasing the magnetic flux is not as great as at low frequencies, the eddy currents contributing to this effect. Small radio-frequency transformers are used in electron tube amplifiers. Small transformers with iron cores, for frequencies up to perhaps 3,000, are also employed in electron tube amplifiers.

A common use of a transformer with radio frequencies is to obtain an alternating current from a pulsating current. For example, in the use of electron tubes for amplifying received signals, pulsations are produced in the plate current, above and below its normal steady value. By passing the plate current through the primary of a transformer, an amplified alternating emf. is obtained in the secondary, and this emf. is applied to the grid circuit of a second electron tube, and so on.

A reactance coil can be made by constructing a hollow coil of wire and sliding an iron core made of sheet iron in or out of it according to whatever adjustment is required. Number 10 wire is suitable for the coil and Number 12 wire for the primary coil. The coil is connected in series with the primary windings.

THE AERIAL

The aerial is a wire or system of wires strung above the surrounding objects and insulated from them and connected to a radio set by means of a lead-in wire. The same aerial can be used for either sending or receiving the electro-magnetic waves. The purpose of the aerial is to radiate electro-magnetic waves when used as the aerial for a transmitting or broadcasting station and to receive or intercept waves when used with the receiving set. Practically any sort of wire will answer the purposes for a receiving aerial. Copper wire, phosphor bronze, copper clad steel, in fact, we have seen used a metal smoke stack, wire netting, a tin roof, a metal bed spring and a number of other metal objects with varying degrees of success. However, for maximum results, we suggest that a single wire be used for receiving and that wherever possible the following dimensions be used:

Aerial Recommended for Various Wave Lengths.

Wave Length in Meters	Height from Ground in Ft.	Length of Aerial in Ft.
150	30	75
200	50	80
200	60	50
200	30	90
250	40	100
300	60	100
400	80	130
500	60	180
600	80	230

Of course, local conditions must be taken into consideration, and probably a little experimenting with aerials of different lengths placed at different angles will assist to get ideal working conditions. Aeroplane wire makes an ideal aerial as it is flexible and easy to work with. As for indoor aerials, these are becoming more popular every day, and the day is not far off when we shall be able to have our receiving set, aerial and loud speaker all enclosed in a cabinet no larger than our present day victrola. It is my opinion that the best indoor aerial is made by winding about 20 or 30 turns of copper wire on a wood frame about 2 feet square. However, both outdoor and indoor aerials may take a number of shapes and each will be found to have its own characteristics and different effects will be obtained from different combinations.

The effectiveness of the antenna system depends largely upon the character of the ground connection. The most practical ground connection is the water supply system. Where this is not available, pipes connected with the heating or gas systems may be used. The drawback with these pipes, however, is that the joints of these pipes are sometimes cemented with insulating material. Ground clamps for attaching the ground wire leading from the receiving set to the water pipes are obtainable at most dealers and electrical supply houses. The water pipes should be carefully scraped to remove all paint or corrosion before attaching clamp. Where the above mentioned means of ground connection is not available, wires or metal plates may be buried in the earth and connected to the apparatus. Such wires or plates should include an area of at least 30 square feet.

A counterpoise consisting of at least the same number of wires as are used in the antenna may be suspended beneath the antenna and used in place of a ground connection for the receiving apparatus.

There are two general classes of antennas, those which act primarily as electrical condensers and those which act primarily as electrical inductances. The

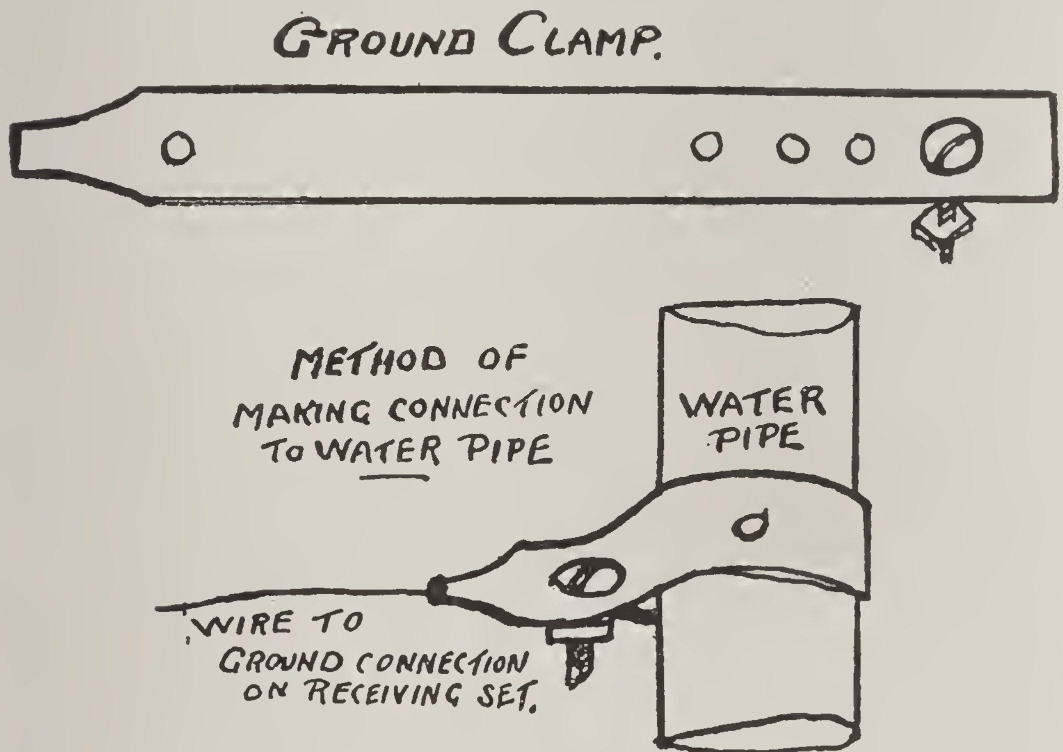


Fig. 13

first type is usually referred to simply as an "antenna." The second type is usually referred to as a "coil antenna," "coil aerial," "loop," or when used for a particular purpose, as a "direction finder."

A simple antenna of the condenser type would consist simply of two parallel metal plates, separated. The energy radiated or absorbed by an antenna of the condenser type depends on its capacity, and to form an antenna of large capacity two metal plates would have to be so large as to be very expensive and cumbersome.

Instead of using two parallel metal plates, it would be possible to form a condenser consisting of one metal plate suspended over and parallel to the ground, providing the surface of the ground is appreciably conducting. The plate is supported above the earth and insulated from it, except for the connection through the wire called the "lead-in wire," or "lead-in." The plate and the conducting surface of the earth form the two plates of a condenser, the air between them furnishing the dielectric. The apparatus used for receiving is introduced into the lead-in, between the plate and the ground. When radio waves reach an antenna they set up an alternating emf. between the wires and the ground. When an alternating emf. is introduced into the wire, charging currents flow into and out of the plate and the earth, the dielectric being strained first in one direction and then in the other. As has been explained in the previous chapter, these strains are equivalent to displacement currents of electricity through the dielectric, which serves to complete the circuit. A region in which the dielectric is undergoing alternating strains is the starting point of electric waves. The larger the plate and the higher it is raised from the earth, the greater the amount of space in which this strained condition exists, and the more powerful the waves which are radiated.

However, in order to construct with a given amount of metal an antenna having the greatest possible capacity, the metal should not be used in the form of a single plate. A much more efficient form consists of a number of parallel wires. The antennas found in practice usually consist of arrangements of wires. A single vertical wire is, for its size, the best radiator, but it has to be made extremely long in order to get sufficient capacity for long wave or long distance work. Antennas consisting of horizontal or inclined wires are, however, also very satisfactory. Any arrangement of wires which will constitute one plate of a condenser may be used, although some arrangements will radiate and receive much better than others.

A satisfactory antenna can also be constructed, using a suitable arrangement of wires for the upper plate of the condenser and using for the lower plate a number of parallel wires elevated a few feet from the earth and insulated from the earth. No connection is then made to the earth itself. The wires forming the lower plate of the condenser are then called a "counterpoise antenna" or simply a "counterpoise."

In reception electric waves reaching an antenna set up an alternating emf. between the wires forming the upper plate of the condenser, and the ground or other lower plate of the condenser. The longer and higher the wires forming the antenna the greater the emf. produced. As a result of this emf. an alternating current will flow in the antenna wires. The energy of the current is absorbed from the passing wave, just as some of the energy of a water wave is used up in causing vibrations in a slender reed which stands in its way.

An antenna consisting of horizontal parallel wires supported between two masts and insulated therefrom is common. This is a standard form for ship stations. If the lead-in wires are attached at the end of the horizontal wires the antenna is said to be of the inverted L type. If the lead-in wires are attached at the center of the horizontal wires, the antenna is said to be of the T type. Both of these types are found at many land stations, including amateur stations. The wires are kept apart by "spreaders," which may be of wood. These two types are often referred to as "flat-top" antennas.

The V type of antenna consists of two sets of horizontal or slightly inclined wires supported by three masts, so that the horizontal portions form an angle. The V type is used to some extent in military work, but is not much used elsewhere.

The "fan" or "harp" antenna consists of a number of wires radiating upwards from a common terminal to various points on a supporting wire to which they are connected. The supporting wire is insulated at each end from the tower or other support. Practical advantages of the fan type are that there are only two insulators, so that leakage is small, and that the mechanical strain to be carried by the supports is comparatively small.

The "cage" type of antenna is used to a considerable extent, particularly on ships. A number of parallel wires, often six or eight, are supported from a single point and are kept apart by star-shaped separators which may be of wood, or by hoops.

For transmission over short distances a very simple antenna may be used, such as, for example, a single wire supported between two stakes at a height of only a few feet from the ground. In some cases a long insulated wire may be laid upon the ground or in a shallow trench, forming a "ground antenna." For receiving stations equipped with good electron tube amplifiers very simple antennas may be employed, even for long-distance work, such as a single suspended wire, a ground antenna, or a coil antenna.

The umbrella type of antenna consists of a number of wires which diverge from the top of a mast, and are attached to anchors in the ground through insulators.

When an emf. is introduced into an antenna, a

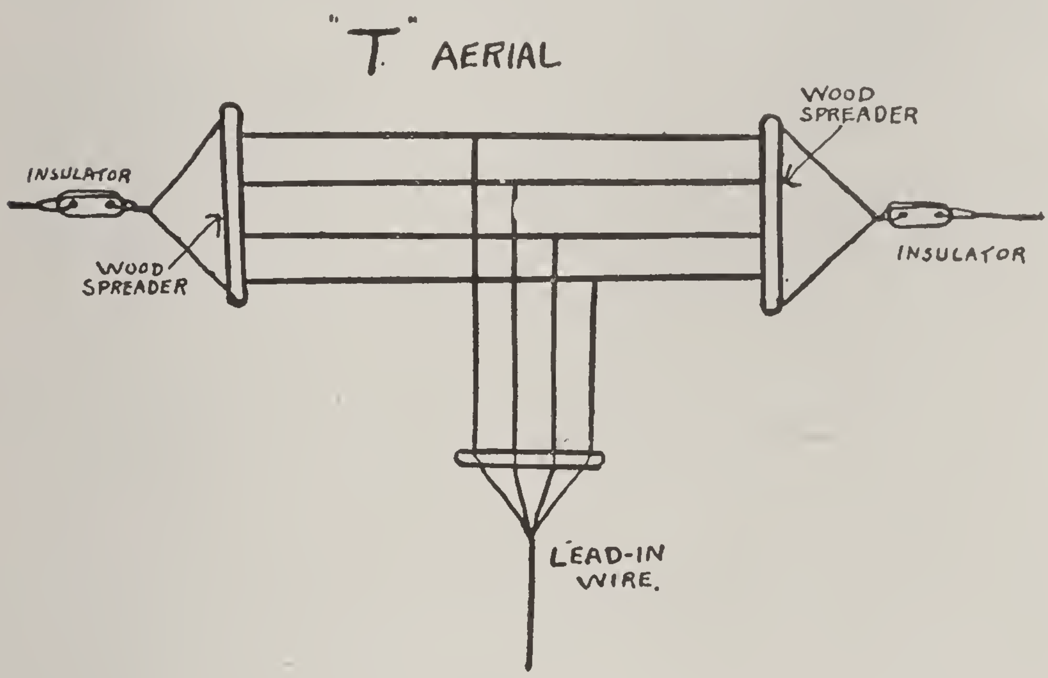


Fig. 14

charging current flows in the wires. If we attempt to form a picture of this process in the wire antenna, we must remember that every inch of the wire forms a little condenser, with the earth acting as the other plate. The antenna is said to have a distributed capacity.

As the electricity flows from the bottom of the antenna, some of it accumulates on each portion of the wire, causing a displacement current through the dielectric to earth. The current in the wire accordingly diminishes as the free end of the antenna is approached, and becomes zero at that end. The current is evidently different at different parts of the antenna, being zero at the free end and a maximum where the antenna is connected to the ground. This is in marked contrast to the case of a direct current, which always has the same value at every point of the circuit. The difference here is brought about by the very high frequency of the currents.

The voltage of the antenna, on the contrary, is zero at the grounded end and has a maximum value at the free end. In fact, the latter is the point where the most intense sparks can be drawn off; therefore the insulation of the antenna from near-by objects and the earth must be particularly good at this point.

A large capacity to earth, concentrated at any point of the antenna, causes a large change in the current at that part of the antenna. If this bunched capacity is located at the top of the antenna, such as is the case with a flat-topped antenna of long wires, with only a few vertical lead-in wires, the average current in the flat top portion will be large, and it increases slightly in strength as the charges pass down through the lead-in wire (picking up the charges there), hence giving a large current through the receiving apparatus. It is a distinct advantage to have as large a part of the total capacity of the antenna as possible at the top.

The wave length of the waves emitted by an antenna when no added inductance or capacity is inserted in the antenna circuit, is known as its "fundamental wave length." By putting inductance coils ("loading coils") in the antenna circuit, longer waves may be radiated, while on the contrary, condensers put in series with the antenna enable it to produce shorter waves than the fundamental. The use of a series condenser is avoided where possible, since it has the effect of decreasing the total capacity of the antenna circuit and thereby diminishing the amount of power which can be given to the antenna. The addition of some inductance has a beneficial effect, since the decrement of the antenna is thereby lessened and a sharper wave results. It is not advisable to load the antenna with a very great inductance, however, as it is not an efficient radiator of waves. The waves emitted are very much longer than the fundamental wave length. As a general rule small sending stations, for short ranges, work best on short waves, and long-distance stations on long waves. Long waves have the advantage for long distance work that they are not absorbed in traveling long distances to the extent that short waves are.

The United States radio laws at present provide that every commercial radio station shall be required to designate a certain definite wave length as its normal transmitting and receiving wave length, and that this wave length must not exceed 600 meters or must be longer than 1600 meters. Ship stations must be equipped to transmit on either 300 or 600 meters. Amateur stations must not transmit on a wave length exceeding 200 meters. It is probable that the radio laws will be revised in the immediate future.

Communication with ships is usually carried on with a wave length of about 600 meters. Radio compass stations on shore operate on 800 meters, and radio beacon stations on shore, which transmit to ships to enable the navigator on the ship to determine its position, usually operate on 1000 meters. Most high-power stations, such as those for transatlantic work, operate on a wave length of at least 2500 meters, usually considerably more. The Annapolis station, for instance, operates on about 16,900 meters and the New Brunswick station on about 13,600 meters.

For a simple vertical wire grounded antenna the fundamental wave length is slightly greater than four times the length of the wire. The constant is often used as 4.2, and applies approximately also to flat top antennas (L or T types) with vertical lead-in wire, the total length being measured from the transmitting apparatus up the lead-in wire and over to the end of the flat top. It is usually easier, and certainly more accurate, to measure the wave length radiated from an antenna directly by the use of a wavemeter. The wavemeter coil needs merely to be brought somewhere near the antenna or lead-in wire and the condenser of the wavemeter adjusted to give maximum current in the wavemeter indicator. The wave length corresponding to the wavemeter setting is then the length of the waves radiated by the antenna. The "fundamental" wave length of the antenna may be determined by gradually decreasing the number of turns in the loading coil, measuring the wave length for each setting of the loading coil, and plotting a curve showing the wave length corresponding to the various numbers of turns of the loading coil. The "fundamental" is the wave length corresponding to zero turns, and corresponds to the point where the extension of the curve cuts the wave length axis.

The amateur is required by law to transmit on a wave length not exceeding 200 meters and is interested to know the kind of antenna to use. It is impossible to give an exact rule for constructing an antenna for a particular wave length, because many local conditions peculiar to each case must receive consideration. An approximate rule which will be found convenient in constructing an antenna which is to transmit on a wave length not exceeding 200 meters is that the over-all length of the circuit from the ground connection through the entire path which the current follows to the end of the antenna must not exceed 120 feet. This distance, 120 feet, includes the distance from ground up the ground lead to the antenna switch, from the antenna switch to the oscillation transformer and back to the antenna switch, through the antenna lead-in to the antenna top, and along the antenna top to its end. This approximate rule applies to the various types of antennas ordinarily found at amateur stations, including inverted *L*, *T*, and fans. In the case of an antenna, for which the lead-in is taken off the antenna top at an intermediate point, as in a *T* antenna, the distance along the antenna top should be measured to the most distant end of the top, if the lead-in is not connected at the middle of the top. If an antenna is constructed in which the distance measured as described does not exceed 120 feet, it is probable that with suitable transmitting apparatus and no loading it will be possible to transmit on less than 200 meters, but if loading inductances are used or equivalent changes made in the transmitting apparatus the emitted wave length may, of course, considerably exceed 200 meters.

It is a familiar fact that devices for transmitting or receiving wave motion of any kind, which are not symmetrical with respect to a line perpendicular to the plane in which the wave travels, will transmit and receive better in one direction than in another. Thus a resonator for receiving sound from a distance should be turned perpendicular to the direction of the source of the sound, to give the maximum response.

A single vertical wire forms an antenna which is entirely symmetrical for radio waves traveling horizontally, and such a wire has no directional effect. If for a given antenna fixed in a given position we plot a curve showing the strength of the received current received from transmitting stations located in different directions, we will find this curve a very useful means of describing the directional characteristics of the antenna. For the single vertical wire the directional characteristic is simply a circle drawn with the foot of the wire as center. Most of the other types of antennas ordinarily used have directional properties, at least to some extent. The inverted L antenna has a considerable directional effect. An inverted L antenna with a long, low top such as are often found at large stations, has a marked directional effect. The length of the line drawn from the central point A in any direction indicates the strength of the current received from a transmitting station located in that direction. It will be noted that the inverted L transmits and receives best in the direction opposite to that in which the antenna top points. Ground antennas have marked directional characteristics. The most important type of directional antenna is, however, the coil antenna. Particular kinds of directional effects can be secured by combining different kinds of directional antennas.

The directional properties are most often made use of for receiving, but are also used for transmitting.

In transmitting, a considerable part of the energy may be concentrated in a particular direction by the use of a directional antenna, and the range of a transmitting station thus increased and interference decreased. Directive transmission may also be very helpful to a ship or airplane in aiding it to determine its location.

In receiving, an antenna having a marked directional characteristic, such as a coil antenna, will receive strong signals from a particular direction, and weaker signals from other directions. This is valuable in reducing interference from stations which it is not desired to receive, since in general the interfer-

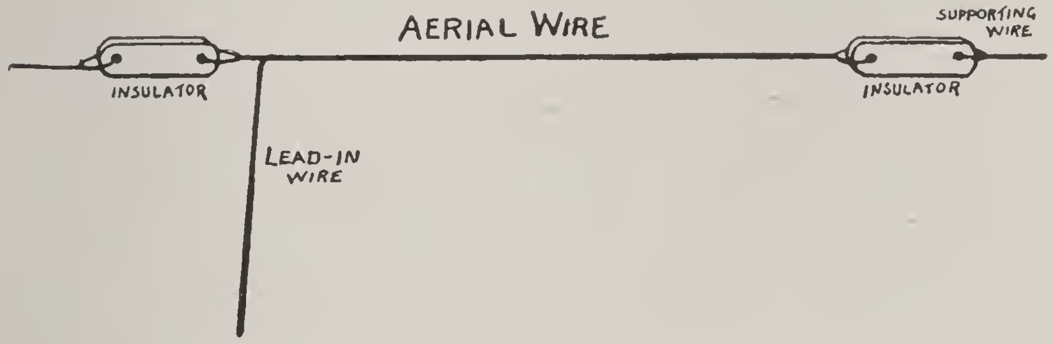


Fig. 15

ing station is not likely to lie in the same direction as the station which it is desired to receive.

Antenna Construction

For land stations wooden masts have been much employed. For portable antennas these are made in sections, which fit together like a fishing rod. For higher-power stations latticed metal masts are common and in some cases tubular metal masts in telescoping sections. Except in special instances, guy ropes or wires are necessary, and in some cases the support is sustained entirely by these. It has been quite generally regarded as a structural advantage to allow a small freedom of movement to the mast, so that it may rock slightly in the wind. A simple one-wire antenna may be held by any support that is available. When a tree is used to support either end, a rope should run out for some distance from the tree and the wire be attached to this by an insulator, so that the antenna wire itself may not be in or near the tree. The standard flat-top ship antenna makes use of the ship's masts for supports. The antenna wires are stretched between two booms or spreaders, from which halyards run to the masts.

The insulation of an antenna is a matter requiring careful attention. If an insulator is defective or dirty or wet, the energy radiated from the antenna will be considerably reduced. Defects of insulators may be caused by breakage after installation or faulty manufacture, such as small cracks or other openings through which the insulator may absorb water, or nonuniformity of the material of the insulator. Dirty insulators are likely to be found near industrial plants, and on ships wet or salt-covered insulators may cause trouble. Porcelain is one of the most satisfactory materials for use in constructing insulators because of the large voltages which it will stand without failure, but it is not suitable for use under severe mechanical vibration. Antenna insulators are often made of compositions, such as the material called "electrose," which is made with a shellac binder. These insulators are made in various shapes, including rods, and usually have eyebolts or other metal pieces molded in. Insulators are also made with ribs or petticoats, the purpose of the ribs is to lengthen the leakage path which the current must follow between eyebolts and to secure better insulation when the insulator is wet by collecting the water on the lowest points of the ribs. In the case of antennas for land stations, wire guys are interrupted by "strain" insulators to prevent the guy from having a natural wave length approximately the same as the wave length of the antenna.

Where the lead-in wires from the antenna pass through the walls of the house in which the sending and receiving apparatus is installed, special care needs to be taken to ensure good insulation. In the case of some large aerials, the supporting mast itself has to be insulated from the ground at its base. The design of an insulator which combines sufficient mechanical strength with good dielectric properties is a difficult matter.

An antenna switch is a necessity in all permanent installations. This has the function of disconnecting the receiving apparatus from the antenna completely when a message is to be sent, and vice versa. The action of such a switch is made such that it is impossible for the operator to make a mistake and impress the large sending voltage upon the delicate receiving apparatus.

Every radio station should be provided with a lightning switch on the outside of the building by means of which the antenna should be grounded at all times when not in use to avoid possible damage from lightning.

Antenna wire.—Desirable qualities in a metal to be used for antenna wire are that it shall not be brittle, that it shall be durable when exposed to weather and other conditions met in service, that its weight shall not be excessive, that its cost shall be reasonable, and that its ohmic resistance shall be low. It is also sometimes important that a metal used for antenna wire shall possess high tensile strength; this is obviously most important for large antennas of long span.

Hard-drawn copper wire is often used, but has the disadvantage that it is brittle and kinks easily. Tinned copper wire is sometimes used. Soft-drawn copper wire may also be used, depending on the tensile strength required for the distance to be covered. Aluminum wire is also used, and is satisfactory if careful attention is given to the connections and joints, to avoid corrosion. An important advantage of aluminum wire is that it is light. This is particularly important in large antennas, which cover long distances.

Iron or steel wire which has been heavily galvanized is also used. Since the current flows largely in the zinc coating, the resistance is much less than that of an ungalvanized steel wire. Steel wire to which a thick coating of copper has been permanently welded, is sometimes used. The resistance losses in the coated steel wires are about the same as in solid copper wire, provided that the coated steel conductors are not too close together.

Bare, uninsulated wires are in general use. In some cases the antenna wire is covered with a thin coating of enamel, whose purpose is to eliminate corrosion of the wire by exposure to the weather, smoke, or acid or other fumes.

Solid copper or other conductor, in sizes such as No. 14, is often used. Stranded conductor, however, has advantages, including flexibility, and lower resistance at high frequencies than solid conductor, because of the skin effect. In the stranded conductor for a given weight of copper there is much more cross-sectional area available for carrying the current than there is in the solid conductor. The individual strands should, however, always be enameled in stranded wire

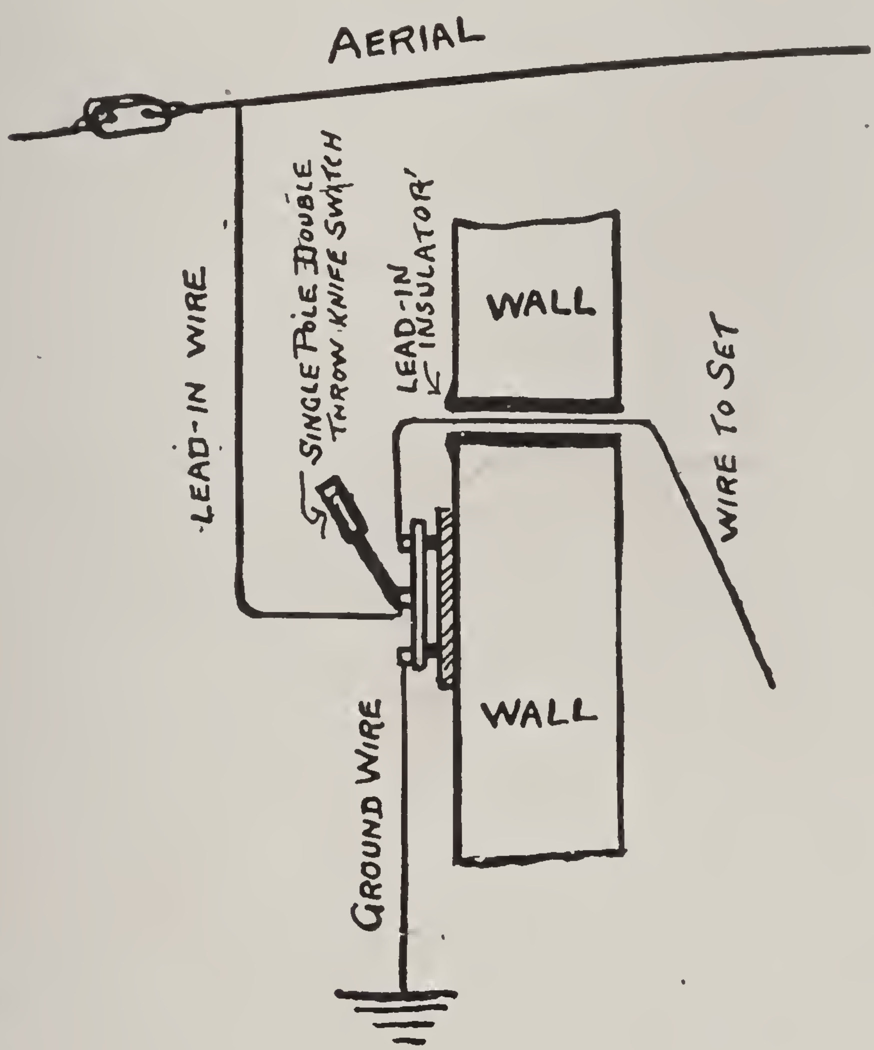


Fig. 16

used for radio-frequency currents, or the stranded conductor may have a higher resistance than solid conductor of the same weight.

An antenna conductor composed of seven or more strands of carefully enameled No. 22 copper wire is usually found to give good satisfaction. Antennas of unenameled solid conductor, which are very satisfactory on the day they are installed, after exposure for even a week to the weather, often show a very considerable increase of resistance. Phosphor-bronze stranded wire of seven or more strands is sometimes used, has a high tensile strength, but is open to the objections that it is relatively very expensive, and has a comparatively high ohmic resistance. Phosphor-bronze wire corrodes easily when exposed to weather, and when corroded is very likely to have higher resistance than a solid conductor. A silicon bronze wire is now being used to some extent, which does not corrode easily, has comparatively low ohmic resistance, high tensile strength, and has been found very satisfactory. For many ordinary antennas, hard-drawn solid copper wire, carefully enameled, will be found most convenient, and will give good satisfaction.

To obtain a good conducting ground connection is a comparatively easy matter for a ship station. In a steel ship a wire is attached to the hull of the ship and the good conductivity of the sea water assures an intimate connection with the ground. A usual method of grounding on a wooden ship propelled by steam is to connect the ground lead to the thrust box and depend on the propeller to make contact with the water. The hulls of some wooden ships are protected by being covered with copper sheathing, and a good ground connection may be made to this sheathing. In some cases a ground for a wooden ship may be made by means of a large metal plate attached to the outside of the ship, under water.

The ground connections for a land station should be designed with the idea of constructing one plate of a condenser of which the antenna is the upper plate. The area covered by the ground connections should be several times the area of the antenna, and should be laid out fairly symmetrically with respect to the antenna. The effort should be made to obtain a considerable number of points of contact with the earth, having paths of low resistance. Metal plates buried in the earth are often used. A good ground system may be constructed by burying metal plates of the same area, symmetrically arranged around the circumference of a circle having the station as the center, and connected to the station by wires suspended a short distance above the earth. A good general principle to follow is that the same current should be carried per unit area by each buried plate. If this principle is not observed, as in a ground system laid out at random consisting of a number of ground connections of different impedances located at varying distances from the station, it may be found that the over-all resistance of the system will be considerably greater than the resistance of the best one of the ground connections used alone. A considerable number of copper wires run radially from the foot of the antenna to a distance considerably greater than the length of the antenna will make a good ground if the earth is moist. When radial wires are used it is often found advantageous to run the wires for a short distance suspended above the ground before burying them. In dry localities a ground connection is sometimes made to a well; this may be found useful for receiving, but in general is not very satisfactory. In cities a ground connection may be made to water pipes or gas pipes. Connections to steam pipes and sometimes to gas pipes may be unsatisfactory because they may make poor contact with the ground. Connections to gas pipes should always be made between the meter and the street.

The counterpoise should be designed with the idea of constructing the lower plate of a condenser of which the antenna is the upper plate, and should cover an area at least as great as that of the antenna, and preferably somewhat greater. The counterpoise may consist of an arrangement of parallel or of radial wires, supported 3 or 4 feet above the surface of the ground and insulated from the ground. Metal screen may also be used. A counterpoise should be supported at as few points as possible to keep its resistance low. To construct an antenna system of low resistance it is necessary to take all precautions to keep low the resistance of the condenser constituting the antenna. Only those insulating materials should be allowed in the field of the counterpoise which have little dielectric power loss. Wooden stakes should be kept out of the field of the counterpoise, because wood usually has a considerable power loss. Porcelain insulators are usually satisfactory. The counterpoise should be carefully insulated from any wooden stakes which support it by suitable insulators. If used for transmission with continuous waves, a counterpoise should be rigidly supported so that it will not sway with the wind in order to prevent variations in the transmitted wave length.

Coil Antennas

The ordinary elevated antenna acts primarily as an electrical condenser, while the coil antenna can be considered to act primarily as an electrical inductance.

A coil antenna consists essentially of one or more turns of wire, forming a simple inductance coil.

In both types of antennas, an approaching radio wave induces an emf. in a wire or arrangement of wires. In the ordinary elevated antenna the induced emf. causes a current to flow in a circuit which includes a condenser consisting of the antenna and ground, or antenna and counterpoise. In the coil antenna the induced emf. causes a current to flow in a circuit connected to the detecting apparatus which is completely metallic.

It is a common experience in radio stations to be able to hear signals on a sensitive receiving set when the antenna is entirely disconnected from the set. This is largely due to the action of the wiring of the set as a coil antenna.

A common type of coil antenna consists of four turns of copper wire wound on a square wooden frame about 4 feet on a side. The amount of energy received on such a coil antenna is far less than that received on any of the ordinary elevated types of antennas as practically used.

It can not be emphasized too strongly that satisfactory results can not be expected in reception using coil antennas unless very good electron tubes amplifiers are used to amplify many times the feeble current received in the coil. Usually a six-stage amplifier is used for satisfactory results, but even with two stages of audio-frequency amplification, some signals can be received from nearby stations.

The practical development of the coil antenna and its present widespread applications are due entirely to the development of the electron tube amplifier to a high state of perfection.

Coil antennas may be used for either transmission or reception, but their use for transmission is rather limited, while their use for reception is extensive and constantly increasing.

A coil antenna may be used with satisfactory results inside an ordinary building. With suitable amplification a comparatively small coil can be used for receiving transatlantic stations.

Coil antennas are particularly used when a compact, portable, type of antenna is desired, or when an antenna having a marked directional characteristic is desired.

The action of the coil antenna can be considered from different points of view. We can imagine two vertical wires of the same length, say 300 meters apart, supported by and insulated from any convenient supports, with their lower ends also insulated. Then any radio wave approaching the two wires will induce an emf. in each wire. If the wave approaches from a direction perpendicular to the plane of the two wires, the crest of the wave will reach each of the wires at the same instant and the two induced emf.'s will be exactly in phase. If the wave approaches from any other direction, the induced emf.'s will in general be out of phase, and for a given wave length the difference of phase will be greatest for a wave approaching in the direction of the plane of the two wires. If we assume a wave approaching from the direction of the plane of the two wires and having a wave length of 600 meters, the emf.'s induced in the two wires will be 180° out of phase, because the time required for the wave to travel the distance of 300 meters between the two wires will be one one-millionth of a second, or one-half the time required for the wave to pass a given point. Hence the emf. at the lower end of one wire will have a positive maximum when the emf. at the lower end of the other wire has a negative maximum. If now the upper ends of the two wires are connected and receiving apparatus is connected across the lower ends of the two vertical wires, a current will flow in the rectangular circuit so formed and can be detected in the usual manner. The horizontal wires contribute nothing to the effective emf. in the coil circuit.

However, for a wave approaching from a direction perpendicular to the plane of the two coils the emf.'s induced in the two vertical wires will be exactly in phase, and the emf. at the lower end of one vertical wire will reach a maximum at the same instant as the

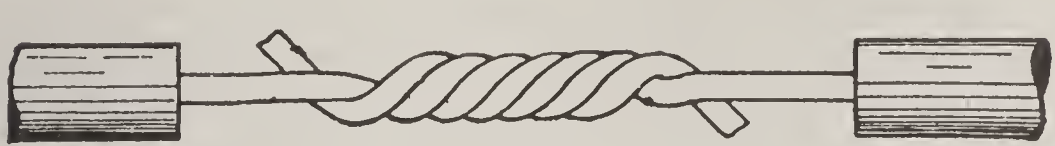


Fig. 17

emf. at the lower end of the other vertical wire, and no current will flow in the rectangular circuit.

A similar explanation will obtain for a wave length other than twice the distance between the two vertical wires. For a given wave length the maximum instantaneous potential difference will exist across the lower ends of the two wires for a wave approaching in the direction of the plane of the two wires, and no potential difference will exist for a wave approaching perpendicular to this direction.

The rectangular circuit, consisting of the two vertical wires and the two horizontal cross connections, of course constitutes a coil antenna. Coils consisting of two or more turns of wire can be regarded as equivalent to vertical antennas of two or more times the height of the side of the coil.

Another way of regarding the action of the coil antenna is to consider it as an inductance coil which is threaded by the magnetic field of varying intensity which is associated with a radio wave. This varying magnetic field is at right angles to the direction of travel of the wave, and it is horizontal. When the wave is traveling in the plane of the coil, the maximum number of lines of magnetic force are linked with the coil. When the wave is traveling in a direction perpendicular to the plane of the coil, no lines of magnetic force are linked with the coil and no emf. is induced in the coil.

It is obvious that if the coil is mounted on a frame which can be rotated about a vertical axis, then for a wave approaching from a given direction the position of the coil can be adjusted so that zero signal will be obtained in receiving apparatus connected in the coil circuit. The adjustment of the position of a coil for zero signal is analogous to the adjustment of the arms of a Wheatstone bridge to obtain zero current in the galvanometer or other detecting apparatus used with the bridge.

The turns of a coil antenna possess a distributed capacity of their own, and the coil has a natural or fundamental wave length of its own. The fundamental wave length of a coil antenna is the wave length which is radiated by the coil when oscillating freely by itself without being loaded with any other capacity or inductance. As a guiding rule, it may be stated that a coil antenna should not be used to receive waves which are shorter than about two or three times its fundamental wave length. However, when not used for direction-finder purposes, very satisfactory results can be obtained by using a coil near its natural wave length. That is, to receive short waves a coil of small inductance and small distributed capacity should be used. Such a coil must have few turns. To receive longer waves, coils of a larger number of turns may be used. Experience shows that best results are obtained with one or two turns embracing a large area for use with short waves, and for long waves coils with 20 to 30 turns, or even 100 turns, not so large in area.

It is, of course, desirable to make the received current as large as possible. It is found that in a coil antenna turned in the direction of the approaching waves the received current is greater, the larger the number of turns of wire on the coil, the greater the area of the coil and the greater its inductance. The current varies directly as the area, directly as the number of turns, inversely as the resistance, and inversely as the wave length of the wave which is being received.

It would seem at first sight that the increase in resistance due to increasing the number of turns and their area would be offset by the rapid increase of the inductance with the number of turns and the area of the coil. The resistance to high-frequency currents is, however, dependent on the wave length and increases rapidly as the latter approaches the value of the fundamental wave length of the coil.

For convenience of construction square coils are found to be the most suitable. The wire may be wound in a flat spiral or on the surface of a square frame. With flat spirals only a few turns are used, since the inner turns rapidly become less useful as the area diminishes. The spiral type of coil is comparatively little used in the United States.

The usual type of coil antenna consists of one or more turns of wire wound on a square or rectangular frame. One or two turns of copper wire wound on a simple wooden frame 3 or 4 feet square will make a simple coil which will be suitable for some purposes. For indoor use for all ordinary purposes the wire used for a coil antenna may be No. 20 or No. 22 ordinary insulated copper wire, with solid conductor.

The spacing of the turns of a coil depends on the allowable capacity of the coil. Spacings of one-half inch and 1 inch are common; a spacing of one-quarter inch is also used sometimes.

The capacity of a coil of given dimensions increases with the number of turns, at first rapidly, and then more slowly. With the wires close together, the capacity is a maximum and grows rapidly less when the wires are separated, until a certain critical spacing is reached, beyond which the capacity changes very slowly.

For a square coil 8 feet on a side the wires should be placed at least 0.35 inch apart; for one 4 feet square, 0.2 inch; and for a 2-foot coil, one-eighth inch. Increasing the distance between the wires decreases the inductance of the coil; at the same time it reduces the capacity. However, it is found that, for a given length of wire, properly spaced as just indicated, the fundamental wave length of the coil is about the same with different dimensions. This fact is illustrated in the following table, where 96 feet of wire are used in each case.

Characteristics of coil antennas

Length of a side of the square (feet).	Number of turns.	Spacing of wire (inch).	Inductance (micro-henries).	Capacity micro-farads.	Fundamental wave length (meters).
8	3	½	96	75	160
6	4	¼	124	66	170
4	6	¼	154	55	174
3	8	⅛	193	49	183

These coils should be used with a condenser of sufficient capacity to bring them into resonance at 500 to 600 meters. The first coil would be most suitable for these wave lengths on account of its small high-frequency resistance and greater effective area.

The following observations, taken on actual coils, show the effective wave-length ranges of different types of construction for a given capacity of tuning condenser, connected directly across the coil terminals.

Coil, 5 feet square, spacing of turns in each case, one-half inch. Using variable condenser having maximum capacity 0.00065 microfarad, minimum capacity 0.00004 microfarad.

With 4 turns............... λ=200 to 400 meters.
With 8 turns............... λ=350 to 700 meters.
With 16 turns.............. λ=500 to 1000 meters.

Coil, 5 feet square. Spacing of turns, one-half inch. Using variable condenser having maximum capacity 0.00140 microfarad, minimum 0.000045 microfarad.

With 4 turns............... λ=380 to 650 meters.
With 8 turns............... λ=400 to 950 meters.
With 16 turns.............. λ=675 to 2300 meters.

Coil, 4 feet square. Four turns, spaced 1 inch. Using variable condenser having maximum capacity

0.00140 microfarad, minimum 0.000045 microfarad, $\lambda = 180$ to 500 meters.

Coil, 4 feet square. Four turns, spaced 1 inch. Using variable condenser having maximum capacity 0.00060 microfarad, minimum 0.00004 microfarad, $\lambda = 150$ to 350 meters.

The distance over which coil antennas can be used

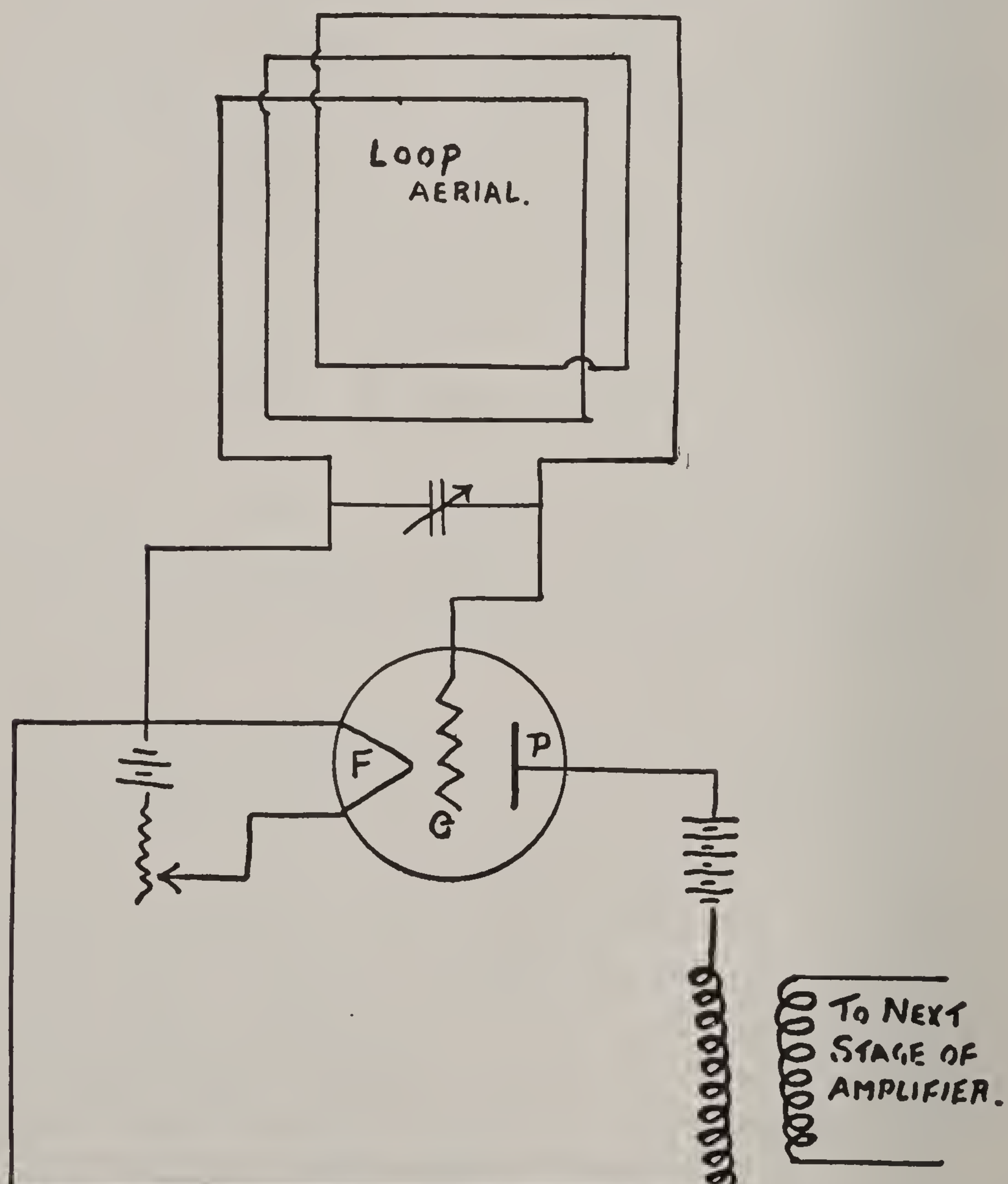


Fig. 18

for the reception of field transmitting sets is, of course, short. When used to receive high-power stations, however, very good results may be obtained. With good amplification the high-power European stations can be heard in Washington, using coil antennas such as have been described. An instance is on record where all the great European stations were received in France on a coil only 18 centimeters square, having 200 turns. On a coil 10 inches in diameter signals have been received in Paris from the arc station at Annapolis.

The name "resonance wave coil" has been applied to a coil antenna consisting of a large number of turns of very fine wire wound on a tube a few inches in diameter. When one terminal of such a coil is connected to ground and the other end left free, and a turn or two of wire coupled to the coil and connected to the input of a good amplifier, signals can be received from a considerable distance. Such a device, however, does not act entirely as a coil antenna.

It is not necessary that a coil antenna be entirely insulated from ground, although this is desirable. Signals can be received with a single-turn coil having the lower cross connection completed through the ground. Thus, in a large building having two perpendicular pipes, perhaps 30 feet or more long and a similar distance apart, running direct from the ground up above the roof, a workable single-turn coil antenna can be constructed by simply connecting the upper ends of the pipes by a wire and inserting the receiving apparatus in the middle of the wire. The current flows from the top of one pipe down that pipe, through the ground, up the other pipe, and across the connecting wire through the receiving apparatus to the top of the first pipe. Good results have been obtained with such a single turn coil, and it has been found to have well-marked directional properties. Since it is always grounded, it is at all times protected against lightning. If it is not convenient to locate the receiving apparatus on the top floor of the building, a pair of wires may be tapped in on the upper connecting wire and run down to a lower floor. On account of the large size of a loop of this kind it is not well adapted for the reception of waves less than about 1000 meters in length, the effective working wave length range of a particular loop depending of course on its dimensions.

Aerial Outfit

The Westinghouse Electric & Manufacturing Company have provided a standard aerial outfit which is ideal for amateur and broadcasting reception. It is especially well adapted to use with their sets. The outfit consists of 150 feet of No. 14 Copper Weld Wire, one Splicer, two Micarta Aerial insulators,

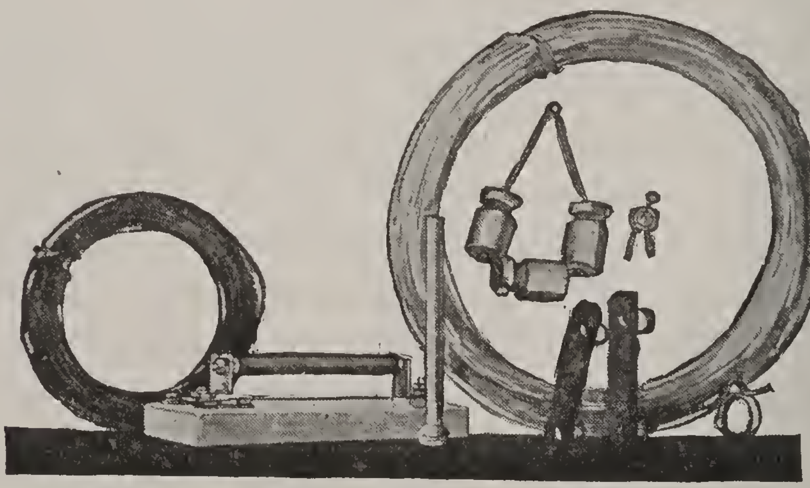


Fig. 19—Westinghouse Complete Aerial Outfit

two Screw Eyes, three Porcelain Knobs with holding screws, one Porcelain Wall Tube, 50 feet of insulated Ground Wire, one Ground Clamp and one Receiving Aerial Protective Device.

The Aerial Protective Device consists of a carefully maintained safety gap and a fuse protector. The safety gap is so set and the value of the fuse such as to assure protection from lightning and power lines.

COUPLED CIRCUITS

When two circuits have some part in common or are linked together through a magnetic or an electrostatic field they are said to be "coupled." If two circuits have an inductance coil in common their relation is said to be "direct inductive coupling." If they have a condenser in common, their relation is said to be "direct capacitive coupling." If they have a resistance in common, their relation is said to be "resistance coupling." If two circuits are mutually in-

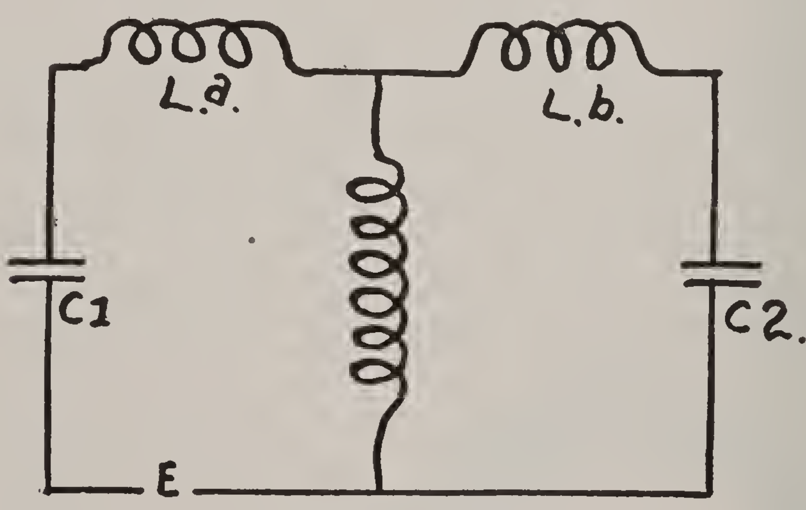


Fig. 20—Direct Coupling

ductive and have no part in common other than the mutual inductance, their relation is said to be "indirect inductive coupling," usually called simply "inductive coupling." Sometimes the coupling is modified by using two additional condensers. Each circuit contains two condensers in series and one condenser in the first circuit is coupled to one condenser in the second circuit through a coupling condenser; this is described as "indirect capacitive coupling." Mutual inductive coupling is used very extensively in constructing radio apparatus. It often happens that the two coils constituting a mutual inductance are so mounted that they also constitute the two plates of a condenser whose capacitive reactance is appreciable

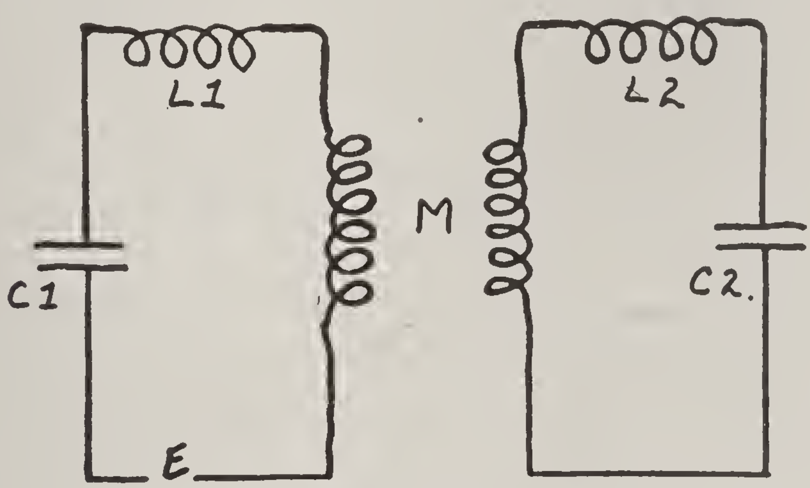


Fig. 21—Inductive Coupling

at radio frequencies, and in this case the effect of the coupled coils is a combination of inductive coupling and capacitive coupling.

It is customary to denote as the "primary" that circuit in which the applied emf. is found, the other being regarded as the "secondary" circuit. When two circuits are coupled they react on one another so that the current in each circuit is not the same as would be the case were the other circuit absent. The extent of the reaction is, however, very different in different cases. Circuits are said to be "closely coupled" when any change in the current in one is able to produce considerable effects in the other. When either circuit is little affected by the other the

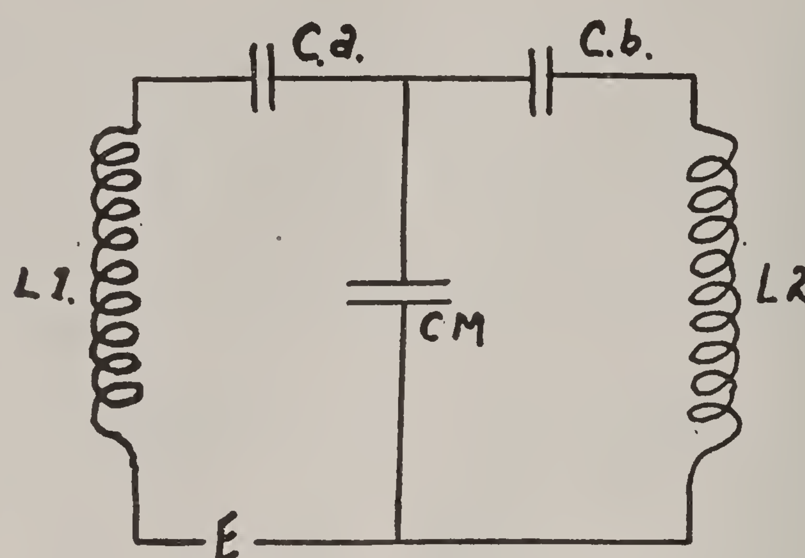


Fig. 22—Capacitive Coupling

coupling is regarded as "loose." The coupling between two inductively coupled circuits is changed by changing the distance between the two coupling coils. In general, increasing the distance between the two coils will make the coupling looser, providing each coil is moved parallel to its original position. If the distance between the two coils is not changed, but they are moved so that the angle between their projected axes is changed, the coupling will also be made looser, since fewer lines of force are then linked with both coils.

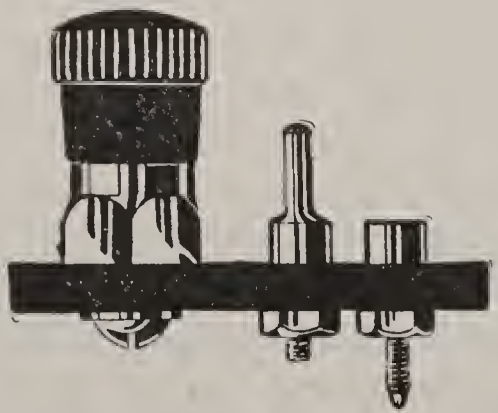


Fig. 23—Binding Posts

DAMPING

Thus far it has been assumed that a constant alternating voltage has been applied to radio circuits, in which case the alternating currents produced are of constant amplitude. Such currents may be regarded as analogous to the forced oscillations which are produced in a mechanical system like a swing or a pendulum, when it is acted upon by a force which varies periodically. The system is forced to vibrate with the same frequency as that of the force.

It is, however, possible to produce oscillations of

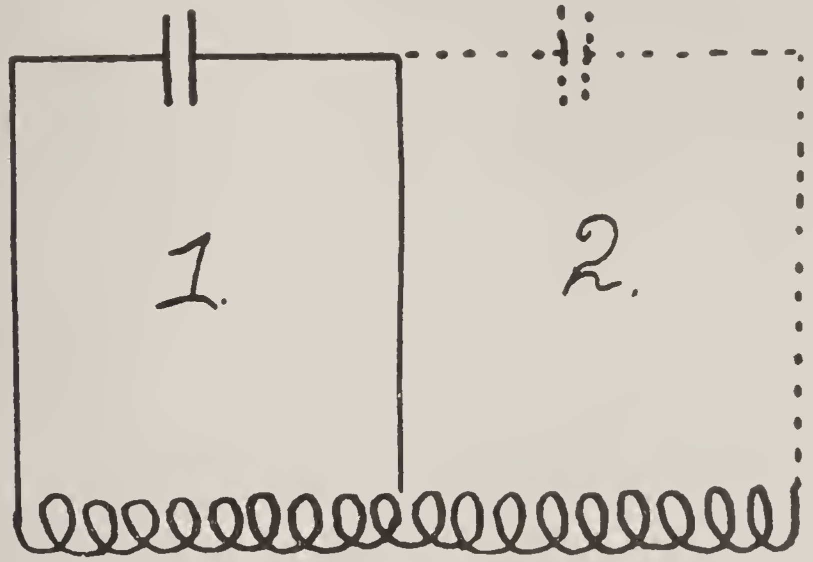


Fig. 24—Effect of Distributed Capacity in the Unused Turns of a Coil

current in a circuit without the necessity of providing a source of alternating emf. A common method is merely to charge a condenser and then to allow it to discharge through a simple radio circuit.

This may be accomplished, for example, by the simple means shown in Fig. 25. By throwing the switch S to the left, the condenser C is charged by the battery E, but when the switch is thrown to the right, it is discharged into the circuit containing the resistance R and the inductance L. If the resistance R is not too great, electric oscillations are set up which, however, steadily die away as their energy is dissipated in heat in the resistance.

To explain this action, we must follow more closely what takes place in the circuit from the moment when the condenser, charged up to a certain potential difference, is inserted in the discharge circuit. When the

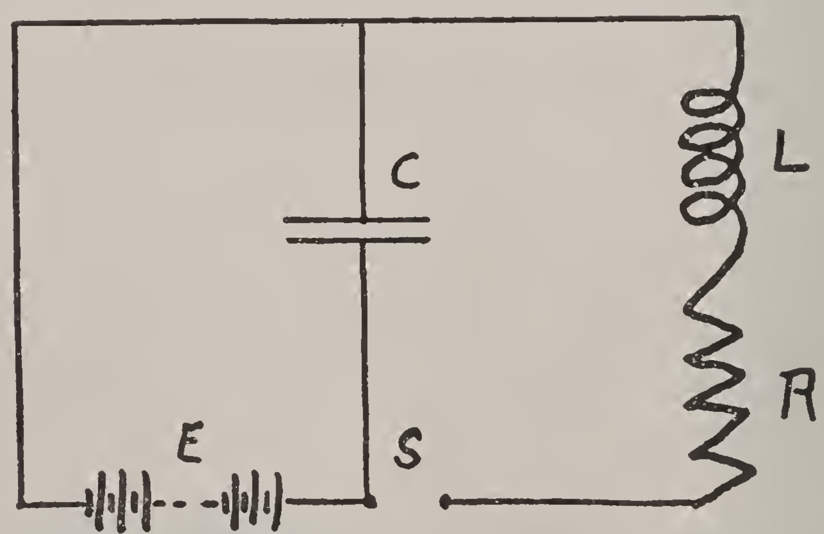


Fig. 25

condenser starts to discharge itself, a current flows out of it, and the potential difference of the plates decreases as a result. At the moment when the plates have reached the same potential, current is still flowing out of the condenser. The current has energy and can not be stopped instantly. In fact, to bring the current to zero value it is necessary to oppose it by an emf., and the amount of emf. necessary is greater the more quickly one wishes to stop the current. It is similar to the case of a moving body. On account of its motion the body possesses energy, and can not be brought to rest instantly. The greater the force which is opposed to it, the more quickly it may be brought to rest, but unless its motion is opposed by some force, it continues to move indefinitely without change of velocity.

The flow of current from the condenser, then, does not cease when the condenser has discharged itself, and, as a result, that plate which was originally at the lower potential takes on a higher potential than the other. The condenser is beginning to charge up in the opposite direction. The potential difference of the plates now acts in such a direction as to oppose the flow of the current, which decreases continually as the potential difference of the plates rises. If the resistance of the circuit were zero, the current would be zero (reversing) at that moment when the potential difference of the plates had become just equal to the original value. This is, the condenser would be as fully charged as at the beginning, only with the potential difference of the plates in the direction opposite to that at the start. Now begins a discharge of electricity from the condenser in the opposite direction to the first discharge, and this discharging current flows until the condenser has become fully recharged in the original direction. The cycle of operations then repeats itself, and so on, over and over again.

The action in the circuit may thus be described as a flow of electricity around the circuit, first in one direction and then in the other. The rate of flow (current) is greatest when the plates have no potential difference, and the current becomes zero and then begins to build up in the opposite direction at the moment when the potential difference of the plates reaches its maximum value. This alternate flow of electricity around the circuit first in one direction and then in the other is known as an "electrical oscillation." Since no outside source of emf., such as an a.c. generator, is acting in the circuit, the oscillations are said to be "free" oscillations.

Mechanical free oscillations are well known. Such, for example, are the swinging of a pendulum and the vibration of a spring which has been bent to one side and then let go. In the case of the pendulum the velocity with which it moves corresponds to the value of the current in the electrical case, while the height of the pendulum bob corresponds to the potential difference of the condenser plates. When the bob is at its highest point its velocity is zero, corresponding to the condenser when the plates are at their maximum potential difference and no current is flowing. When the pendulum bob is at its lowest position it is moving most rapidly. Similarly, when the plates of the condenser have zero potential difference, the current flowing has its maximum value. The pendulum does not stop moving when it passes through its lowest point; neither does the current cease at the moment when the condenser plates are at the same potential. The pendulum rises with a gradually decreasing velocity toward a point at the other end of the swing as high as the starting point. The current gradually decreases as the condenser charges up to an opposite potential difference equal to the original value. The return swing of the pendulum corresponds to the flow of current in the direction opposite to the original discharge.

A pendulum swinging in a vacuum and free from all friction would continue to swing indefinitely, each swing carrying it to the same height as the starting point. Similarly, electric oscillations would persist indefinitely in a circuit—that is, they would be "undamped" if there were no resistance to the current.

Actually, electric oscillations die down in a circuit and finally cease altogether, just as an actual pendulum will make shorter and shorter swings and finally come to rest. Since the occurrence of free oscillations in a circuit presupposes no interference with the circuit from outside, the circuit receives no energy beyond that imparted to it at the moment when the oscillations begin. Thereafter the circuit is self-contained, and any loss of its energy in heat and electromagnetic waves reduces by just so much the energy available for maintaining the oscillations. This loss of energy goes on continuously and the oscillations die away to nothing. They are said to be "damped" oscillations.

At the start there is a definite amount of energy present in a circuit, namely, the energy of the charge given the condenser. The amount of this energy depends upon the capacity of the condenser and the square of the potential difference between its plates (emf. to which it is charged). This energy exists in the dielectric of the condenser, which is in a strained condition due to the charge. As soon as the current begins to flow the condenser gives up some of its energy, and this begins to be associated with the current and is to be found in the magnetic field around the current; that is, principally in the region around the inductance coil. As the current rises in value under the action of the emf. of the condenser, energy is continually leaving the condenser and being stored in the magnetic field of the inductance coil. When the plates of the condenser have no potential difference, the whole energy of the circuits resides in the magnetic field of the coil and none in the condenser. Energy is then drawn from the coil as the current decreases and energy is stored up in the condenser as it is recharged.

If the resistance of the circuit were zero and no energy were radiated in waves or dissipated in other ways, the total energy of the circuit would be constant. The energy dissipated in heat and electric waves is, however, lost to the circuit, so that the total amount of energy, found by adding that present in the condenser to that in the inductance, steadily decreases. Finally all the original store of energy given the circuit has been dissipated and the oscillations cease.

The energy lost when a steady current is flowing in a circuit depends not only on the value of the current, but on the resistance of the circuit, and in a radio circuit this resistance is replaced by a somewhat larger quantity of the same kind, the "effective resistance." The greater the effective resistance the greater the amount of energy dissipated per second when a given current flows.

Ohm's law shows that to keep a current I flowing through a resistance R an emf. RI is necessary and this has to be furnished by the battery, generator, or other source. In an oscillating circuit the same is true, and that portion of the emf. in the circuit which is employed in forcing the current against the resistance is, of course, not available for charging the condenser or building up the discharge current. The changes of current in the circuit described above are thereby hindered, and the current does not rise to as great a value as it would in the absence of resistance. The maximum of emf. between the plates of the condenser is less each time the condenser is discharged, and thus the oscillations of the current die away.

A good analogy to damped electrical oscillations in a circuit is found in the vibrations of a flat spring, clamped at one end in a vise, and then bent to one side and released. The spring vibrates from side to side with decreasing amplitude, until finally it comes to rest in its unbent position. When the spring is bent energy is stored up in it—the energy of bending. On being released the spring moves and gains energy of motion, while the energy of bending decreases. If there were no friction the loss of one kind of energy would be just offset by the gain of the other kind and the sum total would remain constant. The spring would move past the natural undisturbed position, under the influence of its energy of motion, and would be brought to rest at a position just as far to the other side as was the starting point.

Friction has, however, the effect of opposing the motion and causing a dissipation of energy in heat, and each excursion away from the resting point is smaller than the one preceding.

Free oscillations, then, can take place in a circuit containing inductance and capacity. These would be undamped in the ideal case where the resistance can be regarded as zero. In all practical cases of free oscillations, however, the oscillations are damped. To produce undamped waves it is necessary to provide some source of power to make good the energy dissipated in the oscillating circuit. Strictly speaking, undamped free oscillations are impossible in actual circuits. It is of importance to study the effect of the resistance in determining the rapidity with which the oscillations die away.

WHAT HAPPENS IN A TRANSMITTING SET

An alternating current of low voltage enters the primary coil of the transformer, and sets up a magnetic field around the iron core. The secondary coil of the transformer cuts the lines of magnetic force and carries a new current of high voltage to the con-

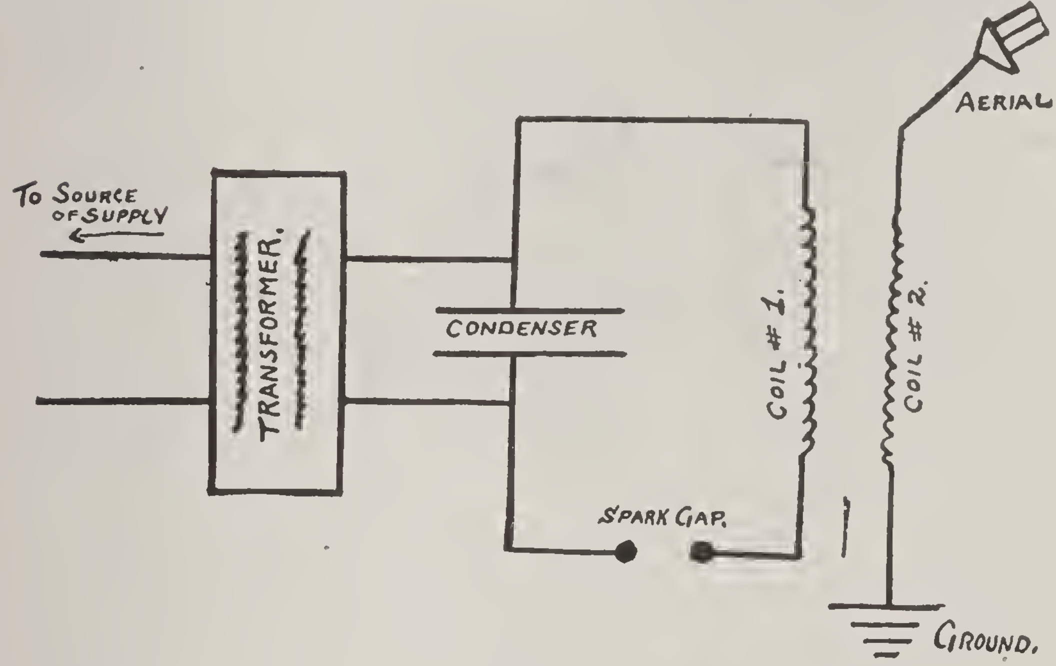


Fig. 26

denser. The condenser discharges a current of sufficient high voltage to jump between the terminals of the spark gap, and in so doing sets up an interchange of electrical energy between the condenser and coil No. 1. Fig. 26. This exchange of energy takes place at a frequency determined by the size of the coil No. 1 and the condenser. By regulating the size of coil No. 1

and the condenser, the size of the wavelength may be regulated as desired. This circuit is termed an "oscillating circuit" because the electrical energy oscillates between the condenser and the coil. The fluctuation of the current in coil No. 1 will induce an alternating current in coil No. 2, providing the two coils are in close proximity and are properly adjusted, and it will carry this current to the transmitting aerial, which will set up the desired disturbance in the ether and start off the electro-magnetic waves on their journey.

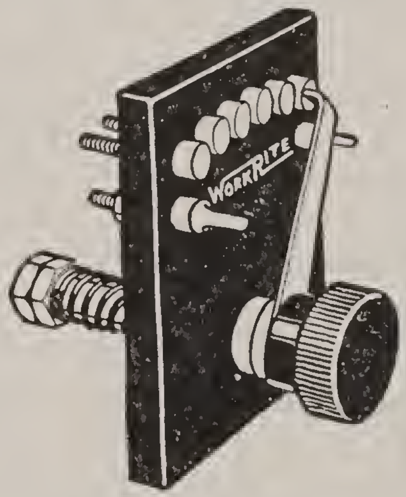


Fig. 27—Variable Contact Switch

THE WESTINGHOUSE TUBE TRANSMITTER

The Type TF Vacuum tube transmitter is designed for Radio communication over distances of at least fifteen miles by telephone or one hundred miles by continuous wave telegraphy.

Four 5-watt Radiotron U.V. 202 tubes, or equivalent, are used, the four tubes being connected in parallel for continuous wave telegraphy. For telephone transmission two of the tubes are used as oscillators and two as modulators.

A four pole double throw anti-capacity switch is provided for throwing from telegraph to telephone. The filament of the tubes are heated by a step-down transformer, the primary of which is connected to the 105 to 115 volt lighting circuit, the primary being tapped for 105, 110 or 115 voltage supply. This transformer is contained within the set.

The plate voltage for the tubes should range between 350 and 500 volts and may be obtained from any direct current source. The Westinghouse Electric & Manufacturing Company's 100-watt motor generator set Style No. 307212 is especially adapted for this purpose. The plate voltage source is fed to the tubes through audio and radio frequency choke coils. A .75 mfd paper condenser is shunted across the generator leads.

The Grid bias voltage for the modulator tubes is obtained by connecting a resistance variable in steps of 50 ohms, from 50 to 150 ohms, between the negative generator lead and the filament of the tubes.

A relay is provided for continuous wave telegraphing, the contacts of which open the negative lead of the plate supply, the magnet coil of the relay being energized by the 6-volt microphone battery in series with the telegraph key. The relay contacts are shunted by a condenser of .05 mfd capacity.

For telephone operation a microphone is connected in series with the 6-volt battery and primary of the modulation transformer, the secondary of this transformer being connected to the modulation tube filaments and grids.

Coupling between the oscillator tube grids and plates is effected through mica condensers and taps on the Antenna Loading Inductance. The oscillating circuit consists of antenna, radio frequency ammeter, loading inductance and counterpoise.

Binding posts are provided on the panel for connecting the telegraph key, 6-volt battery and microphone. The 110-volt A.C. supply to the filament transformer is connected by means of flexible cord brought out at the left hand end of the set. Binding posts are provided within the set for connecting the plate voltage supply.

The loads from the antenna and counterpoise are brought into the set through bushed holes in the back of the box and connected to binding posts on the Antenna Loading Inductance.

Operation

Connect the 105, 110 or 115-volt supply to the proper posts on the primary of the filament transformer. Connect the plate voltage supply to the proper binding posts, positive lead of the generator to positive binding posts. Connect the antenna and counterpoise through the bushed holes of the box to the binding posts within the set marked antenna and counterpoise, connect the 6-volt microphone battery to the binding posts on the panel which are so marked.

Telegraphing

Throw the transfer switch to the position marked "CW" and bring the plate voltage up to 350 volts. Close the telegraph key and note radiation, ammeter should read 1.7 to 1.9 amperes. Oscillation should take place the instant the key is pressed.

Telephony

Throw the transfer switch to the position marked "Phone" and with 350 volts on the plate the radiation should be 1.2 to 1.4 amperes. When a loud tone is sounded into the microphone the antenna current should increase .1 to .2 amperes.

The speech as received on a crystal or a single tube detector, in the vicinity of the set, will be found to be very clear and understandable and the generator and 60 cycle hum will be negligible in volume compared with the speech.

When a higher voltage than 350 is used on the plate a further increase of grid bias within the set will be necessary.

The proper antenna for this set would be one of four wires spaced 2½ ft. and 75 ft. in length. A counterpoise having the same dimensions as the antenna and separated from the antenna by 20 to 50 ft. would give much better results than a ground due to its having lower losses. The capacity of the above antenna would be approximately .0005 mfd.

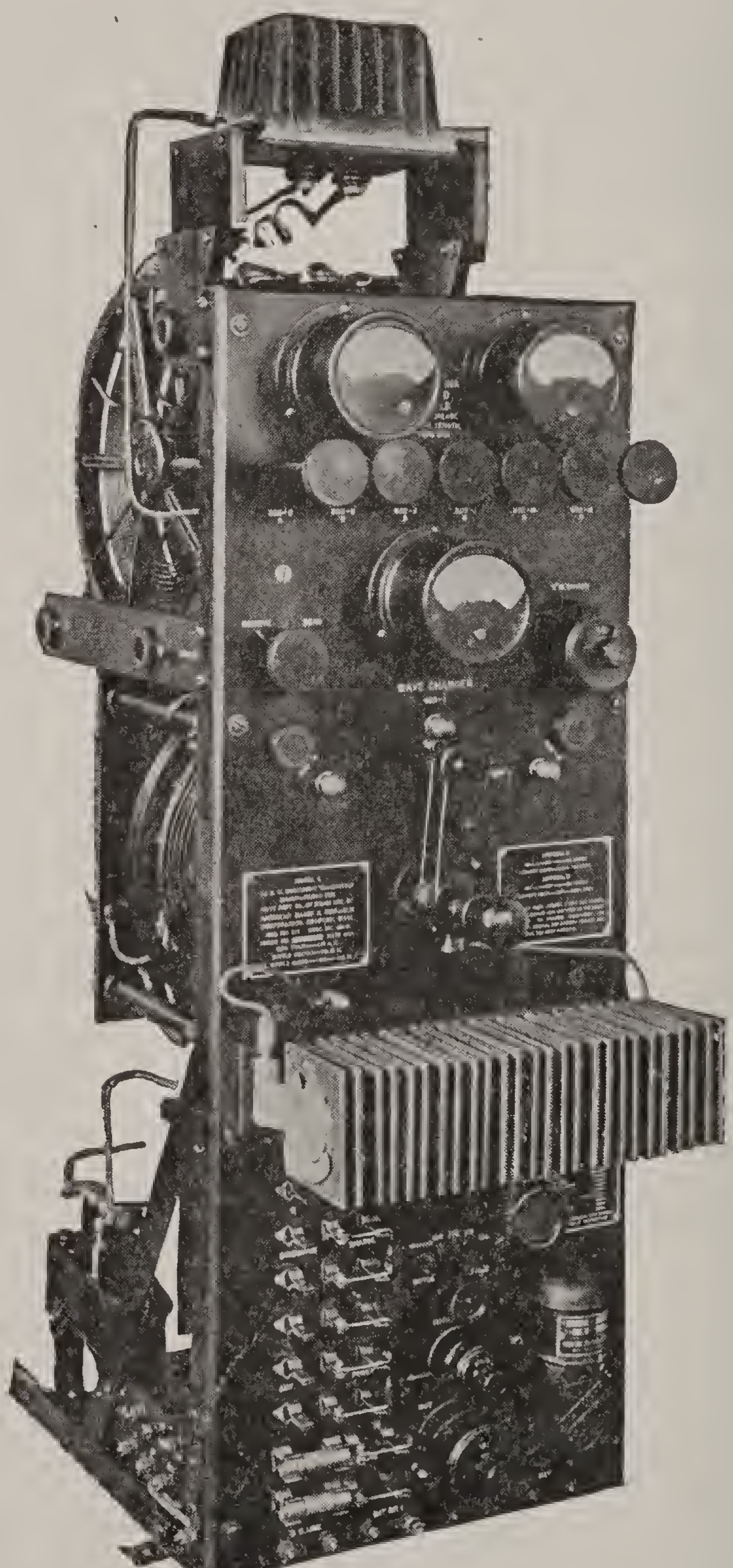


Fig. 28—½ K.W. Transmitter

Apparatus for Undamped Wave Transmission

Undamped oscillations are not broken up into groups like damped oscillations. Exactly similar current cycles follow one another continuously, except as they are interrupted by the sending key or subjected to variations in amplitude. The principal sources of undamped oscillations are the high-frequency alternator, the arc converter, and electron tubes. The timed spark transmitter emits waves which are only very slightly damped.

For transmission over long distances, as between the United States and France, it has been found that much better results are usually obtained by the use of undamped waves. Damped waves are, however, still used for some long-distance work. Desirable characteristics in transmitting apparatus for use in long-distance work are that it should generate a "pure wave"—that is, a fundamental wave in which practically no harmonics are present—that it should provide reliable service economically, that it can be manufactured in units of large size, that it be adapted to high-speed signaling, and that it will efficiently generate a wave of considerable length. For long-distance work it is in fact essential that long wave lengths be used. Thus the usual wave length used by the Annapolis 500-kw. arc station is about 17,100 meters, and the usual wave length used by the New Brunswick 200-kw. high-frequency alternator station is 13,600 meters.

Principal advantages obtained by the use of undamped waves are the following: (1) Radiotelephony is made possible if a pure wave can be obtained. (2) Extremely sharp tuning is obtained, and it is possible for two nearby stations to work on wave lengths which are very close together without interfering with each other. The tuning is, in fact, so sharp that a slight change of adjustment throws a receiving set out of tune and the operator may pass over the correct tuning point by too rapid a movement of the adjusting knobs, particularly on the

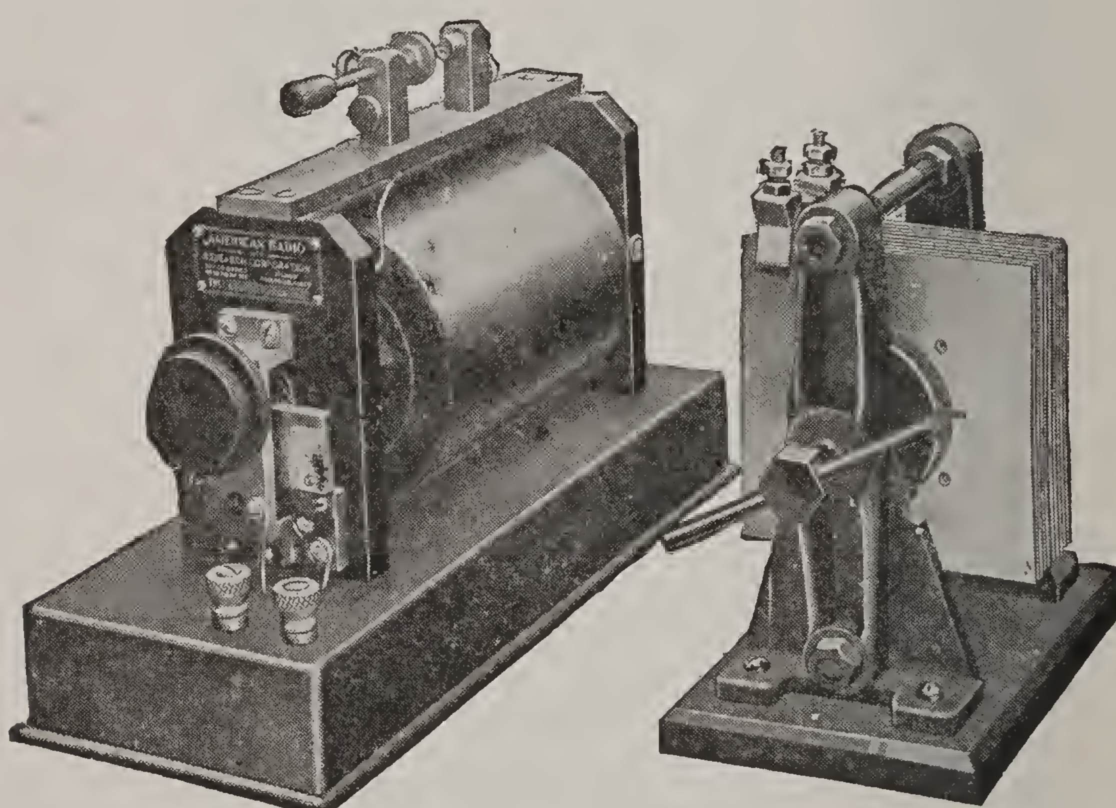


Fig. 29—American Radio Transmission Set

shorter wave lengths. (3) Since the oscillations go on continuously instead of only a small fraction of the time, as in the case of damped waves, their amplitudes need not be so great, and hence the voltages applied to the transmitting condenser and antenna are lower. The antenna is often the most expensive part of the transmitting station, and since the radiat-

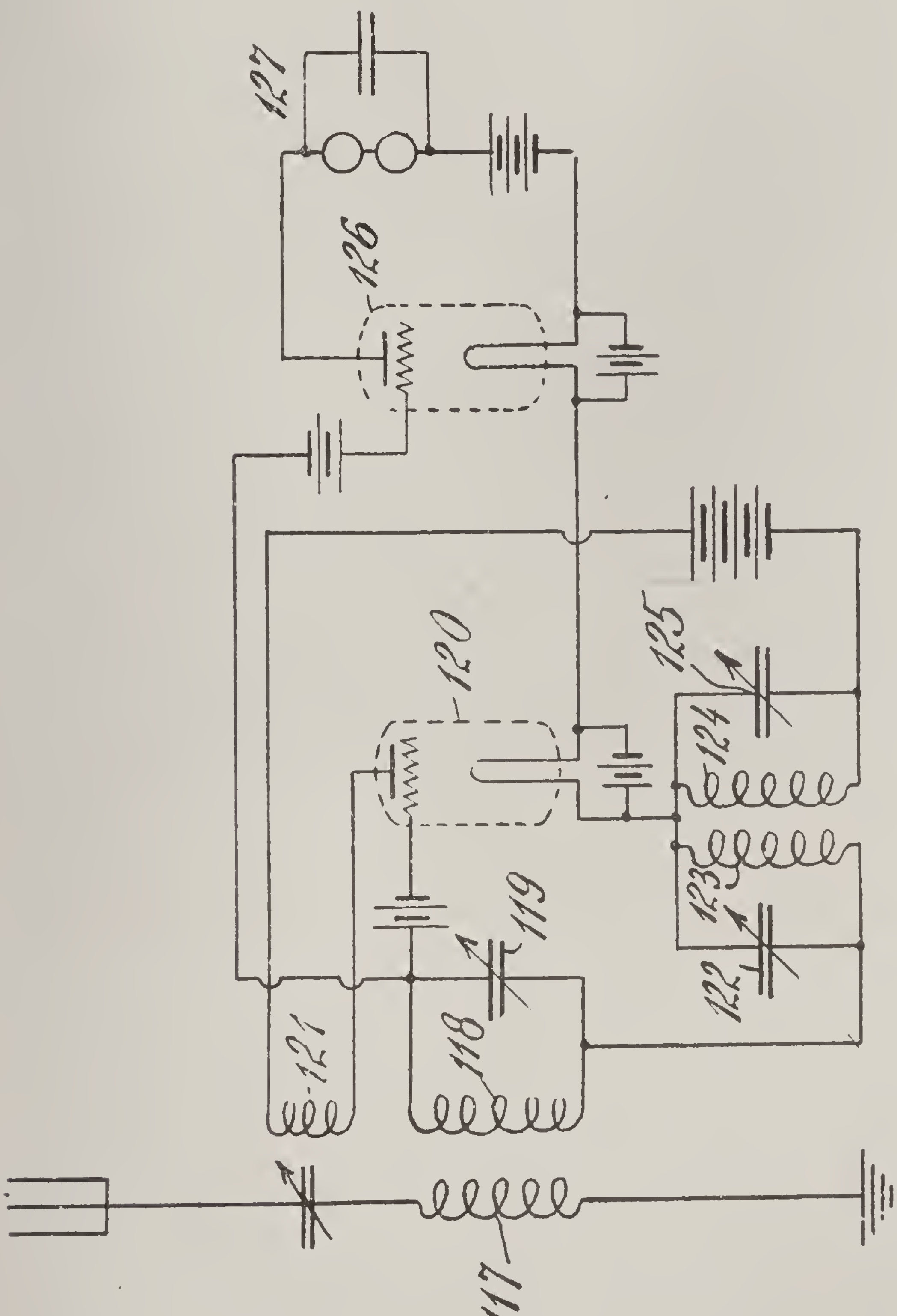


Fig. 30

ing power of an antenna is limited by the maximum voltage during one impulse the radiating power of a given antenna is much greater with a generator of continuous waves than with a spark transmitter. (4) Very sensitive methods of reception can be used, particularly beat reception, which increases the range to which an undamped wave station can work. (5) With damped waves, the pitch or tone of received signals depends wholly upon the number of sparks per second at the transmitter. When the beat method is used for receiving undamped waves the receiving operator controls the tone of the received signals, and this can be varied and made as high as desired to distinguish it from strays and to suit the sensitiveness of the ear and the telephone. These advantages—freedom from interference from other stations through selective tuning, the use of high tones, and the greater freedom from strays—combine to permit a higher speed of telegraphy than could otherwise be obtained.

WIRE TELEGRAPHY AND TELEPHONY

An ordinary wire telegraph system consists simply of an electric circuit connecting two stations and simple equipment inserted directly in the line at each station. The same kind of equipment is generally used at each station, and communication can be had in either direction. On short lines the equipment of each station consists of a "key" and a "sounder" connected in series in the line. The key is a simple device for rapidly opening and closing the circuit and is so constructed that it can be conveniently and rapidly operated by hand. There is only a small clearance between the contacts of the key. When the key is not being operated and is up in its normal position the circuit is open. At all times when no signals are being transmitted at a given station the terminals of the key are short-circuited by a switch. The sounder is an electromagnet with an armature so mounted, close to the poles of the electromagnet on a pivoted arm, that the armature moves through a small distance when the current passes through the magnet windings. The end of the arm moves between two fixed tops, which may be screws. The arm moves in accordance with the current impulses on the line, corresponding to the opening and closing of the key at the distant station, and the contact of the end of the arm with the stops causes a click both when contact is made with the lower and with the upper stop. Signals are transmitted by means of depressing the key to make "dots" and "dashes." A dot is made by depressing the key for an instant; a dash is made by holding the key down a little longer. A dash is equal in length to three dots. Messages are transmitted by a "code" or arrangement of groups of dots and dashes representing the letters of the alphabet. The code use on land lines in the United States is the "Morse" code. On the Continent of Europe land lines use the "Continental" code or "International Morse code." This code is used throughout the world in radio telegraphy.

In ordinary practice there is only one wire between two stations, and one terminal of the station apparatus at each end is connected to the earth, through which the return current flows. Ordinarily a number of intermediate stations are cut in on a telegraph line at points between the two terminal stations. Telegraph lines are usually operated as closed circuits—that is, current is flowing through the line at all times except when the line is actually in use for transmitting signals. The power for operation may be supplied by a closed-circuit battery, such as a battery of "gravity" cells, or by a direct-current generator. On all except short lines the line current is not strong enough to operate a sounder directly so that signals can be read, and a relay is connected in the line. The operation of the relay by the line current opens and closes a local circuit which operates the sounder.

The telegraph system here described represents the simplest case. In actual practice many modifications may be made. Signals may be transmitted and recorded at high speed by automatic apparatus. There are very few operators who can copy as many as 50 words per minute, but with automatic apparatus several hundred words per minute may be transmitted. With suitable apparatus it is possible at one time to transmit several messages over the same wire without one message interfering at all with the others; this is called ''multiplex'' telegraphy.

In ordinary telephony the voice itself is electrically transmitted over wires and reproduced at a distant point. The essential parts of a simple telephone system are (*a*) a device called the ''transmitter,'' by means of which sound vibrations cause corresponding variations of an electric current, (*b*) a device for changing the electric current variations back into the corresponding sounds, and (*c*) an electric circuit for connecting the two devices.

In the telephone exchanges in use in large cities the connecting circuit and switching apparatus are very intricate. In some cities automatic switching equipment is in use for connecting subscribers at the central office. This equipment operates automatically directly under the control of the calling subscriber, without an operator at the central office, and may be very elaborate.

The device by means of which sound vibrations cause corresponding variations of an electric current is usually the carbon microphone transmitter. This type of transmitter is a speech-controlled variable resistance, and its operation is based on the fact that the resistance of carbon varies with pressure changes. A low voltage, as from a battery of a few cells, is connected to opposite sides of a small cup containing carbon granules. The pressure on the carbon granules is controlled by the position of a metal diaphragm on which the sound is impressed.

Fig. 31 shows a telephone transmitter of a type which is in general use throughout the United States, called the "solid-back" transmitter. This name is used because the cup containing the carbon granules is supported on a solid back which consists of a metal bar attached at its ends to the case of the transmitter. In the figure *D* is the diaphragm, usually

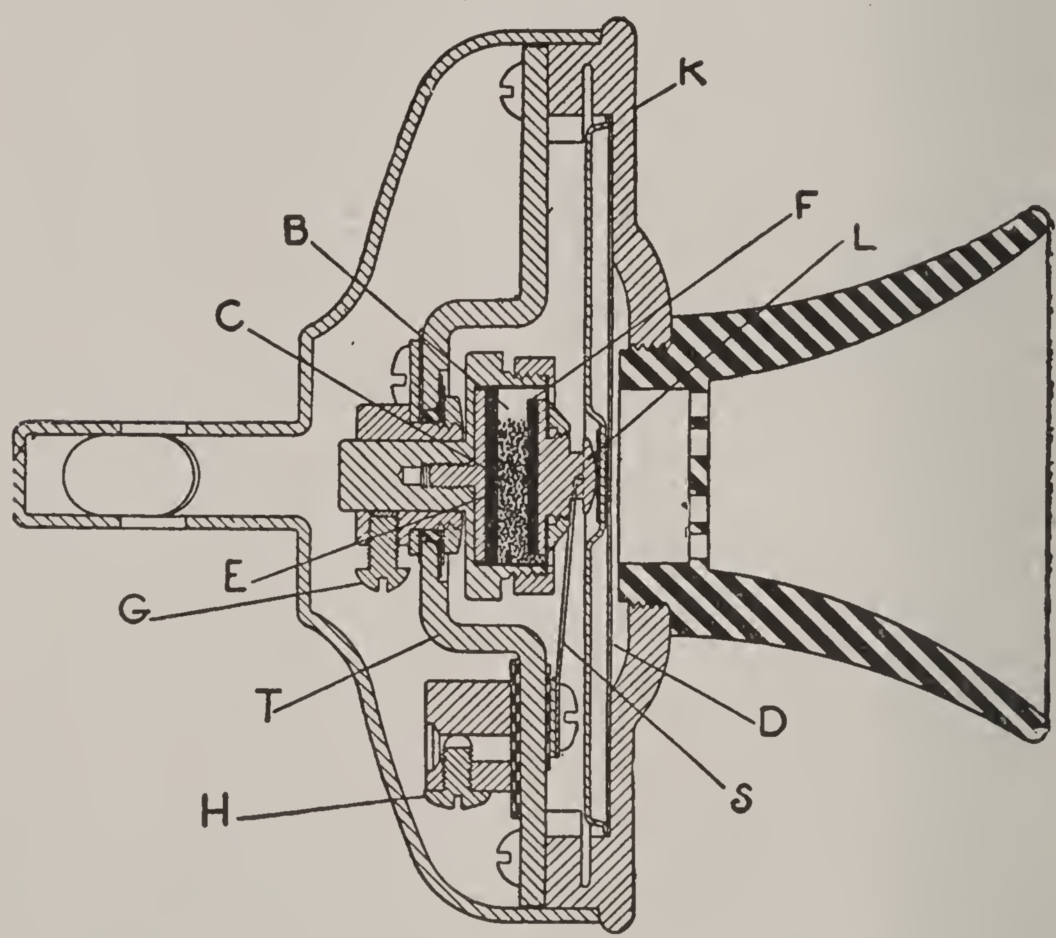


Fig. 31—Microphone Transmitter

an aluminum disk about 2½ inches in diameter. *T* is the solid back, on which is mounted the metal cup *B*, containing the carbon granules *C*. At the back of the cup is a small hardened carbon plate *E*, which serves as one electrode of the carbon microphone. At the front is another very hard carbon plate *F*, which serves as a lid for the small metal cup. The diameter of this plate is a little less than the diameter of the inside of the cup, but the cup is completely closed by a flexible mica disk, which is attached to the rim of the cup and to the carbon disk. This carbon lid or cover forms the second electrode of the transmitter. The button *L* attached to the carbon plate *F* is maintained in contact with the diaphragm by a metal spring *S*, which serves also to damp the vibrations of the diaphragm. The space between the carbon cover *F* and the back electrode *E* is nearly filled with carbon granules, and the electrodes *E* and *F* are so insulated that the electric current in the transmitter circuit, in passing from one electrode to the other, passes through the entire mass of carbon granules. The two wires leading to the transmitter are connected to the binding posts *G* and *H*. The metal face *K* of the transmitter is made heavy to prevent excessive vibration, and the exposed metal parts are usually insulated from the current-carrying parts. In practice it is not usually found desirable to have the transmitter extremely sensitive, because outside noises are then transmitted, and it is therefore difficult to understand the speech. The current through the usual type of microphone transmitter is about 0.2 ampere, and the power consumed in the transmitter is about 2 watts.

The microphone transmitters used in radiotelephony at the present time do not differ essentially from those used in wire telephony, and, in fact, the identical transmitter usually furnished by operating telephone companies can be used for radiotelephony.

The device by means of which the variations in the electric current reproduce the corresponding sounds is the telephone receiver, which is made in a variety of forms. The type of receiver, shown in Fig. 32, called the "watchcase" receiver, is often used in wire telephony, and is almost universally used in both radiotelegraphy and radiotelephony. Two watchcase receivers are commonly used together, connected by a metallic "headband," constituting a "head set." In Fig. 32, *C* is a cup which is the case of the receiver. This cup may be metal or hard rubber or a composition. In the bottom of this cup a permanent magnet of horseshoe shape is placed; the ends of this permanent magnet are shown at *HH*. To the ends of the permanent magnet are attached the bent, soft-iron pole pieces *NP, SQ*. The earpiece *E* is usually

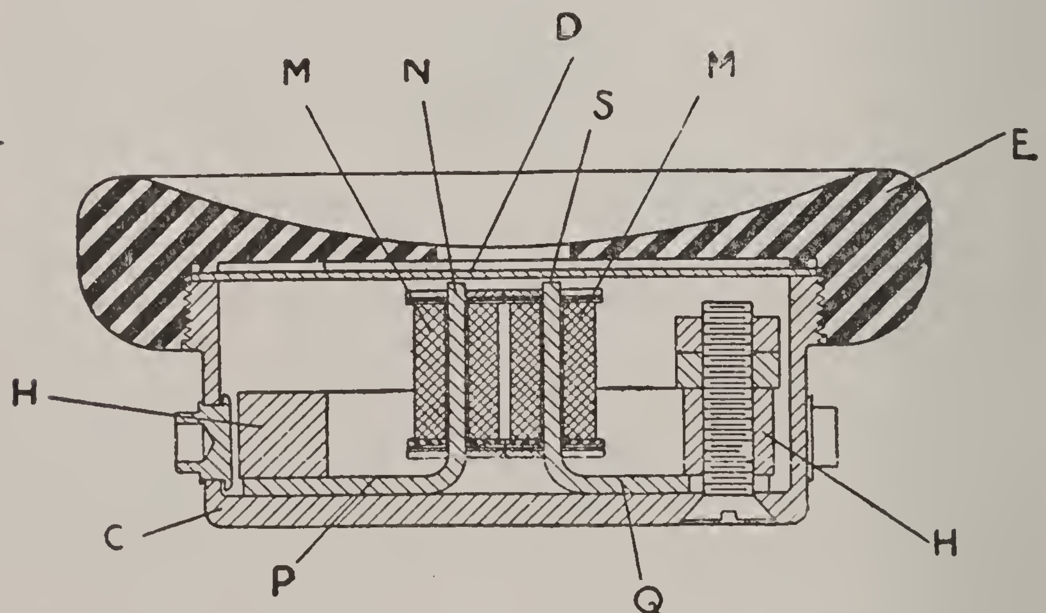


Fig. 32—Telephone Receiver

hard rubber or a composition and is threaded to the cup *C*. Around each pole piece a coil of fine insulated wire is wound, forming the windings *MM*. These two windings are usually connected in series, so that the received current passes through both windings.

In some instruments for use with feeble currents the wire is very fine and the two coils contain some thousands of turns, sometimes as many as 10,000 turns. In the ordinary standard receiver the number of turns is, roughly, about 1000. The resistance measured with direct current of a receiver for wire telephony may vary considerably, but for the standard receiver is usually about 100 ohms. A receiver designed for the very feeble currents sometimes used in radio communication may have a d. c. resistance of 8000 ohms, and seldom has a resistance of less than 1000 ohms. The coils of a receiver, particularly those designed for radio work, have considerable inductance, and at high frequencies the impedance in ohms of the coils of the receiver may be many times the resistance of the coils measured with direct current. The larger the number of turns used, the greater is the magnetic effect in the receiver for a current of given strength.

Above the pole pieces and very close to them is a thin, circular, soft-iron disk *D*, called the diaphragm." The diaphragm of a receiver can be seen through the hole in the center of the earpiece. The distance between the pole pieces and the diaphragm is important in determining the sensitivity of the receiver; in standard instruments this distance is about 0.003 inch. The permanent magnet pulls the diaphragm toward the pole pieces a certain distance, which depends upon the flexibility of the diaphragm. The variations in the current in the receiver windings, corresponding to the sound vibrations of the voice spoken into the transmitter, produce corresponding variations in the magnetic field of the pole pieces, and the diaphragm moves in accordance with these variations and reproduces the voice spoken into the transmitter.

It is possible to use a telephone receiver as a transmitter. With a circuit containing only two identical sensitive telephone receivers and no battery, the same instrument can be used alternately as receiver and transmitter by the person at each end of the line, and speech thus transmitted. This was, in fact, done in the early days of telephony, but the currents so generated by using the receiver as a transmitter are so feeble that other devices are now used for practical purposes.

Words spoken into the transmitter vary the pressure of the carbon granules, and hence the resistance between the transmitter terminals and corresponding variations in the output current of the transmitter are thus produced. The nature of the electric current transmitted by the wires leading to the receiving station depends upon the auxiliary apparatus used with the transmitter. The electric current passing between the stations is often a feeble alternating current having a frequency from perhaps 100 cycles per second to 3000 cycles per second, considerably higher than the frequencies used for commercial lighting purposes. These frequencies, in fact, correspond to the frequencies of the sound waves impressed upon the transmitter diaphragm. Thus the note "middle C," which corresponds to a sound wave having 256 vibrations per second, causes an alternating current having a frequency of 256 cycles per second. In the case of some kinds of telephone systems the wires may transmit a pulsating direct current of several tenths of an ampere, whose pulsations correspond to the impressed sound waves.

Speech transmitted by telephone instruments is not entirely natural, because the vibrating parts, both electrical and mechanical, of the telephone equipment used produce distortions during the transmission of the sound. In the early days of telephony, when the causes of distortion were not well understood, serious effects of this kind occurred when talking over very short distances. At the present time it is possible to talk from New York to San Francisco by wire. This result has been attained only after years of experience and investigation and the development of instruments involving principles only recently discovered. Successful transmission over such long distances requires many refinements in the design of every device used.

It is possible at the same time to transmit both telegraph and telephone messages over the same line; such a line is often called a "composite" line.

With the currents used in ordinary telephony, it is possible at the same time to transmit three telephone messages over two pairs of wires by adding at each end a "phantom" circuit, which is an additional circuit balanced across the two main circuits through suitable impedances. The operation of a telephone system so that one pair of wires carries more than one message is called "multiplex telephony." Besides the use of the phantom circuit, multiplex telephony can be attained by the use of alternating currents of the high frequencies used in radio communication.

RADIOTELEPHONY

Speech is composed of complex vibrations, and a graphic record of the sound wave in air which transmits the simplest word shows a very complex wave form. The problem of any form of telephony is to accurately reproduce electrically at the distant receiving station the complex sound wave which is spoken into the transmitter. The principles of radiotelephony are the same as those of radiotelegraphy by undamped waves. In radiotelephony the sending key used in radiotelegraphy is replaced by apparatus which varies the transmitting antenna current in accordance with the sound waves produced by the voice.

There are a number of ways in which a graphic record can be made of the wave form of the wave in air which corresponds to a given sound. A simple method is to record the sound on a phonograph record, then play the record slowly, and greatly magnify the motion of the needle by a lever arrangement which traces the wave. The wave forms corresponding to many different sounds have been studied. A tuning fork may give nearly a pure sine wave, but the wave forms corresponding to most sounds are very complex.

In the transmission of radiotelegraphic signals by undamped waves, the pitch of the note in the telephone receivers is determined in part by the apparatus at the receiving station—as, for example, in heterodyne or autodyne reception. For transmission of sounds of definite pitch, or for transmission of speech, the nature of the received signal must depend upon

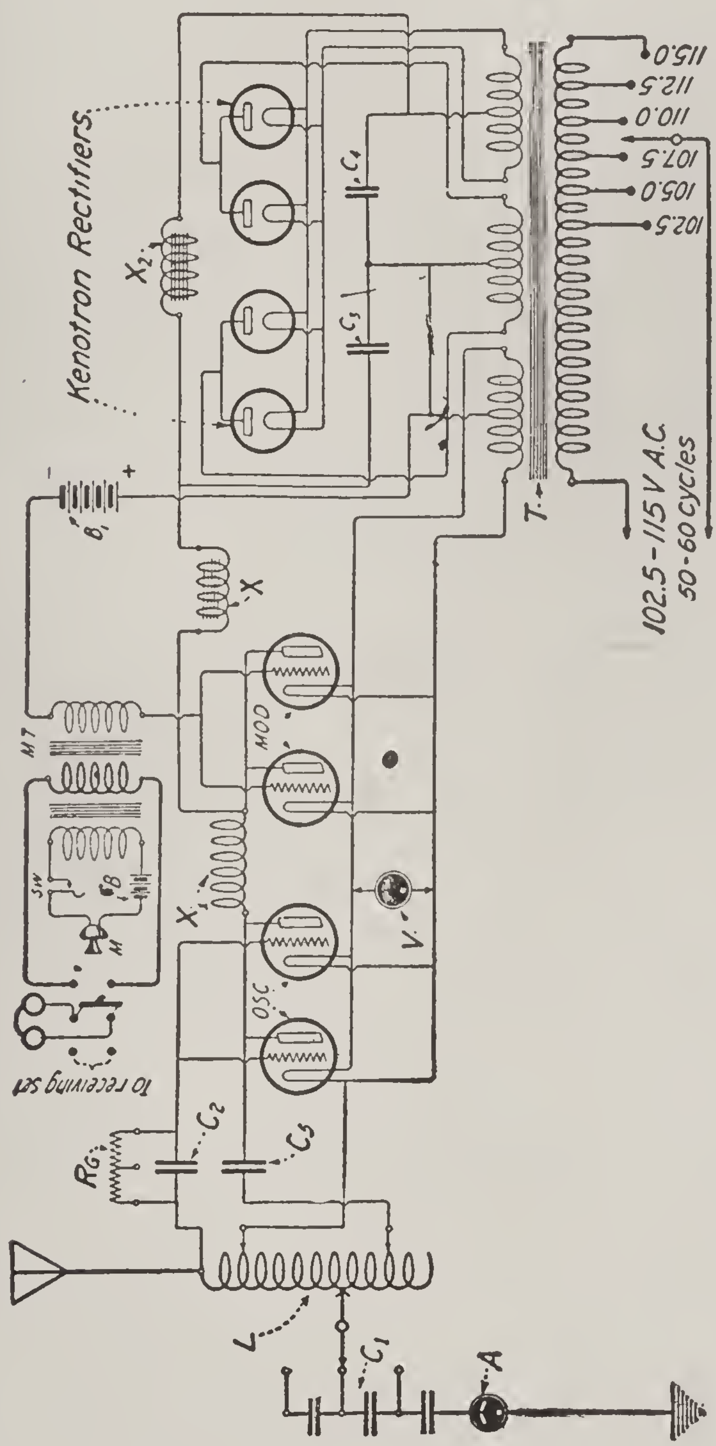


Fig. 33. Radiophone Circuit

the nature of the current in the transmitting aerial. In spark transmission the note depends upon the number of wave trains per second leaving the aerial, this being determined by the speed of the rotary gap or the frequency used in charging the primary condenser. Spark, tone, and radiotelephone transmitters differ from transmitters of undamped waves in that the strength of the radio-frequency antenna current is varying at an audio frequency. Ordinarily, the radiation from a spark transmitter is treated as being composed of successive trains of waves of radio frequencies. An alternative method is to describe it as a single wave whose amplitude is varying at audio frequencies.

An alternating current is said to be *modulated* when the amplitude of its oscillations is varied periodically. The frequency at which the variations occur is necessarily less than the frequency of the alternating current which is being modulated. The nature of the variations may assume almost any form. Thus we may have dot-and-dash modulation, "chopper" modulation, buzzer modulation, sine-wave modulation (as at 800 cycles), and speech modulation. Speech modulation of radio-frequency currents radiated through space constitutes radiotelephony. Chopper, buzzer, and sine-wave modulation are often referred to under the general name of "tone modulation."

When the usual dot-and-dash code signals are transmitted by undamped radio-frequency waves which have not been modulated at the transmitting station by a chopper, buzzer, 800-cycle alternating current, or similar method, it is necessary to use at the receiving station a chopper, heterodyne, or similar method. The dot-and-dash interruption of the transmitted wave

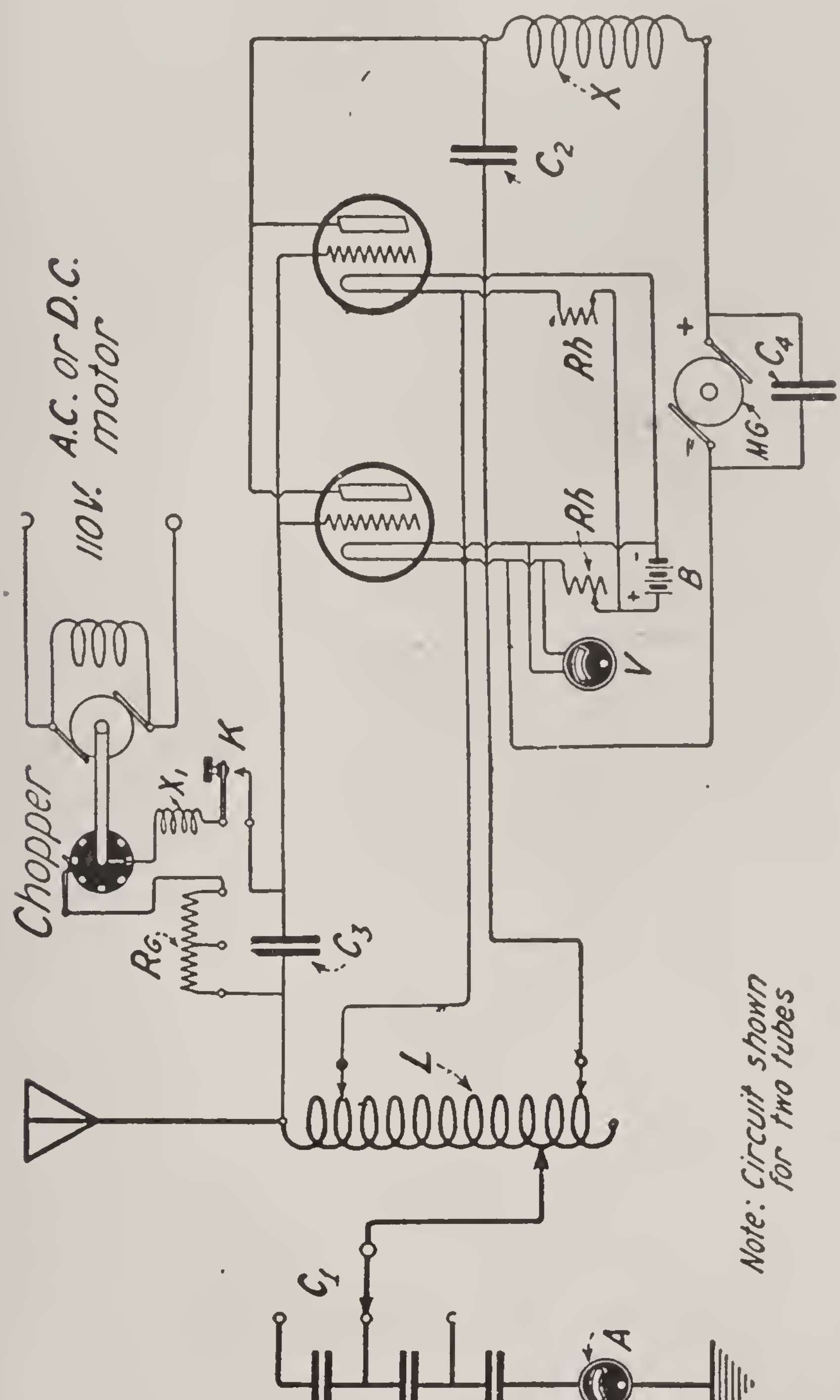


Fig. 34. Direct Current C.W. and I.C.W. Circuit

constitutes, however, a variation of the transmitted wave, which is a form of modulation, and causes "side waves" having wave lengths irregularly distributed over a band. When dot-and-dash signals are transmitted at high speeds by automatic devices the band of wave lengths between the side frequencies is broader, and greater interference is caused. When automatic devices are used for both transmitting and receiving, the transmitting station does not usually transmit the signals of the International Code, but a series of impulses arranged only with regard to the most convenient operation of the apparatus.

When a radio-frequency wave is modulated by an audio-frequency wave the amplitude of the resultant wave at each instant is determined by the *product* of the instantaneous value of the amplitude of the radio-frequency wave at that instant. Thus modulating action should be carefully distinguished from heterodyne action, since in heterodyne action the instantaneous value of the resultant is determined by the *sum* of the instantaneous values of the two component radio-frequency waves.

In modulating action the audio-frequency wave whose amplitude is multiplied by the amplitude of the radio-frequency wave is ordinarily the sum of an audio-frequency wave (alternating current) and an unvarying component (direct current). The amplitude of the radio frequency is varied periodically above and below a certain value which is not zero.

For rough purposes of illustration of the process of modulation, the unmodulated radio-frequency wave can be thought of as a plastic substance which is molded in a form shaped like the form of the audio-frequency modulating wave. An illustration of a

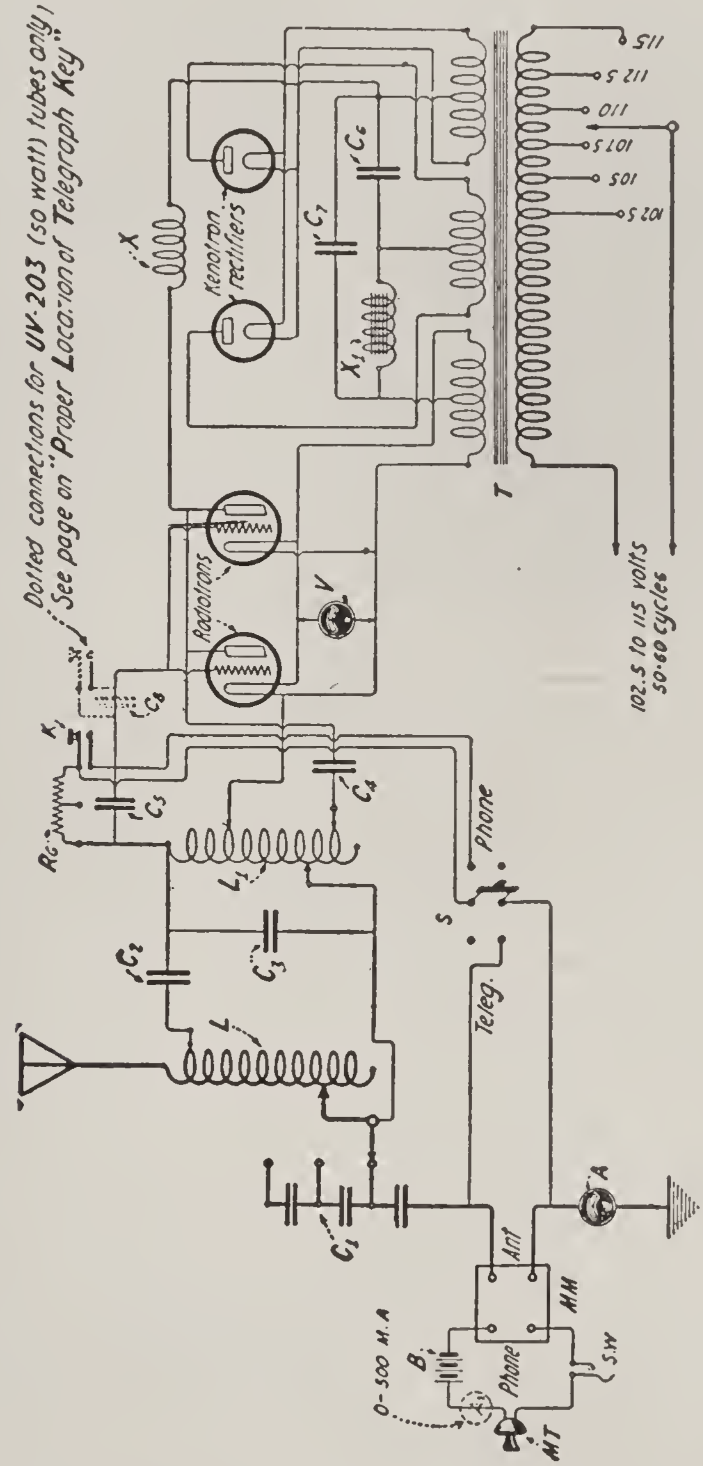


Fig. 35. Alternating Current Radiophone Circuit

similar process is found in the impression of the wave form of a voice on the plastic wax of a master phonograph record, from which many records are made which will faithfully reproduce the voice. In radiotelephony the wave form of the voice, impressed on the radio-frequency carrier wave, is reproduced at many receiving stations.

The strength of the received signal depends not only on the average radio-frequency amplitude but also on the degree to which it is changed or modulated. An alternating current is said to be *completely modulated* when the amplitude of its oscillations is periodically reduced to zero.

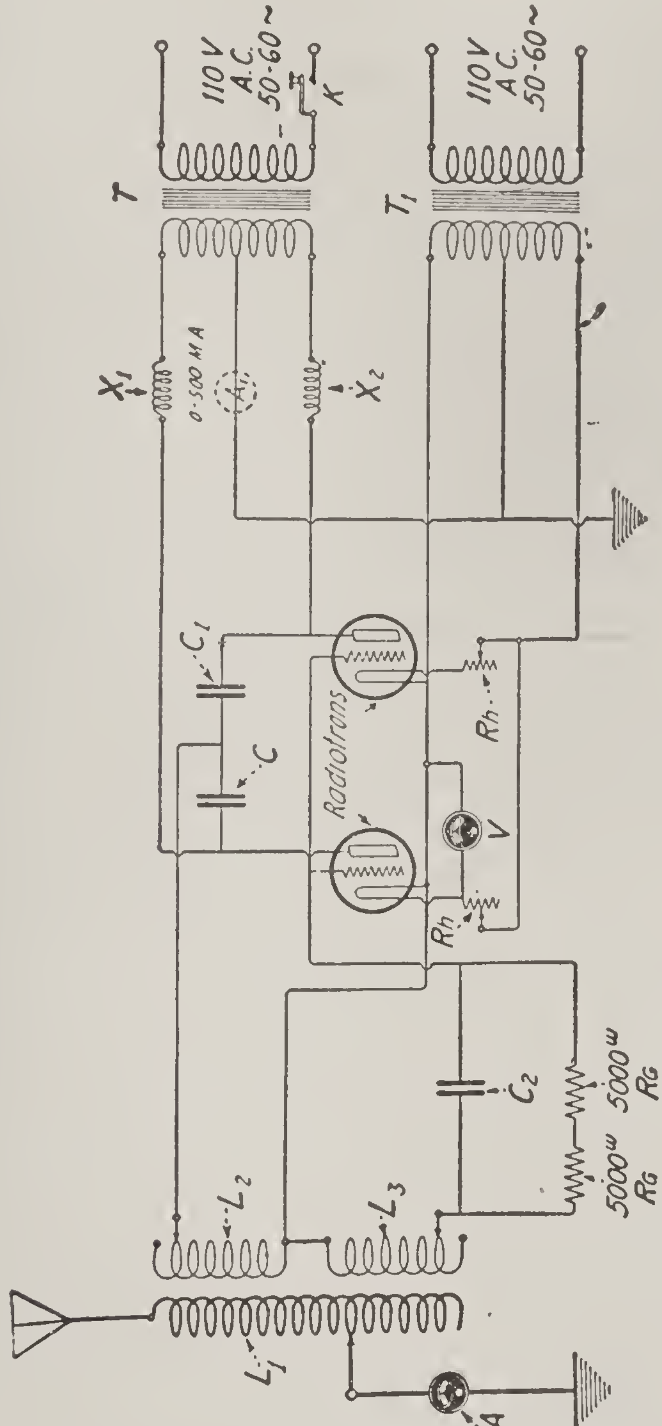


Fig. 36—Self-rectifying C.W. Telegraph Circuit

VACUUM TUBES

During the past few years there has been added to the apparatus employed in radio communication a new device, called the "electron tube," which has made possible many important advances in the art. A small electron tube of a simple type resembles closely in general appearance an ordinary 10-watt incandescent electric lamp. Since these tubes may be used for a variety of purposes—to generate, to amplify, and to modulate radio oscillations, as well as to detect them—they now are used in most types of radio apparatus. New applications have come rapidly, and there is every reason to believe that further developments may be expected. The electron tube is of primary importance in radio communication, but it has many important applications in other fields of electrical engineering, particularly in ordinary telephony with wires, where its use makes possible conversation between points separated by a distance of 3000 miles. One fact of importance is that such tubes make possible the use of apparatus that is easily portable—a primary consideration in military communication, and of importance also in various commercial applications. The principles which underlie the operation of electron tubes and their action under the widely different conditions met in actual practice therefore deserve careful study.

The name "electron tube" is derived from the fact that the action of the tube is due to very small particles of matter called "electrons." An electron is much smaller than an atom, and is the building block of which atoms are constructed. An idea of the extremely small size of the electron may be obtained from the estimate that in a very tiny spherical globule of copper having a diameter of one one-hundred-thousandth of an inch, there are about 20 billion electrons. The atom was formerly regarded as the smallest particle of matter which could exist; something like 25,000 hydrogen atoms would have to be placed in contact in a row to make up a length of one ten-thousandth of an inch. The weight of an electron is only about one two-thousandths of the weight of a hydrogen atom. An electron carries a charge of negative electricity whose value can be measured. Since the comparatively recent general recognition by scientific men of the existence of the electron, many ideas formerly held as the explanations of various physical phenomena have been considerably modified. The fact that the electron carries a charge of negative electricity makes possible the use of the electron tube in radio communication.

If two wires are connected to a battery, one to each terminal, the other two ends of the wires may be brought very close together in air, yet so long as they do not touch no current flows between them. The two ends may be inclosed in a bulb like that of an incandescent electric lamp and the air pumped out, and still so long as the ends are separated no current will flow. Thus, when the filament in an incandescent electric lamp breaks, the current stops and the light goes out.

About 1884 Edison discovered that if inside an exhausted incandescent electric lamp of the ordinary type, containing a filament whose two ends were connected to two wires insulated from each other, there was introduced a third wire insulated from the filament connections and maintained at a voltage positive with respect to the filament, then a current would flow across the vacuum inside the tube from the third wire to the filament as long as the filament was incandescent, but that the current ceased as soon as the filament became cold. This phenomenon is generally called the "Edison effect." It is due to the fact that the incandescent filament shoots off electrons at high velocity, each carrying its charge of negative electricity, and that the electrons are attracted to the positively charged third wire. The passage to the third wire of the negative charges of the electrons is equivalent to the flow of a current between the filament and third wire. In order that a current of one-billionth of an ampere should flow between the filament and the plate, it is necessary that more than six billion electrons should pass each second from the filament to the plate. It should be particularly noted that while the electrons move from the heated filament to the cold third wire, the current passes from the third wire to the filament, according to the usual idea that the direction of an electric current is from the positive (higher) to the negative (lower) voltage. This distinction between the direction of *electron flow* and the direction of *current flow* should be carefully noted.

As each electron leaves the filament, the filament acquires a charge of positive electricity equal in amount to the negative charge carried by the electron. If no voltage is applied to the third wire, electrons will still be emitted by the incandescent filament, but will travel only a very short distance before being attracted back to the filament by the positive charge acquired by the filament. The voltage applied to the third wire must be sufficient to overcome this attraction of the filament. No current will flow if the negative terminal of the battery is connected to the third wire, because the electrons will not be attracted by the negatively charged third wire, and, in fact, will be repelled back into the filament.

A tube containing a filament and one additional wire or other piece of metal, is called a two-electrode tube, the filament being considered as one electrode, and the additional piece of metal the scond electrode.

The above explanation of the mechanism of the flow of current between the filament and plate in an electron tube applies to a tube having a very perfect vacuum. If there is more than the merest trace of gas remaining in the tube, the operation is more complicated, and a larger current will usually flow with the same applied voltage. This happens in the following manner.

In a rarefied gas some of the electrons present are constituent parts of atoms and some are free. These free electrons move about with great velocity, and if one of them strikes an atom it may dislodge another electron from the atom. Under the action of the emf. between plate and filament the newly freed electron will acquire velocity in one direction—the direction in which the colliding electron is moving—and the positively charged remainder of the atom, called an "ion," will move in the opposite direction. Thus both of the parts of the disrupted atom become carriers of electricity and contribute to the flow of current through the gas. This action of a colliding electron upon an atom is called "ionization by collision," and, on account of it, relatively large plate currents are obtained in electron tubes having a poor vacuum. The earlier tubes were of this sort, but at the present time most tubes are made with a better vacuum than formerly, so that ionization by collision is responsible for but a small part of the current flow.

At first it would seem to be an advantage to have ionization by collision, because a larger plate current can be obtained, but there are two difficulties which have proved so great that tubes are now usually so made as to have only the pure electron flow. The first of these difficulties is a rapid deterioration of the filament when there is flowing a large plate current which is caused by ionization by collision. The positively charged parts of the atoms are driven violently against the negatively charged filament, and since they are much more massive than electrons (an oxygen or nitrogen ion has about 25,000 times the mass of an electron), this bombardment actually seems to tear away the surface of the filament. A second disadvantage of tubes with poor vacuum is that too large a battery voltage may cause a "blue-glow" discharge.

Two similar tubes with poor vacuum seldom, if ever, contain just the same quantity of gas, and therefore their electrical characteristics may be considerably different. For this reason it is not ordinarily practicable to connect in parallel two tubes having poor vacuum. Tubes with high vacuum, on the other hand, can be constructed very uniformly, so that a number can be connected in parallel. It is often advantageous to be able to connect several tubes in parallel in generating sets.

Tubes containing a little gas, i. e., having a poor vacuum, are often called "gas tubes," or "soft tubes." Tubes with high vacuum are often called "hard tubes." "Soft" tubes are particularly useful as detectors, and if properly selected and used may be much more satisfactory as detectors than "hard" tubes of similar construction.

Let us consider what happens in a two-electrode tube having a good vacuum, when there is a variation in either the temperature of the filament or the voltage of the battery connected between the plate and filament.

Suppose first that the filament temperature is kept constant. Then a definite number of electrons will be sent out per second. The number of electrons that travel across the tube and reach the plate per second determines the magnitude of the current through the plate circuit. The number of electrons that reaches the plate increases with an increase of the battery connected between the plate and filament (Fig. 37). If this voltage is continuously increased, a value will be reached at which all the electrons sent out from the filament arrive at the plate. No further increase of current is possible by increasing the voltage, and this value of current is called the saturation current.

If now the temperature of the filament is raised to a higher constant value by means of the filament-heating battery and the same voltage steps again applied, the plate current curve will coincide with that obtained before, until the bend is reached; then it will rise higher. The explanation of this is that the number of electrons sent out by the filament increases with the temperature approximately as the square of the excess of the filament temperature above red heat, and thus more electrons are available to be drawn over to the plate. Thus a higher value of plate current will be obtained before reaching the limiting condition when all the electrons emitted arrive at the plate. When this finally happens, the curve, as before, bends over until nearly horizontal.

Suppose now that the voltage of the plate battery is kept at a constant value and the filament temperature is gradually raised by increasing the current

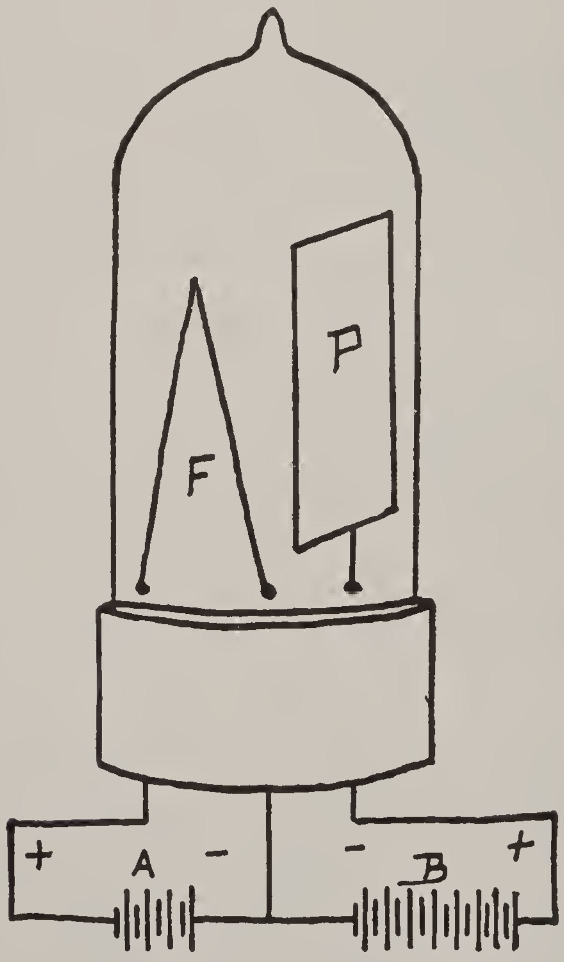


Fig. 37
F—Filament. P—Plate.
A—Battery for Heating Filament.
B—Battery for Sending Current Through Space Between Plate and Filament.

from the filament-heating battery. The number of electrons sent out will continue to increase as the temperature rises. The electric field intensity due to the presence of the negative electrons in the space between filament and plate may at last equal and neutralize that due to the positive potential of the plate, so that there is no force acting on the electrons near the filament. This effect of the electrons in the space is called the "space charge effect." It must not be supposed that the space charge effect is caused by the same electrons all the time. Electrons near the plate are constantly entering it, but new electrons emitted by the filament are entering the space, so that the total number between filament and plate remains constant at a given temperature. After the temperature of the filament has reached a point where the effect of the electrons present in the space between filament and plate neutralizes the effect of the plate voltage, any further increase of the filament temperature is unable to cause an increase of the current. The tendency of the filament to emit more electrons per second, because of the increased temperature, is offset by the increase in space charge effect which would result if electrons were emitted more rapidly, or, more exactly, for any extra electrons emitted, an equal number of those in the space are repelled back into the filament.

Between the filament and plate of a tube we may insert another piece of metal. This third electrode interposed in the stream of electrons between filament and grid is usually in the form of a metallic gauze or a grid of fine wires, and is generally called the "grid." A tube which contains a filament, plate, and grid is called a three-electrode tube and is capable of many more uses than the two-electrode tube. The addition of the third electrode makes it possible to increase or decrease the current between plate and filament through wide limits. If a voltage is impressed upon the grid by means of a third battery connected between the filament and grid, the space charge effect will be modified. The electrons traveling from filament to plate pass between the wires forming the grid. If the grid is given a potential which is negative with respect to the filament the grid will repel the electrons, but many of them will still pass through, and reach the plate, because of their high velocity, because the positive plate potential still affects them to some extent. If the grid potential is made still more negative the plate current will diminish until finally it may be stopped entirely.

Suppose, however, that the grid is given a positive potential instead of negative. Electrons are now attracted to the grid as well as to the plate, and more electrons are now drawn toward the plate than would otherwise pass, so that the plate current increases. The charge of the grid partially neutralizes the effect of the space charge. As in the two-electrode tube, a limit to the magnitude of the plate current will finally be reached, when the space charge caused by the large number of negative electrons in the tube fully counteracts the influence of the positive charges on grid and plate. The attainment of the limiting or *saturation* value of the plate current is assisted by the absorption of more electrons into the grid if its positive potential is increased. This absorption gives rise to a relatively small current in the circuit *FGCF*, which is called the grid current. The total electron flow is the sum of the plate current and the grid current. As the potential of the grid is made more and more positive, more and more electrons will be absorbed by the grid.

When using the larger power tubes with transmission sets certain precautions are necessary to lengthen the life of the tube. Most of the damage to tubes is caused during the testing and adjustment of the circuit, and great care should be taken during these periods.

The life of radiotron tubes can be materially lengthened by mounting them in the proper position. Radiotron No. 13248, Type UV-202 and No. 13247, Type UV-203, should be installed in a vertical position, while radiotron No. 13246, Type UV-204, may be operated in either a vertical or horizontal position. When mounted in a horizontal position the plates should be in a vertical plane, with the seal-off tip down. On any tube or group of tubes delivering over 50 watts A.C. or operated at a plate potential above 2,000 volts, a safety spark gap should be provided between the grid and filament terminals at or near the tube socket or mounting. This gap should be adjusted to between 1-32 inch and ¼ inch, depending upon the plate voltage employed and the number of tubes and type of tubes used. The life of the filament of radiotron power tubes is dependent upon its temperature, a 3% increase in filament current will halve the life of your tubes, and a 5% decrease will double the life. Do not use a greater voltage on the filament than that specified, and do not overload the plate by using an excessive plate voltage. Power tube filaments should be burned at constant voltage rather than constant current.

Occasionally in the parallel operation of radiotron power tubes ultra high frequency oscillations develop in the plate and grid circuits which prevent the realization of full output, and cause excessive plate and grid currents. This effect may be avoided by inserting an inductance of a few micro-henries (10 turns in one layer on a tube 1 inch in diameter is suggested) in one or more of the individual grid leads of each tube as close to the grid terminal of the socket as possible.

This protective gap should be placed between the coil and the grid terminal of the socket. The best arrangement is to mount the gap directly on the socket terminals and one terminal of the coil directly to the grid terminal of the socket.

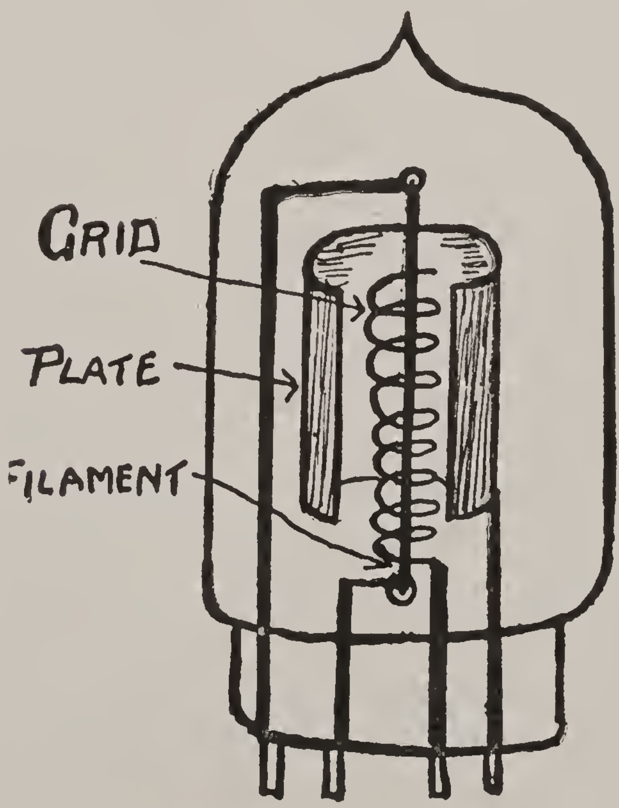


Fig. 38—Diagram of Vacuum Tube

THE ELECTRON TUBE AS A DETECTOR

There are two methods of using an electron tube as a detector.

In the first method the detector tube is connected directly across the condenser in the receiving circuit (Fig. 40). Suppose the receiving antenna picks up a signal. Then oscillations in the tuned circuit LC are set up and the radio-frequency alternating voltage across the condenser C1 is impressed between the grid and filament, bringing about changes in the plate current. If the plate current is normally at a point on the bend of the characteristic curve the increase of plate current when the grid voltage is positive is greater than the decrease of plate current when the grid voltage is negative. Thus, on the average, the plate current is increased while the oscillations due to the signal last. In Fig. 39 are shown, roughly, the form of (1) the high-frequency oscillations impressed upon the grid, (2) the high-frequency variations in plate current, (3) the audio-frequency fluctuations of telephone current. The frequency with which these telephone fluctuations occur in the frequency of the incoming wave trains and in order to be heard must be within the range of audible sound. The radio-frequency fluctuations which occur in the plate current shown in (2) do not pass through the windings of the telephone receivers, because the inductance of the coils in the telephone receiver is so great that the radio-frequency variations in the plate current cannot flow through them, but flow through the capacity existing between the leads and windings and across the by-pass condenser. Thus these radio-frequency variations are by-passed by this effective capacity of the

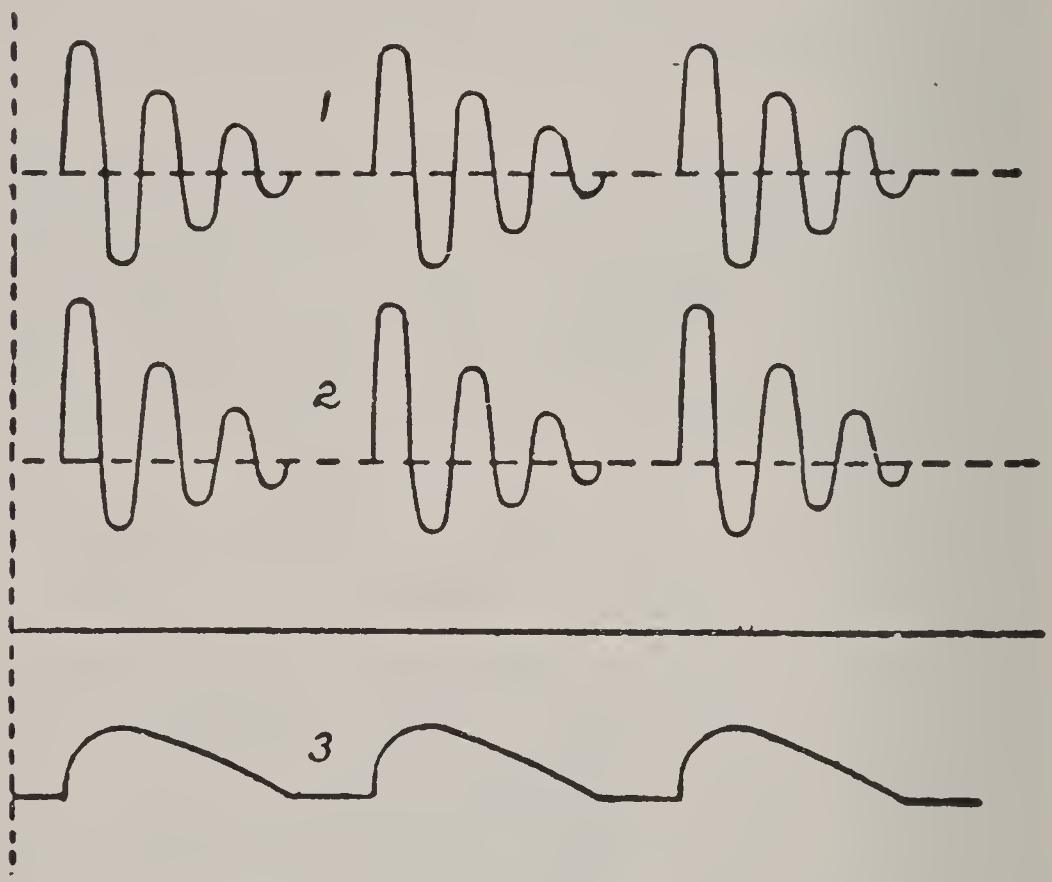


Fig. 39.—Action of Electron Tube as Detector

leads of the telephone receiver and only the average current flows through the inductance of the telephone receiver windings (3). When using this method of detection, no current flows in the grid circuit because the average value of the grid voltage is maintained negative with respect to the filament in order to operate on the curved portion of the curve showing the relation between plate current and grid voltage.

With simple detector action of the kind here described, when signals of ordinary intensity are being received, the mean value of the change of the plate current, for a given operating point on the grid voltage-plate current curve, is very nearly proportional to the square of the amplitude of the voltage oscilla-

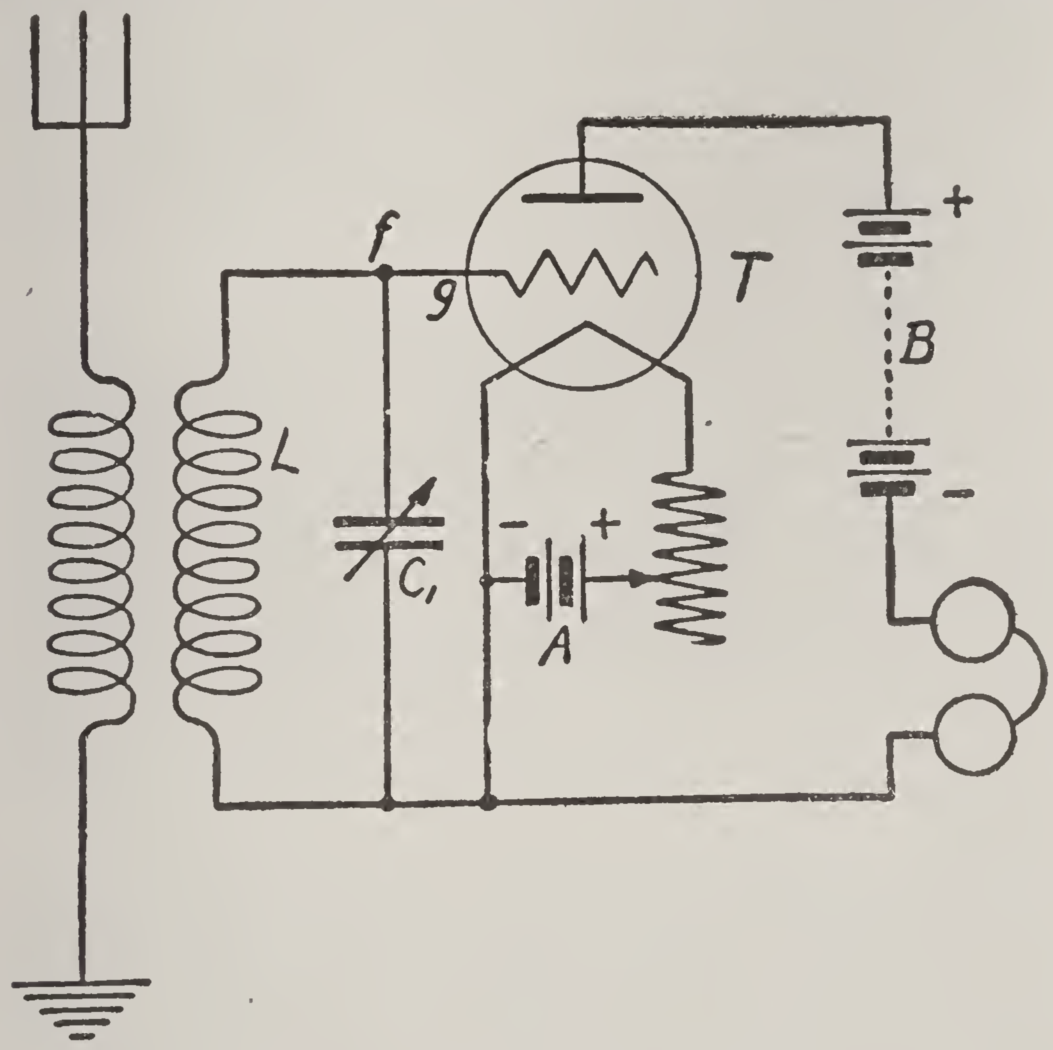


Fig. 40—Connections for Using Tube as a Detector

tions impressed on the grid. For very strong signals, however, this relation does not hold. This is a relation which holds for any detector which operates by virtue of the curvature of the curve showing the current which it delivers for various impressed voltages.

In some cases it is necessary to use an additional battery, called a "C" battery, between points *f* and *g* (Fig. 40) in order to bring the plate current to the bend of the characteristic curve. This, however, does not change the action; the variations of the plate current are brought about by the alternating emf. between the terminals of the coil L just as when the battery C is absent. It is interesting to note here that we are employing resonance in the circuit LC_1 to obtain as large an emf. as possible between the terminals of the coil and condenser with a given signal.

If the grid battery voltage is adjusted so that the plate current has a value near the upper bend of the curve showing plate current plotted against grid voltage, instead of near the lower bend, the action will be essentially the same, but the effect of the arrival of a wave train will be to decrease momentarily the plate current instead of to increase it. As before, there will be fluctuations of the plate current keeping time with the arrival of wave trains, and there will be a sound in the telephone of a pitch corresponding to the number of wave trains per second.

Care must be taken in the use of receiving tubes that the plate battery voltage is never high enough to cause the visible "blue glow." The tube becomes very erratic in behavior when in this condition and is very uncertain and is not sensitive as a receiver. This is because the plate current becomes so large that it is unaffected by variations of the grid voltage. Characteristic curves will not repeat themselves if the tube shows the blue glow, and sharp breaks may appear in any or all of the curves. Furthermore, the electrodes are heated and may be damaged by the blue-glow discharge.

With many tubes louder signals are obtained if the grid is made positive with respect to the negative end of the filament, so that current flows in the grid circuit. Instead of operating on the curved portion of the grid-voltage, plate-current curve the tube operates upon the curved portion of the grid-voltage, grid-current curve and the straight portion of the

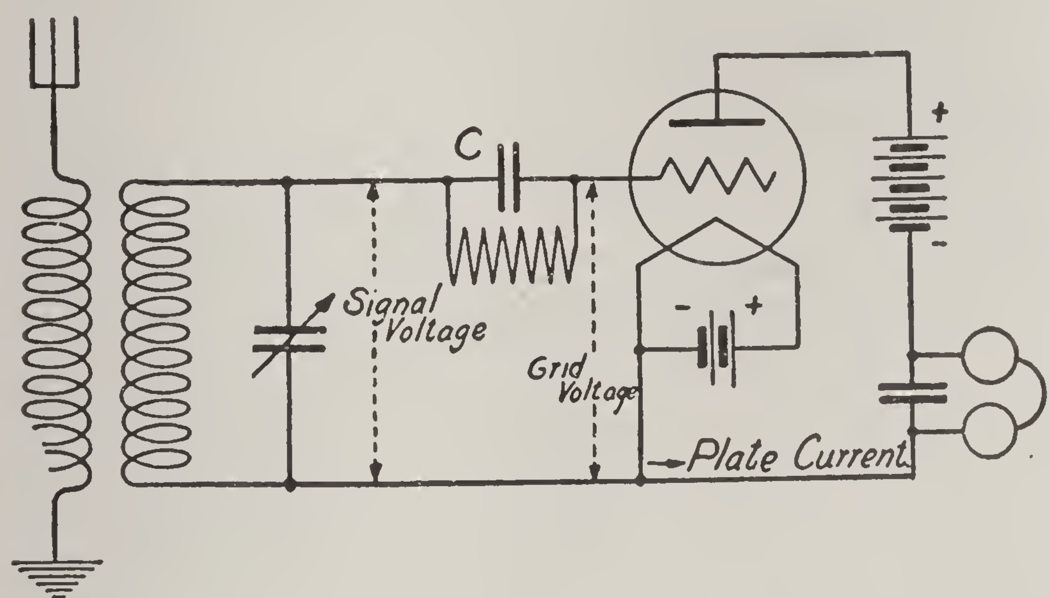
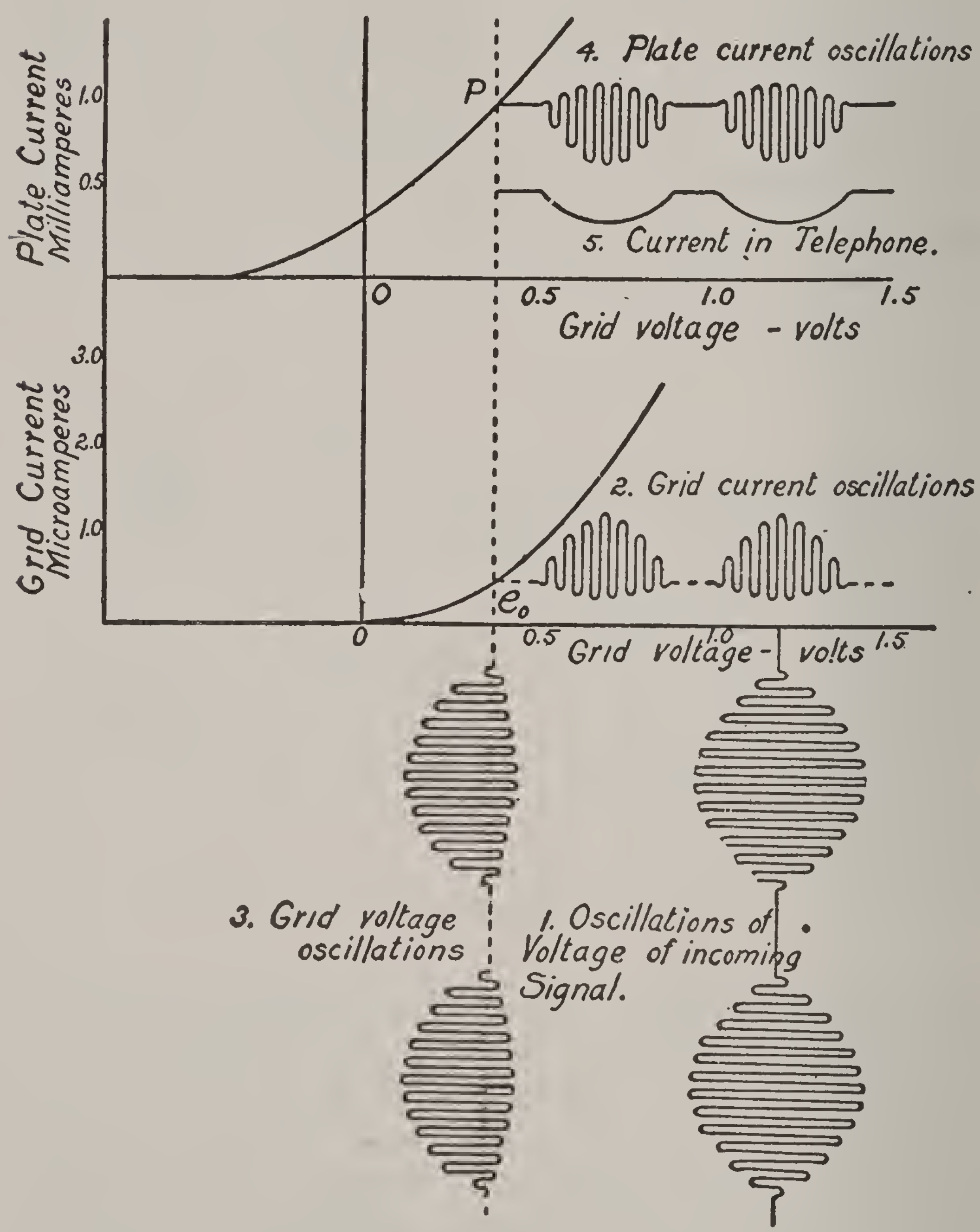


Fig. 41

grid-voltage, plate-current curve. When using the curvature of the grid-current characteristic in this fashion, a condenser is connected in a series with the detector tube and with the receiving circuit from which the signal voltage is obtained. Now suppose that a series of wave trains falls upon the antenna of Fig. 41, as shown in (1) of Fig. 42. If the circuit LC is tuned to the same wave length as the antenna circuit, oscillations will be set up in it and similar voltage oscillations will be communicated to the



4. Plate current oscillations
P
Plate Current
Milliamperes
1.0
0.5
5. Current in Telephone.
0
0.5
1.0
1.5
Grid voltage - volts
3.0
2.0
1.0
Grid Current
Microamperes
2. Grid current oscillations
e_0
0
0.5
1.0
1.5
Grid voltage - volts
3. Grid voltage oscillations
1. Oscillations of Voltage of incoming Signal.

Fig. 42

grid by means of the condenser C. As shown in (2) Fig 42, each time the grid becomes positive the electron current which flows at the voltage *eo* will be increased more than it is decreased when the grid voltage goes below *eo*. Thus during each wave train the grid will continue gaining negative charge and its voltage will, on the average, be mostly negative, as shown in (3), Fig. 42. This negative charge on the grid opposes the flow of electrons from filament to plate and produces a much magnified decrease in the plate current throughout the train of oscillations, as shown in (4), Fig. 42. At the end of each wave train this charge leaks off either through the condenser or through the walls of the tube, or both, and the plate current becomes steady again at its normal value (4), Fig. 42. This should happen before the next wave train comes along, and in order to insure this a resistance of about a megohm (a million ohms) is shunted across the condenser. Such a resistance is called a "grid leak." As has been stated above, the inductance of the coils in the telephone receivers is so great that the radio-frequency variations in the plate current can not flow through them, but flow through the capacity existing between the leads and windings and across the by-pass condenser. The current which actually flows through the windings and operates the telephone receivers, if drawn, will look something like the dotted line in (4) and the heavy line in (5). Thus, as in the case of the circuit of Fig. 40, the note head in the telephone corresponds in pitch to the frequency of the wave trains. If the waves falling upon the antenna are undamped waves, they may be detected using either of these circuits if they are first divided off into audio-frequency groups.

To receive undamped waves which are not divided into groups of audible frequency, electron tubes may be used in special ways called the heterodyne and autodyne methods, through the high leak resistance, this fixes the steady voltage of the grid at about 0.5 to 0.8 volts positive with respect to the negative end of the filament.

In order to get a readable signal from a good tube detector, it is usually necessary to apply to the grid a voltage of two millivolts effective value, which would correspond approximately to an alternating current of about 0.01 microampere in the grid circuit. These values apply to a completely modulated wave—that is, a wave whose oscillations reach a zero value at regular intervals which correspond to the audio frequency of the wave trains.

The Tube as an Amplifier

An electron tube acts as a detector or rectifier because an alternating voltage applied to the grid circuit can be made to produce unsymmetrical oscillations in the plate circuit. While the tube is thus acting as a detector it is also, as a matter of fact, acting as an amplifier—that is, oscillations of greater power are produced in the plate circuit for a given alternating voltage in the grid circuit than would be produced by the same voltage directly in the plate circuit. This explains why the electron tube may be a more sensitive detector than the crystal detector, which acts as a rectifier only.

It is sometimes desired to amplify an alternating current without any rectifying or detecting action. This is done by keeping a voltage on the grid of such value that the symmetry of the oscillations in the plate circuit is not altered. Thus, if there is a steady voltage applied on the grid of such value that the plate current is on the part of the characteristic curve that is nearly straight, then a small change in grid voltage in either direction causes the plate current to

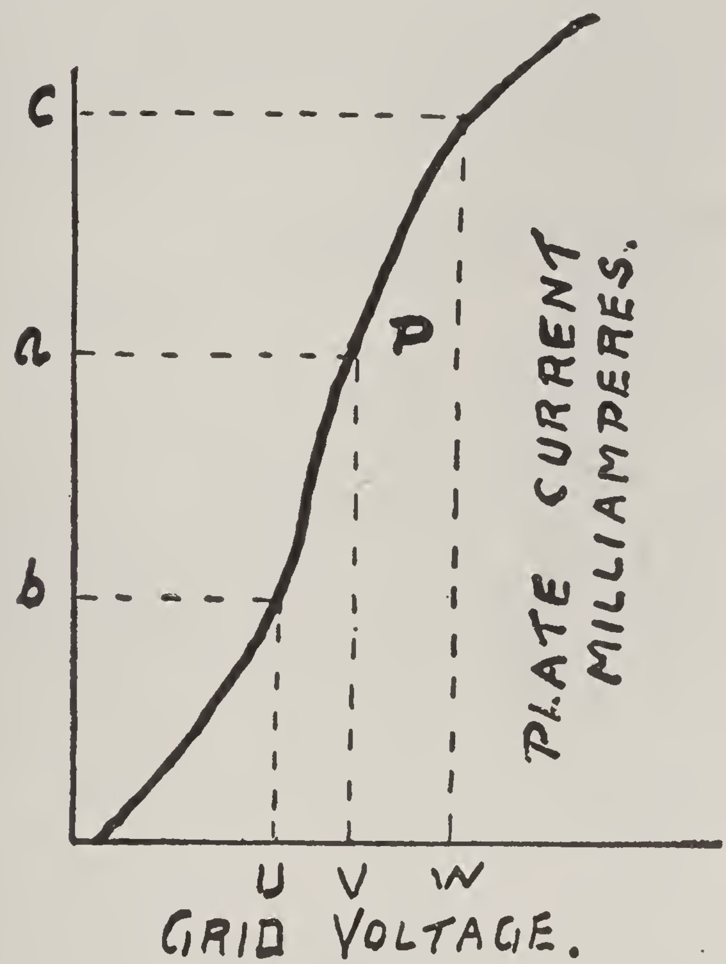


Fig. 43

increase or decrease the same amount. For instance, if the grid voltage is increased from *v* to *w* (Fig. 43) or decreased by an equal amount from *v to u*, the current will, in the first case, increase from *a* to *c* and in the second case fall off by an equal amount, from *a* to *b*. In other words, the wave form of the grid voltage variation will be repeated in the fluctuating plate current. The latter will now be equivalent to an alternating current superimposed upon the steady plate current from the plate battery. The magnitude of the alternating-current part of the plate current will be greater, the steeper the slope of the curve at the point P.

For the same voltage acting in the two circuits the power expended in maintaining the oscillations of the grid current is far less than that involved in the cor-

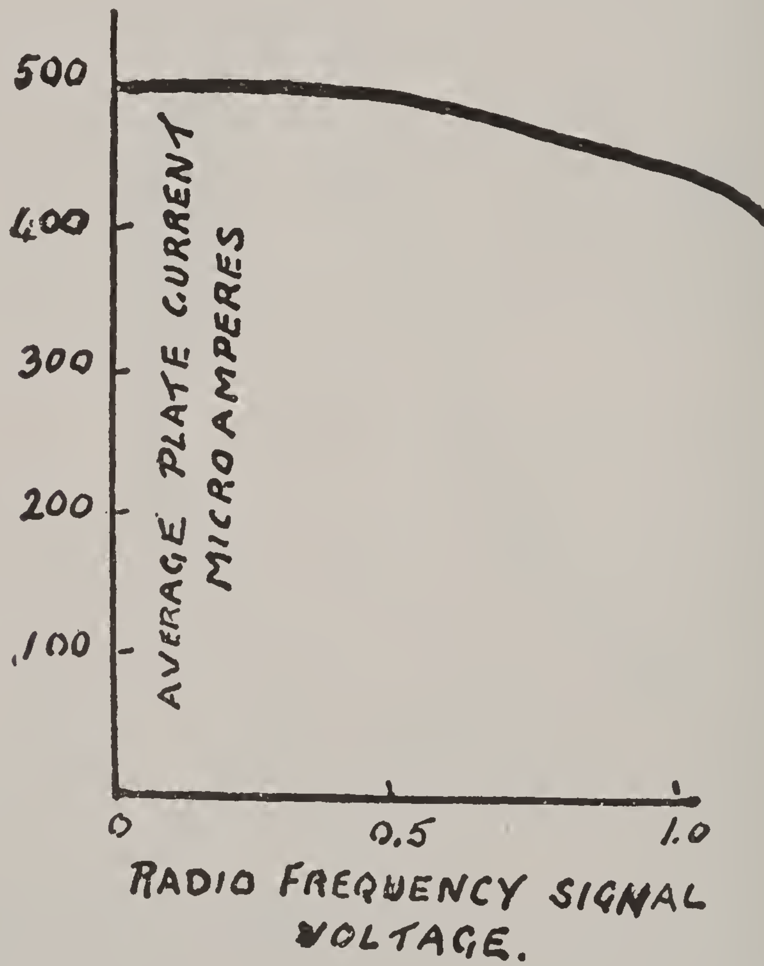


Fig. 44—Effect of Applying Signal to Electron Tube Detector

responding variations in the plate current. The signals may be thought of as exerting a sort of relay action on the plate circuit, causing magnified power to be drawn from the plate battery. The tube is said in this case to act as an "amplifier." The variations of current in the grid circuit have been compared to the slide valve of an engine, since they admit energy from the battery into the plate circuit much as the slide valve admits energy into the cylinder of the engine. The oscillations impressed on the grid circuit may be of high radio frequency or of an audible frequency of perhaps 300 to 3000 cycles per second.

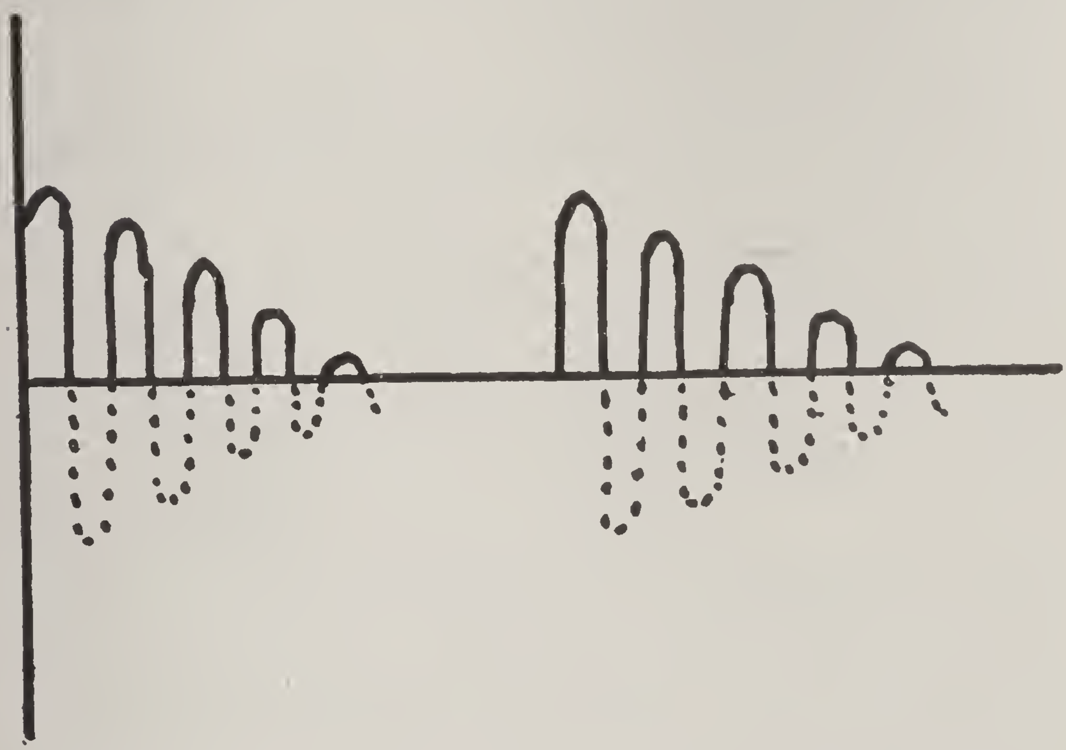


Fig. 45—Action of Rectifier on Received Wave Trains

To utilize the amplified alternating current in the plate circuit, the primary of a transformer T (Fig. 46) may be placed in the plate circuit. From the secondary of this transformer the alternating current is delivered to a detector, which may be an electron tube operating as a rectifier or a crystal detector. If further amplification is desirable, the alternating current from the secondary of the transformer may be delivered to the grid circuit of a second amplifying tube, as shown in Fig. 46. From the second tube it then goes to a detector tube or to a crystal detector. This method of successively using two or more tubes for amplification is called *cascade amplification.* The last tube in such an amplifier of radio-frequency waves is called the detector tube, and the other tubes are called amplifier tubes. An amplifier consisting of one detector tube and two amplifier tubes is said to have two stages of amplification.

Instead of transferring the amplified energy by means of a transformer coupling, the coupling may

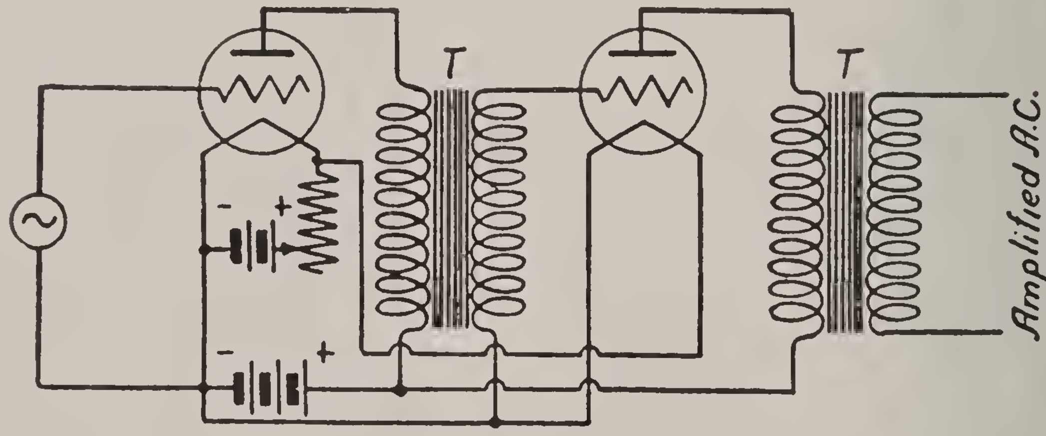


Fig. 46—Cascade Amplification Transformer Coupling Connections

be simply a resistance, or may be a condenser. A circuit using resistance coupling is shown in Fig. 47, in which the radio-frequency power is amplified by two tubes coupled together through resistances, and then detected. After passing through the detector, the currents of audio-frequency can be further amplified by one or more audio-frequency stages. An amplifier in which the signal is amplified *before* reaching the detector is called a radio-frequency amplifier. An amplifier in which the signal is amplified *after* passing through the detector is called an audio-frequency amplifier. Resistance couplings in radio-frequency amplifiers have been extensively used in France, but not to so great an extent in the United States. The advantage of a resistance-coupled amplifier is that while the amplification per tube may not be so great as with transformer couplings, the amount of amplification is practically independent of the

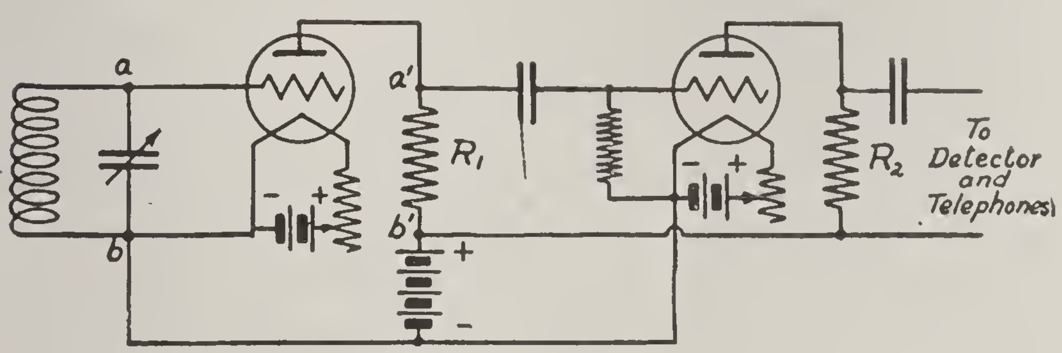


Fig. 47—Resistance Coupled Amplifier

wave length for long wave lengths. Resistance-coupled amplifiers seldom give full amplification at wave lengths below 1,000 meters. In order to get the greatest power output, and hence the greatest power amplification, from a tube, a resistance should be used in the plate circuit of a value equal to the average internal resistance of the tube between plate and filament. In this respect the tube is similar to any other electrical machine and to a battery. Usually, however, such small currents flow into the detector used with radio-frequency amplifier that the detector may be considered a voltage-operated device, in which case the maximum voltage output and not the maximum power output is desired from the amplifier tubes. This is realized by making the coupling resistances larger than the internal resistance of the tube between plate and filament, in some cases two or three times as large. These high resistances require higher plate voltages than are required for transformer coupling, perhaps voltages two or three times as great as for transformer coupling. In some cases, as in some military applications, this may be a real disadvantage.

For audio-frequency amplification, iron core transformers are used. For transformer-coupled radio-frequency amplification the small transformers used generally have air cores—that is, no iron is used. There have recently been developed radio-frequency transformers with iron cores, very thin laminations being used.

Elementary Theory of Amplification.—The characteristic curves of an electron tube show that an increase in the grid voltage makes a much greater increase in the plate current than the same increase in the plate voltage itself would do. A volt added to the grid voltage makes eight times as much change in the plate current as a volt added to the plate voltage would make. This number, which represents the relative effects of grid voltage and plate voltage upon plate current, is called the "amplification coefficient" of the tube. The greater the value of this amplification co-efficient is for a given value of internal plate-circuit resistance of the tube, the more efficient is the tube as an amplifier of weak signals. The amplification coefficient may be defined at the ratio of the change in plate current per volt change on the grid, to the change in plate current per volt change on the plate.

The two principal constants of a tube are the amplification coefficient just defined and the internal output resistance or internal plate-circuit resistance. The internal plate-circuit resistance is the resistance to small alternating currents which exists between the plate and the filament in the tube, and, since it is the resistance of the output circuit of the tube, is often called the internal output resistance. These two constants may be calculated from the characteristic curves of the tube or may be measured by a simple method like a bridge measurement or may be calculated approximately from the structural dimensions of the tube. The voltage amplification given by an amplifying circuit may be calculated from these two constants of the electron tube.

The voltage amplification may be defined as the ratio of the voltage change produced in the output apparatus in the plate circuit to the change in the voltage impressed on the grid. Thus, in the resistance-coupled amplifier of Fig. 47, it is the ratio of the voltage between *a* and *b* at the terminals of R to the voltage applied between *a* and *b*. Calling the amplification coefficient K and the internal output resistance Ro, it can be shown that the voltage amplification for such a combination is

$$\frac{KR}{R + Ro}$$

Audio-Frequency Amplification.—In the preceding discussion of amplification it was pointed out that after a radio-frequency current is amplified it is passed through a rectifying device, often a detector tube, and the term "audio-frequency amplifier" was defined. If an audio-frequency current is to be amplified, it is not necessary to pass the amplified current through a detector, since the amplified current is audible if received with a telephone receiver placed in the plate circuit of the amplifier. It is sometimes desired to amplify the audio-frequency current produced in a radio rectifying device, in which case the amplifier is an audio-frequency amplifier. In this case the radio current consisting of groups of radio-frequency oscillations is first impressed upon the detector and the pulses of current having the group frequency are passed on into the amplifier. The amplifying process may be carried on through several steps, as in the cascade amplification shown in Fig. 46. An amplifier consisting of two Type VT-1 tubes in cascade may give a power amplification of 20,000 times.

In some amplifiers as many as six tubes may be used. In such cases it is general practice to use perhaps three tubes as radio-frequency amplifiers, then the detector tube, and then perhaps two tubes as audio-frequency amplifiers. One reason for using the radio-frequency amplification is because under proper operating conditions with signals of moderate intensity the output of a detector tube is approximately proportional to the square of the input voltage, and hence the output of the detector tube increases rapidly as the input voltage is increased. If more than three stages of radio-frequency amplification are used, troublesome regenerative effects are very likely to occur in the output circuit of the amplifier. Regenerative effects are also likely to occur if more than two stages of audio-frequency amplification are used, causing "howling" noises in the output circuit. If, therefore, we wish to use as many as six tubes in an amplifier, it is necessary to use both radio-frequency and audio-frequency amplification. These troublesome effects can be reduced by properly shielding the various circuits of the amplifier, as by inclosing in metal. If very feeble incoming oscillations are impressed on the input of such a six-tube amplifier of a type now in extensive use, the over-all voltage amplification of the amplifier may be several million. It is only by the

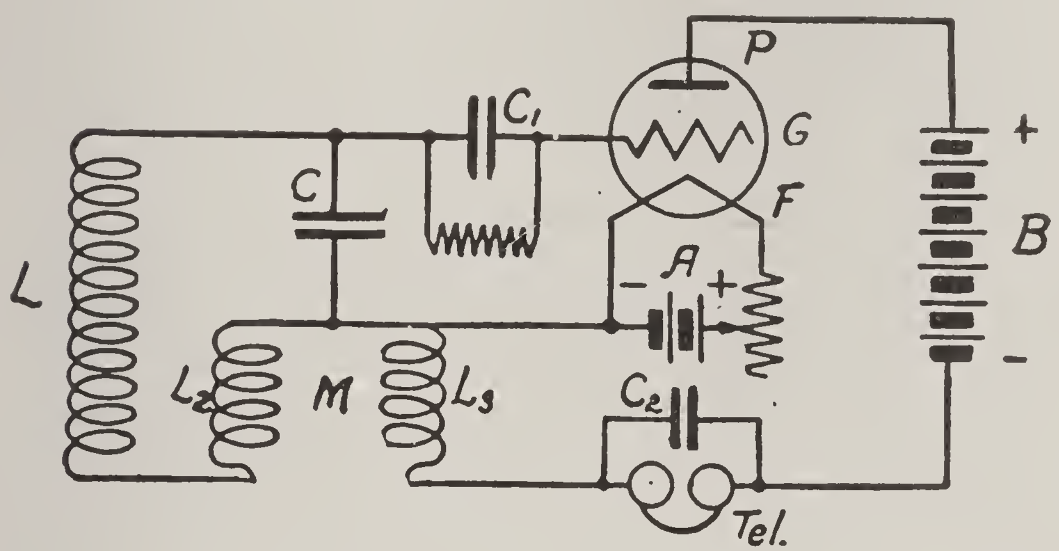


Fig. 48—Regenerative Circuit for Simultaneous Amplifying and Rectifying

use of amplifiers of this type that it has been possible to use the coil antennas, which may be 4 feet square or even smaller, as receiving devices and as radio compasses.

Amplifiers with a large number of tubes have been used, especially for very short waves, such as 50 meters. The use of even six tubes requires very careful design to prevent difficulties due to regenerative effects. With a greater number of tubes and greater amplification every disturbance is magnified, and even greater care in design is essential and shielding is particularly important. The use of more than six tubes in a compact, portable, unit, is especially difficult. A six-tube amplifier, properly designed, will usually give all the amplification necessary for ordinary purposes.

The use of radio-frequency amplification for short wave lengths, particularly for less than 300 meters, is attended with many difficulties caused by the low-impedance paths which the capacities between the leads and between the elements of the tubes offer at high frequencies. For short waves the high frequency may be changed before amplification by the beat method.

If an amplifier with transformer coupling or capacitive coupling is to be used on one particular wave length a much more effective amplifier can be designed than if it is required that the amplifier operate over a considerable range of wave lengths. The performance of a resistance-coupled amplifier, however, when used on long wave lengths depends very little on the wave length. Resistance-coupled amplifiers seldom give full amplification at wave lengths below 1000 meters.

The grid of a tube may be maintained at a definite voltage above the negative terminal of the filament, so that the tube operates at a particular point on the characteristic curve showing the relation between grid voltage and plate current. For a detector it is desirable to have the operating point at the sharpest bend in the characteristic curve, as has been explained above. For an audio-frequency amplifier it is usually desirable to have the operating point at about the center of the steepest part of the characteristic curve. The d. c. voltage so used is often called a ''biasing potential.'' A method of obtaining this biasing potential, which is extensively employed, is by the use of a voltage divider arrangement, which consists of a resistance of perhaps 200 or 300 ohms connected across the filament battery terminals and an adjustable contact, which is connected to the grid.

Stabilizer.—In receiving damped waves or interrupted continuous waves with an amplifier it is necessary to prevent the various tubes in the amplifier from oscillating. This may be done by applying a positive voltage of the proper magnitude to the grid. The voltage divider arrangement just mentioned may be used for this purpose, and when so applied to amplifier tubes is called a ''stabilizer.'' The stabilizer is usually so adjusted that the circuit of the tube for which it is used is just below the oscillating condition. In an amplifier of several stages, such as the six-tube amplifier mentioned above, having both radio-frequency stages and audio-frequency stages, it is desirable to have one separate stabilizer for the radio-frequency stages and one stabilizer for the audio-frequency stages. A separate voltage divider should also be used for adjusting the grid potential of the detector tube. The use of the stabilizer makes the grid sufficiently positive so that the grid circuit will absorb an appreciable amount of power. Stabilizers may be used with amplifiers having either inductive, capacitive, or resistance coupling. Stabilizers may greatly increase the sensitivity and usefulness of an amplifier and are now found on many radio-frequency amplifiers of recent design.

Regenerative Amplification.—The sensitiveness of an electron tube as a detector may be enormously increased by a method which multiplies its amplifying action. The connections are shown in Fig. 48. The explanation of the amplifying action is as follows: Oscillations in the circuit LL2C applied to the grid through the condenser C-1 produce corresponding

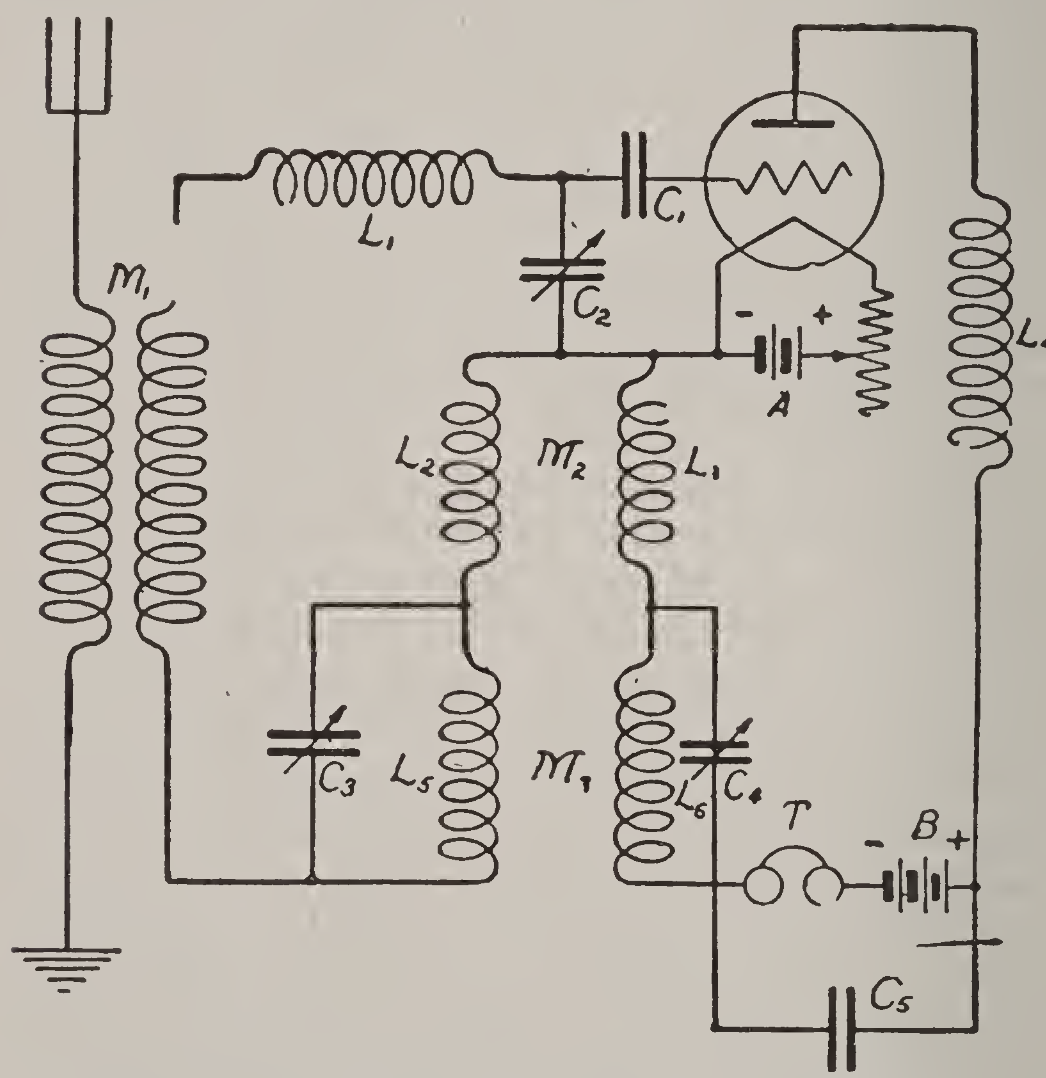


Fig. 49—Combination Radio and Audio Frequency Amplification

variations in the continuous plate current, the energy of which is supplied by the plate battery B, (Fig. 48.) This plate current flows through L-3, and by means of the mutual inductance M some of the energy of the plate oscillations is transferred back to the grid circuit, and the current in the circuit LL2C is thus increased. This produces amplified grid oscillations which by means of the grid, produce larger variations in the plate current, thus still further reinforcing the oscillations of the system. Simultaneously with this

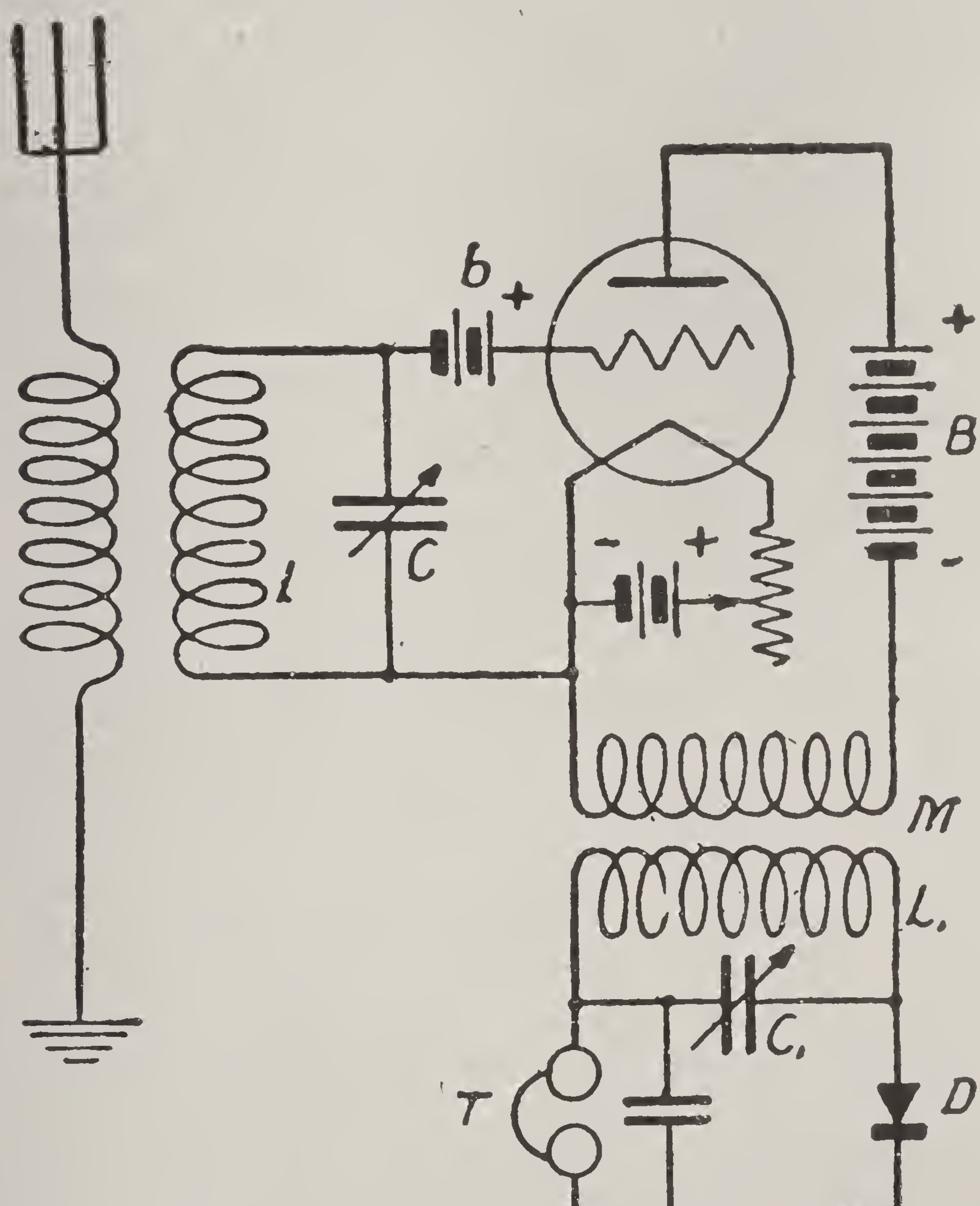


Fig. 50—Combination of Electron Tube Amplifier and Crystal Detector

amplification the regular detecting action goes on; the condenser C-1 is charged in the usual way, but accumulates a charge which is proportional not to the original signal strength but to the final amplitude of the oscillations in the grid circuit. The result is a current in the telephone much greater than would have been obtained from the original oscillations in the circuit.

To obtain maximum voltage on the grid, the circuit LL2C should have large inductance and small capacity. The connections between L-2 and L-3 must be so made that their mutual inductance is of proper sign to produce an emf, which will aid the oscillations instead of opposing them. Various modifications of this method are used. The condenser C may be across L-3, so that the tuned oscillatory circuit is in series with the plate instead of the grid; or C may be connected across all of the inductance in series, the oscillation circuit then including L, L-2, and L-3.

Combination Radio and Audio Regenerative Amplification.—A single electron tube can be used to amplify and detect radio-frequency current and simultaneously to amplify the telephone pulses of audio-frequency. The circuits are shown in Fig. 49. Here M_2 represents the coupling for the radio frequency and the coils are of relatively small inductance. M_3 is the coupling for the audio-frequency, and the transformer is made up of coils having an inductance of a henry or more. The variable condensers C_3 and C_4 have the double purpose of tuning M_3 to the audio-frequency and of by-passing the radio frequencies. The radio-frequency variations in the plate current flow through the circuit $PFL_3C_4C_5L_4$ and at the same time the audio-frequency variations flow through the circuit $PFL_3L_6TBL_4$. The audibility of weak signals received by this method is about 100 times the audibility obtained with a single tube connected in a simple detector circuit. On stronger signals the amplification is smaller.

Electron Tube Amplifier with Crystal Detector.—The characteristic curves of an electron tube show that the best value of grid voltage for amplification is not the same as for best detecting action, which is an argument for using separate tubes for these two purposes. This adds somewhat to the complexity of the apparatus, and in apparatus in which for some reason it is desired to use only one tube the combination of an electron tube for amplifying and a crystal detector for detecting may be used. Such a circuit is shown in Fig. 50.

This oscillating circuit LC is coupled to the antenna and is tuned to the frequency of the latter, which is the frequency of the incoming waves. The alternations of voltage between the terminals of the coil L are applied between the filament F and the grid G through the battery *b*, which has been previously adjusted in voltage so that the plate current has a value corresponding to a point on the straight part of its characteristic.

The amplified oscillations in the plate circuit are communicated to the oscillating circuit L-1, C-1, which is coupled to the plate circuit through the coil M. The circuit L-1, C-1, is tuned to the frequency of the received waves like the other two circuits. The alternations of voltage between the terminals of the coil L-1 are rectified in the crystal detector D in the usual way and cause an audio-frequency current to flow through the telephone receivers.

THE ELECTRON TUBE AS A GENERATOR

Conditions for Oscillation.—The electron tube can be made to generate high-frequency currents and thus act as a source of radio current for the transmission of signals and other purposes. Any regenerative circuit, such as that shown in Fig. 48, can be made to

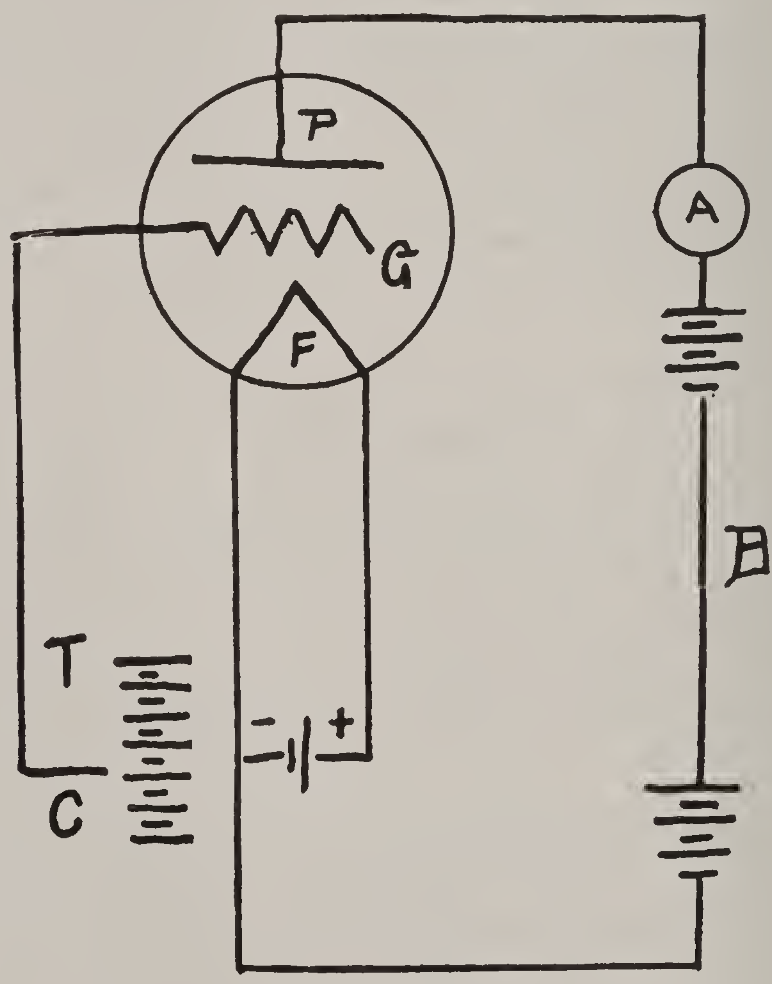


Fig. 51—Use of Grid in Electron Tube

generate spontaneous oscillations, if it be so arranged that any change in grid voltage makes a change in plate current of such magnitude that there is induced in the grid circuit a larger voltage than that originally acting. It has already been pointed out that in any electron tube much more power is produced by variations in the current to the plate than must be expended in changing the grid voltage to produce these variations. Thus there are a great variety of circuits in which the plate circuit is coupled back to the grid circuit in such a manner as to supply this small power to the grid and make the surplus power available for use in an external circuit in the form of continuous or undamped oscillations of any frequency from even less than one per second to 10,000,000 or more per second.

This "feed-back" action can be obtained by the use of direct coupling from the plate back to the grid circuit, by inductive coupling, or by electrostatic coupling. The only requirement for continuous oscillations is that the voltage induced in the grid circuit must vary the plate current through an amplitude which supplies to the external or coupling circuits power sufficient or more than sufficient to maintain this voltage in the grid circuit.

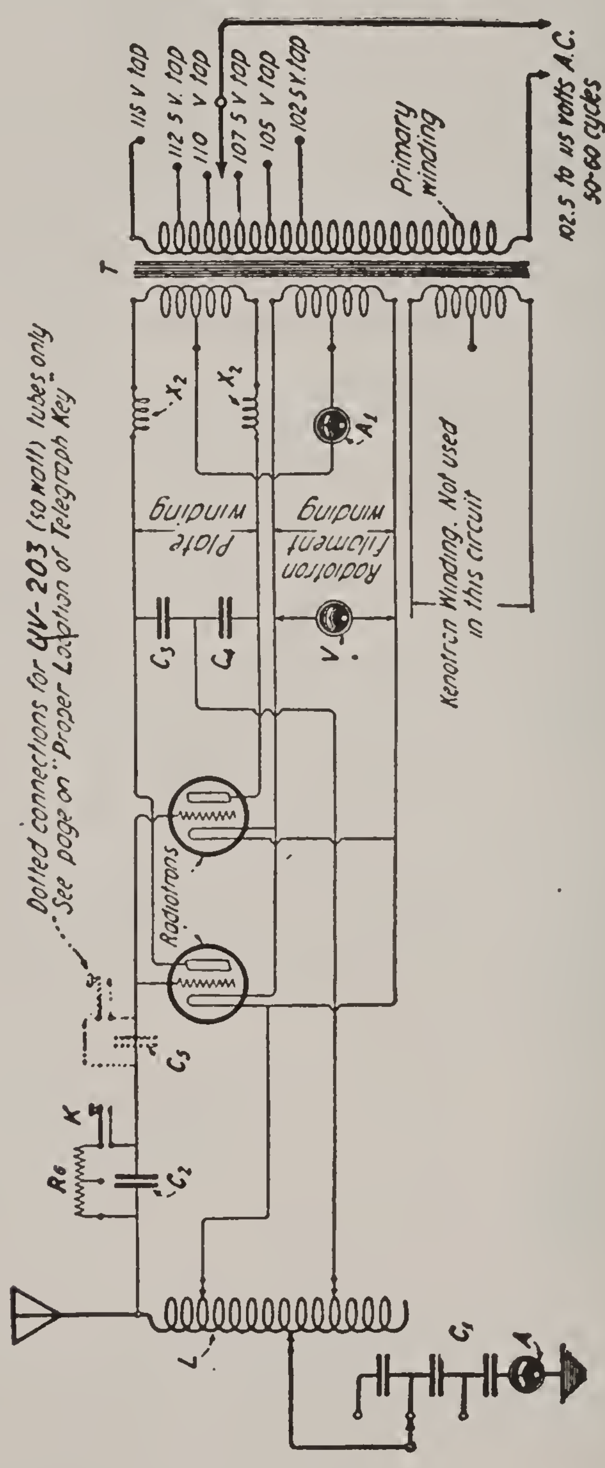


Fig. 52—Radiotron Power Tube Circuit

WHAT HAPPENS IN A RECEIVING SET

The aerial is placed in such a position that it can pick up or catch the radio waves (electro-magnetic waves), these waves having been set in motion at the transmitting or broadcasting station and travel from this station through space at the rate of 186,000 miles per second. As soon as these waves set up oscillations in the receiving aerial, a current is passed from the aerial down the lead-in wire to the primary coil of the transformer. The action of the current in this coil sets up a magnetic field; this current is induced into the secondary coil of the transformer and this pro-

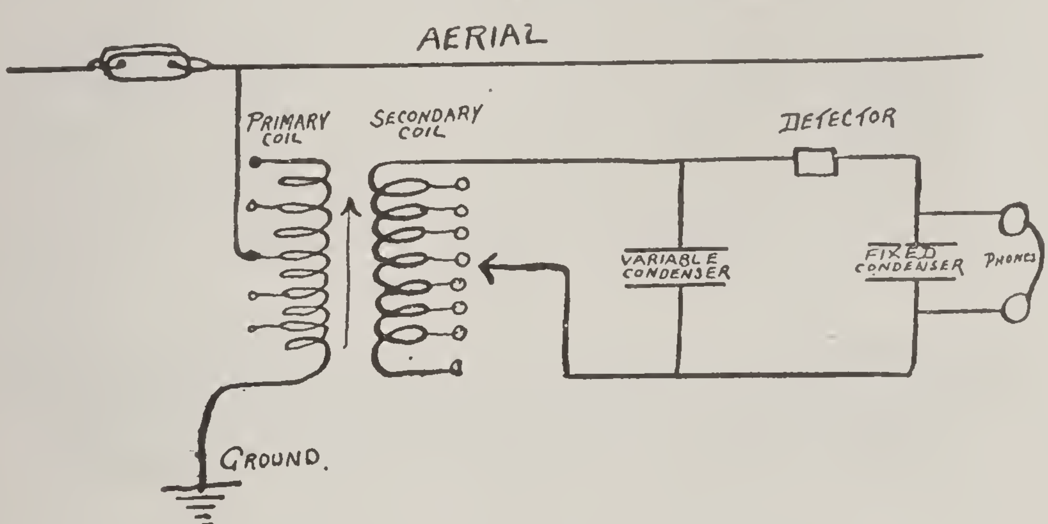
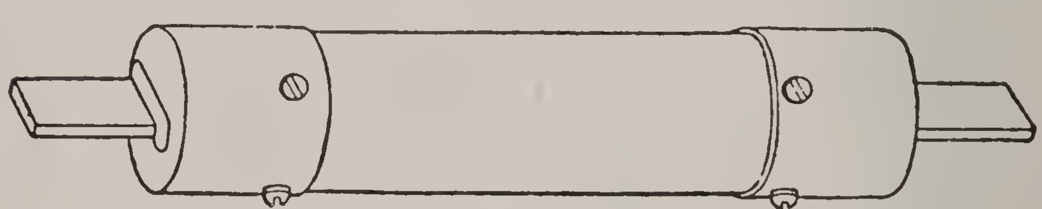


Fig. 53

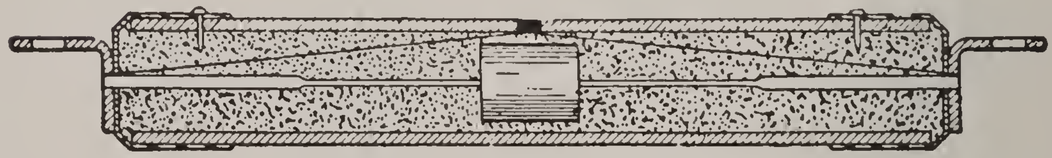
duces a radio frequency current which is gradually built up by adjusting the primary and secondary in electrical resonance. The variable condenser is placed in the circuit to allow the secondary circuit to be adjusted to resonance with the primary circuit and also to allow of close adjustment. The induced current will overflow to the detector circuit as soon as the secondary circuit has been put in resonance with the primary circuit. The detector will then rectify this current by transforming the high frequency to low frequency. The current then passes to the condenser, where it is stored; as soon as a single wave train has accumulated in the condenser the condenser will discharge the current into the phone receivers, where by its action in vibrating the diaphragm it makes the magnetic waves received by the aerial audible to the ear.

Tuning

The apparatus for tuning a receiving set consists of an adjustable circuit containing variable capacity and



Enclosed or Cartridge Fuse



Section of Enclosed Fuse

Fig. 54

inductance. The operation of the tuning apparatus is very simple. We have already seen that this apparatus is used to vary the wave length of the receiving set, making it receptive to incoming signals.

As in order to receive signals, the receiving set must be adjusted so that the receiving circuits are in tune with the transmitting circuits. In other words, the time period of oscillation must be the same in both the transmitting and receiving circuits. Thus should we desire to receive the music or speeches from a broadcasting station using a 360 meter wavelength, then it would be necessary for us to adjust our receiving set to as near that wavelength as possible to get maximum results.

What Is Meant by Wavelength

Electro-magnetic waves like light waves travel at the rate of 186,000 miles or 300,000,000 meters per second, if we are using an alternating current of 25,000 cycles per second and cause a disturbance in the air of that frequency then each cycle will travel from the aerial through space at the rate of 300,000,000 meters per second. So that at the end of the second, just as we are causing the last of the 25,000 disturbances the first cycle or disturbance is 300,000,000 meters away. In one second we have made 25,000 separate disturbances, which have traveled 300,000,000 meters, each disturbance separated by the number of meters, that 25,000 divided into 300,000,000 will give—300,000,000 divided by 25,000 equals 12,000 meters—it is this distance between the separate disturbances that is known as the wavelength.

Rule for Wavelength

Add the length of the aerial to the lead-in wire. Add to the sum the ground and if more than one wire, one-third of length of aerial. Divide this total by two and add the result to the addition above. The answer will give the approximate wavelength in meters. Example:

Length of aerial 100 feet, length of ground wire 40 feet, length of lead-in wire 20 feet; 100+40+20=160 feet. One-third of 100=33+160=193; 193÷2=96; 193+96=284, which is the approximate wavelength in meters.

RECEIVING SETS

While the installation and operation of a receiving set is a simple matter, it means more than the connection of aerial and ground wires, and adjusting of the head phones. Thousands of owners of receiving sets are receiving the daily concerts, etc., but they are not getting the maximum results from the sets. The various makes of receiving sets each have their own characteristics, and we approached the manufacturers with the request that they supply us with the information necessary to help obtain the best results out of their instruments. On the following pages we describe the construction, operation and care of these sets, and would ask that these directions be followed. The writer of this book will be pleased to help solve your radio troubles if you will write him direct, in care of the publishers.

Apparatus for Reception of Waves

Receiving sets are divided into two general classes, those suitable for the reception of damped waves and undamped waves modulated at an audible frequency and those suitable for the reception of unmodulated undamped waves. The former involve the simpler construction, and will be discussed first. With a few modifications, a set for receiving damped waves can be adapted to receive unmodulated undamped waves. Damped waves may be received in a simple circuit containing a crystal detector or simple electron tube detector and a telephone receiver. The tone heard in the telephone receiver is that corresponding to the frequency of the groups of damped waves. Undamped waves are ordinarily received by an electron tube method which produces beats.

The fundamental principle of reception of signals is that of resonance. If the receiving circuits are tuned to oscillate at the same natural frequency as the incoming waves, then these waves, though extremely feeble, will after a few impulses build up comparatively big oscillations in the circuits. In reality, then, for reception of signals all that is needed is an antenna circuit tuned to the same wave lengths as that of the transmitting station and an instrument capable of evidencing the current which flows in the antenna-connecting wire. This is shown in Fig. 55. This is the simplest possible arrangement for reception and will operate on either damped or undamped waves. A current-indicating instrument is shown at A. In practice the current is too feeble for any hot-wire ammeter. An ammeter is more suitable for quantitative measurements than for receiving telegraphic signals, since the dots and dashes are not readily distinguished unless made so slowly as to be impracticable for transmitting messages.

A telephone receiver having magnet windings consisting of a large number of turns of fine wire is a much more sensitive receiving device. The diaphragm can follow the audio-frequency variations of current occurring in ordinary speech, but can not follow the very rapid radio-frequency variations. The effect is as if the diaphragm tried to go both ways at once, with the result that no observable motion takes place. For this reason a telephone receiver alone can not be used to receive radio waves. To remove this difficulty a crystal detector is put into the circuit, which permits current to flow in one direction but not in the other; or, more exactly, the current in the reverse direction is negligibly small compared with the current in the principal direction. Referring to the reception of damped waves, it is well to remember that the waves are in widely separated groups. The action of a crystal detector upon damped oscillations is shown in Fig. 45; the lower halves of the waves

Fig. 55

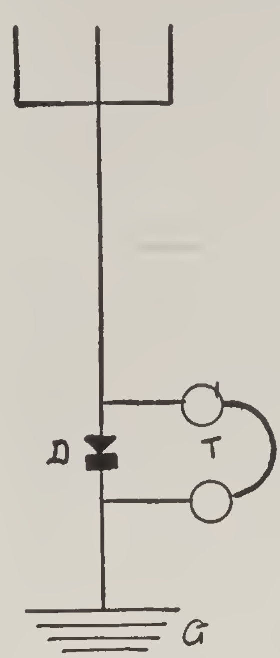


Fig. 56

are drawn dotted to indicate the portion of the current that is cut off by the crystal detector.

It is found that the cumulative effect of one group or train of waves—for instance, that due to one condenser discharge at the transmitter—pulls the telephone diaphragm away from its neutral position. The number of such pulls per second is equal to the number of wave trains per second. With a 300-meter wave having 1000 wave trains per second the radio frequency is 1,000,000 and the audio frequency is 1000, or one is a thousand times as high as the other. The upper limit of audio frequency for the human ear is 16,000 to 20,000 sound waves per second, so that even if the telephone diaphragm could, without a rectifier, follow the radio frequency, the ear would not hear the signals. In telegraphic signaling either a dot or a dash lasts long enough to contain many wave groups, and in the telephone, where the pitch

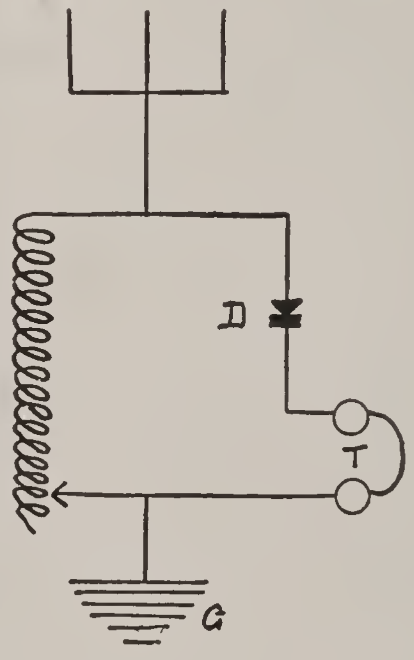


Fig. 57

corresponds to the spark frequency, a tone is heard during the length of the dot or dash.

In Fig. 56 is shown the simplest connection for reception with a telephone receiver. It is suitable only for damped waves. At D is shown the rectifier, commonly called a "detector," although it detects nothing; it alters the waves so that the telephone can detect them. The apparatus shown receives strongest signals from a station transmitting waves of the same length, or nearly the same length, as the wave length of the receiving circuit. The fact that the current from the antenna to ground must pass through either the telephone or the detector, both of which have a high resistance, renders this circuit not very selective, so that it will respond to a wide range of wave lengths. The circuit may be tuned by inserting a variable inductor in series between the antenna and the detector, the inductance being varied to change the wave length.

A simple variation of this circuit which allows fairly sharp tuning is shown in Fig. 57, in which the detector and telephone are connected at the ends of the tuning inductance. It is well to notice how simple is the apparatus actually needed for reception, contrary to what the uninitiated person supposes. Three pieces of apparatus—telephone receiver, rectifier, and tuning coil—with a suitable antenna, are all that are necessary to receive effectively from stations transmitting damped waves.

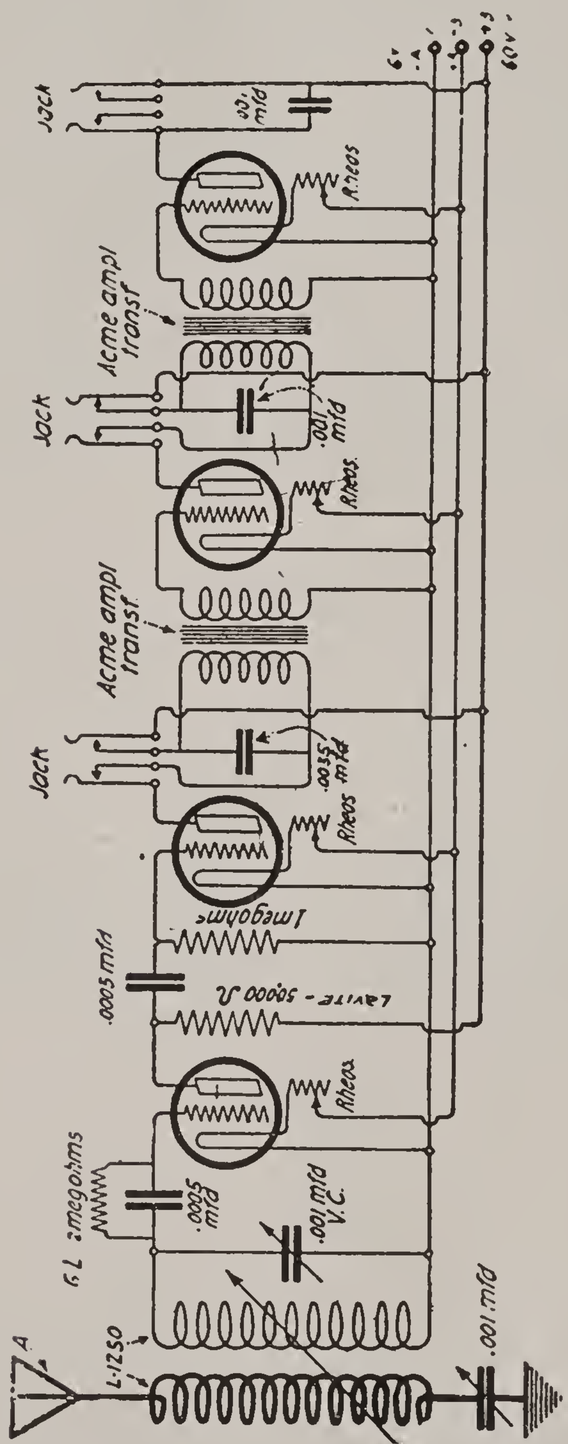


Fig. 58—Diagram of the New York "Times" Long Distance Receiving Set

WESTINGHOUSE CRYSTAL RECEIVING SET

The Aeriola Jr. consists of a variometer, a two-section fixed mica condenser, one telephone by-pass condenser and a crystal detector contained in a nicely finished wood box having a separate compartment for telephones, the telephones being sold with the set.

The variometer is made of micarta tubing and has a minimum amount of material in the field, thereby reducing dielectric losses. The small mica fixed condenser is connected in series with the antenna and the variometer, the small section of the condenser being used for the reception of wavelengths between 190 and 300 meters and the large section for wavelengths between 300 and 500 meters.

The crystal and telephones are shunted across a certain portion of the variometer, which gives the greatest volume of signal.

Operation

Connections from each section of the small mica condenser are brought out to separate binding posts permitting a change from one wavelength range of the set to the other by merely changing the antenna from one post to the other. With the aerial ground and telephones connected to their respective binding posts it is only necessary to adjust the crystal detector and tune with the variometer handle until the expected signal is heard. After a signal is tuned in further signal strength may be obtained by further adjustment of the detector.

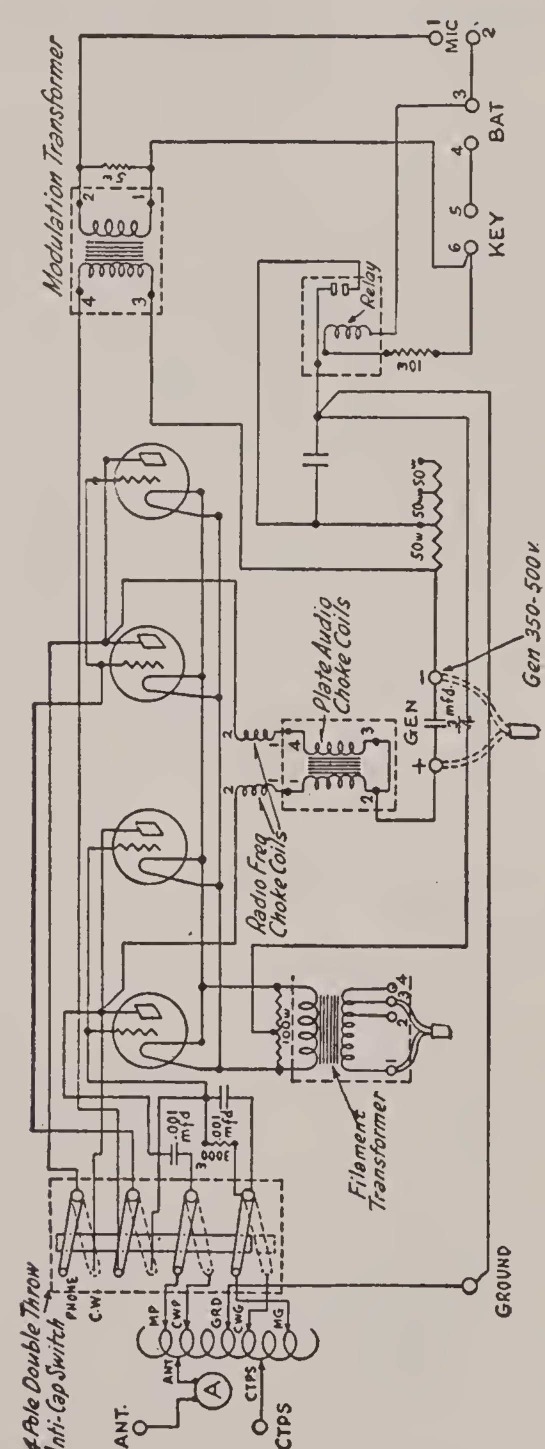


Fig. 59

Westinghouse Type "T. F." Transmitter

WESTINGHOUSE TYPE R. C. SET

The type RC regenerative set was designed to be used for operation of a loud speaker and for long distance reception with the use of telephones.

Construction

This set consists of the type RA tuner, the type DA detector amplifier and the type CB loading coil. The wavelength range of the set is 180 to 700 meters, with the loading coil short circuited, and 1600 to 2800 meters with the loading coil in circuit. This range permits reception of amateur broadcasting, up to 700 meters, as well as commercial and time signals between 1800 and 2800 meters, with the loading coil in circuit.

The tuner consists of a variable condenser and variometer mounted on the same shaft, as a tuning unit. The capacity and inductance of the circuit is thereby increased simultaneously and in the proper L to C ratio. The tuning condenser is paralleled by a three-plate vernier condenser for sharp tuning. A tapped tickler is used on the type RC set and is wound on the same tube and alongside of the stator winding of the variometer. The tickler is so tapped as to permit a close adjustment of regeneration, thereby securing maximum sensitivity.

The amplifier used in this set consists of a socket for the detector tube, telephone by-pass condenser, two sockets for amplifier tubes, two special audio frequency transformers and two moulded porcelain base rheostats. The detector and amplifier tubes are mounted on a flexible rubber shock absorbing cradle, which prevents audio noises due to local vibrations from being amplified. Three jacks are provided so that the detector tube, first step of amplification, or second step of amplification, may be used.

The loading coil used with the set consists of two universal wound coils, one used as a loading inductance and the other as a tickler for regenerating the loading inductance. The two coils are mounted in a block moulded bakelite enclosed case which is equipped with a plunger type switch to short circuit the loading coil when using the short wavelength range of the set. The switch permits permanent installation of the loading coil on the set. The leads of the coils are brought out to the four legs of the switch blades, an extension of these blades also serves as a connection to be clamped under the binding posts of the set.

An electro-static shield is used to minimize the capacity effect of the operator's body, this shield is located on the back of the panel and is kept at ground potential.

The tickler and tuning knobs are secured to Micarta shaft extensions, thereby further minimizing capacity effect of the operator's body. The connections are brought out to the rear of the tuner and amplifier by means of extension rods, and the high potential connections are thereby kept away from the operator, avoiding the capacity effect of the body, and, detuning and howling, as consequent results.

The lead from the grid inductance is connected to the positive side of the filament of the detector tube and the transformer secondary winding is connected to the negative side of the filament of the amplifier

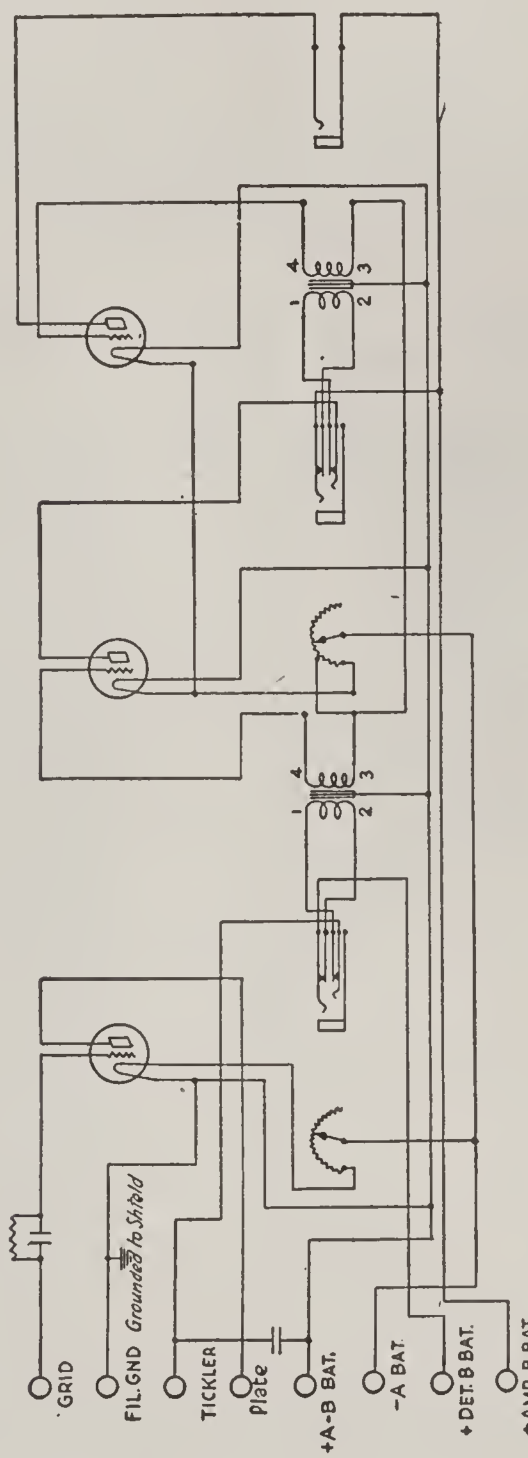


Fig. 60

Wiring Diagram of Detector and Two-Stage Amplifier

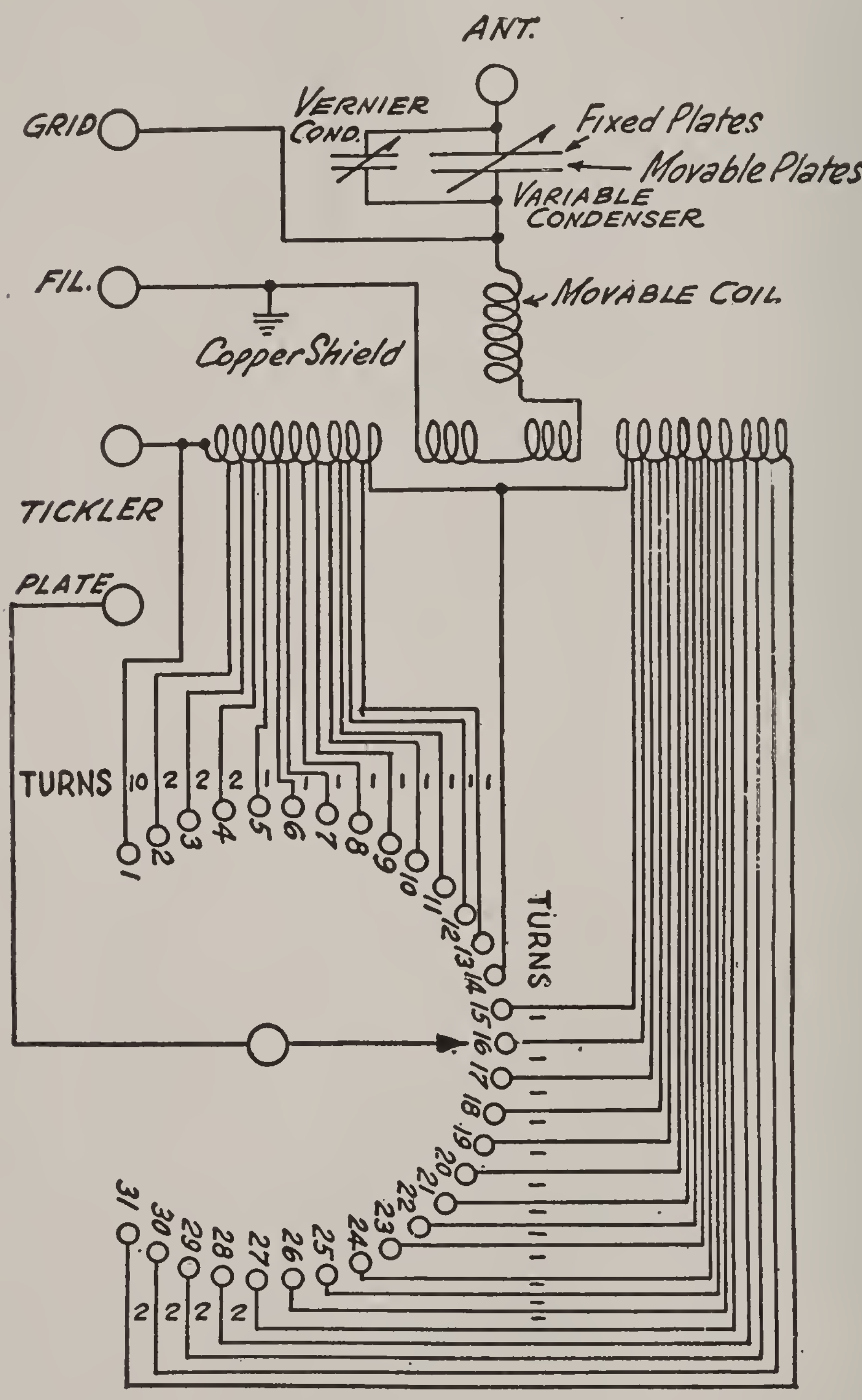


Fig. 61—Westinghouse Single Circuit Type Radio Receiver

tubes, with a bias of approximately one volt obtained by keeping a certain portion of the filament rheostat between the transformer winding and the filament of the tube. This grid bias allows a material increase in amplification, and is such as to cause the least amount of distortion in the reception of speech or music.

In connecting up the Type RC set it is necessary to put a jumper (furnished for that purpose) between the grid binding post of the tuner and the grid binding post of the amplifier, and also a jumper between the tickler binding post of the tuner and the tickler binding post of the amplifier. The loading coil is then connected between the filament post of the tuner and the filament post of the amplifier and between the plate binding post of the tuner and the plate binding post of the amplifier in such a manner as to have the loading coil switch handle vertical and at the top of the cabinet. (In the absence of a loading coil put jumpers in between the tuner and amplifier to replace the loading coil.) The aerial and "A" and "B" batteries are to be connected to their proper binding posts of the set and the ground connection taken off of the filament binding post of the amplifier. If a "soft" (low vacuum) tube is used as a detector, do not connect more than 22½ volts across the detector "B" battery binding posts.

Operation

To operate the set, plug the telephones in on the detector, first step of amplification or second step of amplification, adjust the tickler for regeneration by means of the tickler dial on the panel and tune by means of the large tuning dial on the panel until the desired signal is heard. For a finer adjustment of tuning it is necessary to use the small vernier dial to the left of the tickler dial. After a signal has been tuned in accurately, a further adjustment of the tickler for maximum regeneration will increase the signal strength materially.

Care should be taken not to use too much amplification. If the music or speech being received is sufficiently strong on the first stage of amplification, do not attempt to use more amplification. The use of more amplification would "block" the second amplifier tube and cause local atmospheric disturbances to be amplified in excess of the signal amplification. The blocking of the second tube causes the music or speech to be distorted, the amplification of atmospheric disturbances in excess of the amplification of signal, naturally does not improve the clearness of the music or speech received.

When using the loading coil to secure the wavelength range between 1600 and 2800 meters, the plunger switch is pulled up. To use the set for reception of wavelengths between 180 and 700 meters, the loading coil plunger switch must be pushed down, thereby shortening the loading coils out of circuit.

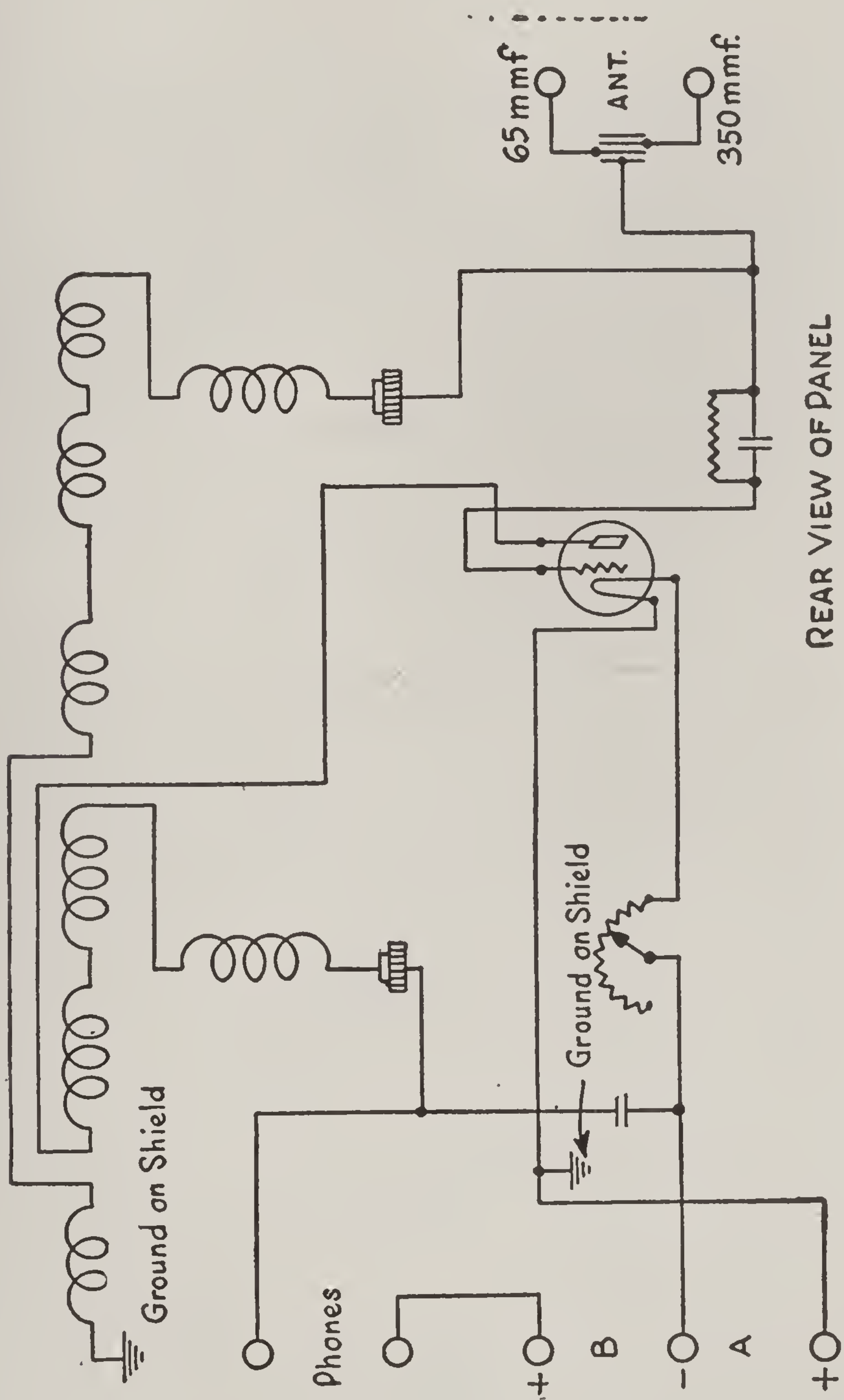


Fig. 62—Aeriola Sr. Regenerative Receiver

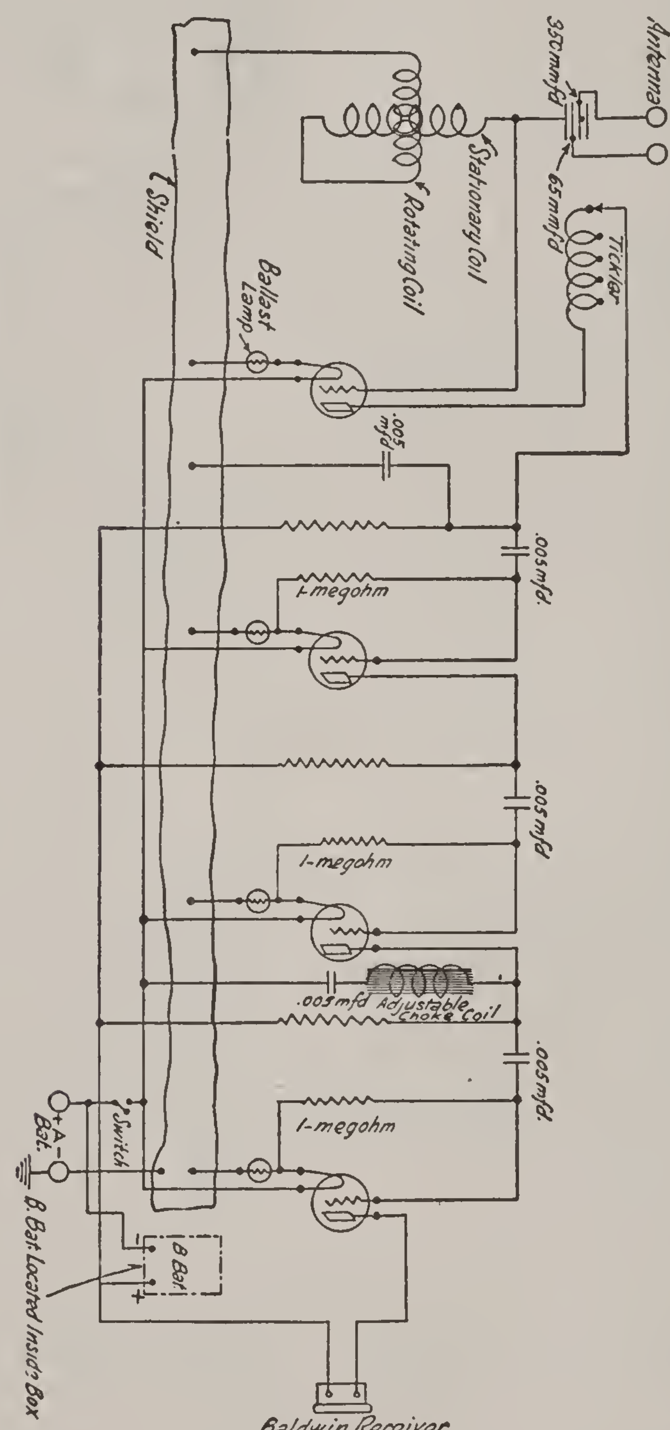


Fig. 63—Westinghouse Aeriola Grand

AERIOLA SR. RECEIVING SET

The Aeriola Sr., a regenerative set, was designed to satisfy the demand for a vacuum tube set which did not require a storage battery to light the filament. A special tube, developed by the Westinghouse Electric & Manufacturing Company, which requires one 1½ volt dry cell and uses .23 amperes of current to heat the filament and using either 20 or 40 volts as a plate battery, is used with this set.

Construction

The Aeriola Sr. consists of two variometers, the stator windings of each being wound on the same micarta tube, the distance between windings and the value of each stator and rotor winding being such as to give an even increase in regenerative control.

One variometer is used as a tickler winding for securing regeneration and the other variometer serves as a variable inductance which is used in conjunction with the two sections of the small mica condenser to secure the wavelength range of 190 to 500 meters.

A rheostat having the resistance wire wound on special fibre support and the resistance unit secured to a moulded porcelain base is used to control the filament current.

The bulb socket is set back from the panel so as to allow the top of the tube to protrude through a hole in the panel far enough to permit removal of the tube, yet not so far as to prevent the lid of the box being closed when the tube is in the socket.

Operation

The lead from each section of the small mica condenser has been brought out to separate binding posts and the wavelength range of the set is determined by the post to which the antenna lead is connected, one post being the connection to the small section of the mica condenser and having a wavelength range of 190 to 300 meters and the other post being connected to the large section of the condenser and having a wavelength range of 300 to 500 meters.

Refer to the connection diagram in the lid of the box and connect the antenna, ground and telephones to the proper binding posts of the set. Connect the 1½ volt dry cell to the proper binding posts, positive lead of the battery to the positive binding post of the set. Connect the plate dry battery of 20 to 40 volts to the proper binding posts, taking care to have the positive lead of the battery to the post marked positive "B" battery of the set. Care must be taken NOT to connect the "B" battery to the filament battery posts of the set, doing so would burn the filament of the tube out.

Having made the above connections properly, the set is then ready for operation. Turn the filament rheostat knob until the filament of the tube glows a dull red. The filament is oxide-coated and must NOT be burned brightly. Tune the set by means of the variometer handle and increase the tickler until considerable regeneration is obtained. Avoid using sufficient tickler to cause the set to oscillate when receiving music or spark signals. In order to secure best results it is necessary to make a final adjustment of the tickler after the signal has been tuned in by means of the variometer handle.

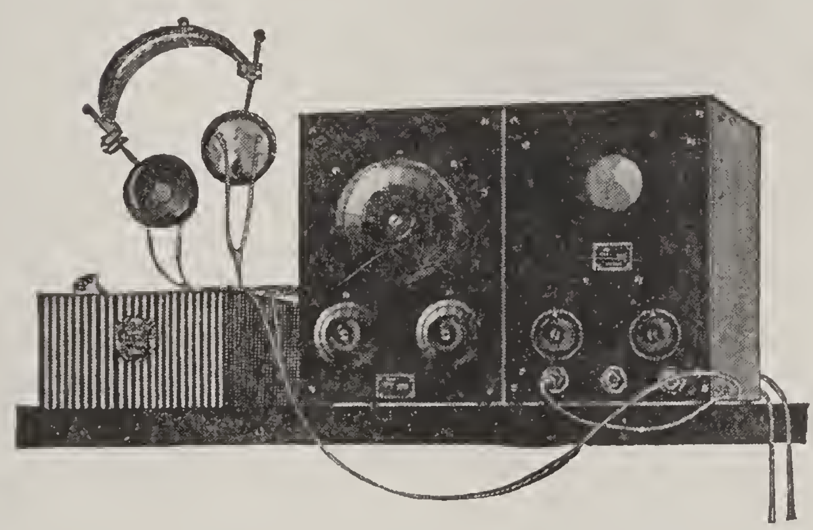


Fig. 64—Westinghouse R. C. Receiving Set

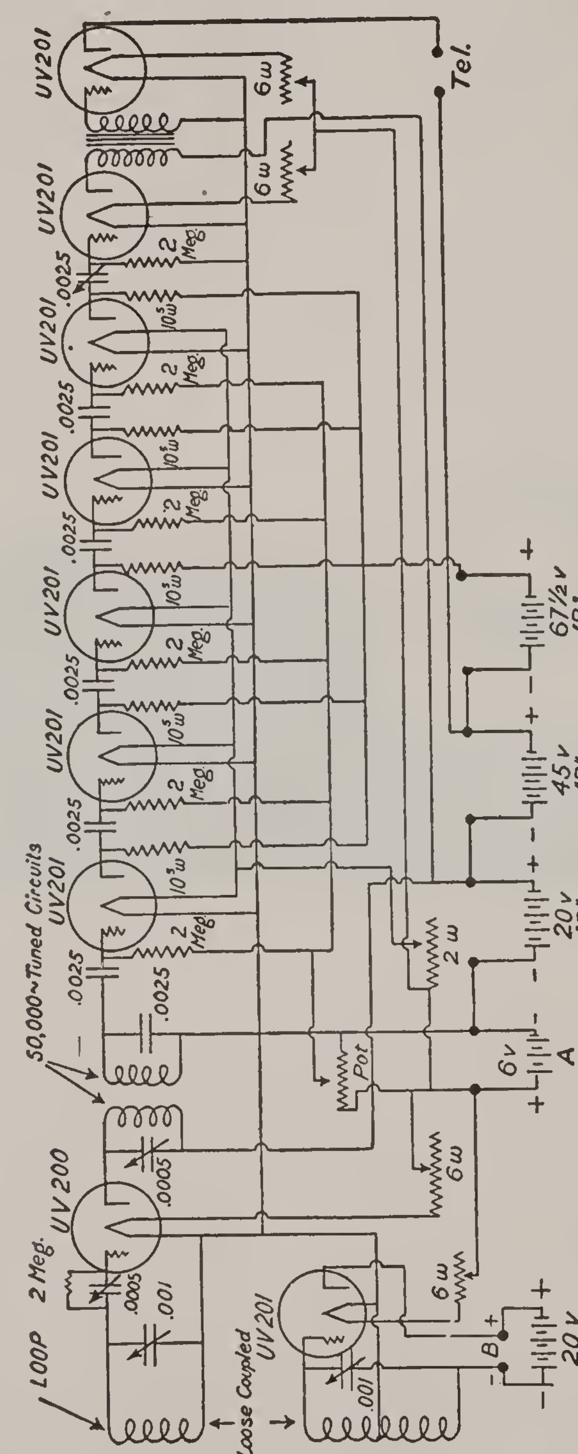


Fig. 65—Super-Hetrodyne Receiving Set

AERIOLA GRAND

In order to receive music or speech free of disturbing noises it is necessary that the signal be much stronger than local disturbances. It is not necessary that a set be extremely sensitive for such reception. To the contrary, it is not advisable to have a supersensitive set, such a set would detect and amplify local disturbances, and a conglomeration of noises would accompany the reception of music and speech.

The Aeriola Grand Regenerative Receiving Set is a parlor outfit of extreme simplicity in operation.

It consists of a nicely finished box shaped very much like that of the modern phonograph. The set is panel mounted, the panel being what would ordinarily be the turn table of a phonograph. This panel being hinged at the rear forms a false lid for the box and permits the apparatus to be readily inspected. The plate batteries are placed in retainers within the box alongside of the loud speaking telephone, which is coupled to the sound chamber of the box. The panel is shielded to prevent the capacity effect of the hand from being troublesome.

The four vacuum tubes and four ballast resistance tubes are mounted so as to protrude far enough through the panel as to be readily removed, yet not so far as to interfere with closing the lid. A small push button switch, which is in the filament battery supply line, is located on the panel.

The tuning system consists of a fixed capacity, in the form of a small mica condenser, and a variometer which serves as a variable inductance, the handle of the variometer being located on the panel for tuning. The set is regenerative, due to a coil in the plate circuit, which is coupled to the variometer winding, this coil being tapped and pre-adjusted at the time of installation to give proper regeneration, no adjustment being provided from the panel.

One detector tube and three resistance coupled amplifier tubes are used in this set. The detector tube naturally serves as the rectifier and its grid is so maintained at a negative potential as to give the best rectification possible. The grids of the amplifier tubes are maintained at a constant D.C. potential with respect to the filament as to give the greatest amplification possible without distortion.

The last amplifier coupling resistance is shorted by a condenser and coil in series which has been precalibrated to the natural period of the loud speaking telephone, thereby lowering the telephone amplification of the audio note at the frequency which the telephone would respond to most strongly and keeping the efficiency of the loud speaker more uniform for all frequencies.

In order to simplify this set as much as possible, the filament rheostats are omitted and a separate ballast resistance tube placed in series with each filament. The ballast resistance consists of a certain length of iron wire in an atmosphere of hydrogen. The wire supported and the hydrogen gas maintained in a glass casing resembling a vacuum tube, but having two pins for contact on the base instead of the customary four. The function of the ballast resistance being to maintain a predetermined filament current throughout a wide range in voltage of the filament battery.

THE DETECTOR

One of the most important parts of the receiving set is the detector. The human ear cannot record frequencies above 15,000 cycles, and as we have already been shown that the cycles in radio work are very high, sometimes running as high as 1,500,000 cycles per second, it will be readily seen that some apparatus must be introduced to reduce the extremely high frequency used in wireless work to a frequency that will be audible by using the telephone receivers.

There are many forms of detectors. We shall first deal with the crystal type, which up to a few months ago was the one most commonly used. Crystal rectifiers consist of certain metal compounds having the property of rectifying the high frequency oscillations.

Galena (a sulphide of lead) is the mineral mostly used today.

The construction and operation of a crystal detector is simplicity itself. On a wood base mount a small piece of galena between two adjustable contacts in such a manner that the most sensitive part of the crystal can be easily located by searching the surface of the mineral with the end of a thin (catwhisker) wire.

Crystals must be kept clean to retain their sensitiveness. Washing with alcohol greatly improves them if they have been left standing without use for any length of time.

Crystal Detector

The type DB crystal detector was designed by the Westinghouse Electric & Manufacturing Company to fulfill the needs of amateurs and novices. This crystal detector consists of two sets of crystals with a switch to throw from one to the other. Necessary binding posts are provided for connecting the detector to the receiving set and to the telephones.

One set of crystals are of the heavy contact type, providing a stable adjustment.

These crystals abound with sensitive points and require no skill whatsoever to adjust.

The other set of crystals consist of a fixed crystal of tested galena and an adjustable catwhisker tipped with a special composition bead. This is a relatively light contact detector and super-sensitive. A signal may be detected on the heavy contact set of crystals without difficulty in making the adjustment and if greater volume is desired the switch may be thrown to the super-sensitive crystals and further adjustments made there.

INSTRUCTIONS FOR THE INSTALLATION AND OPERATION OF GREBE SHORT-WAVE REGENERATIVE RECEIVERS

Installation

The receiver should be placed in a position convenient for operating control. Connect the Antenna and ground leads to the terminals so marked. Connect a 6-volt storage battery to the terminals marked "Filament Battery." Connect a 22½ volt battery unit to the terminals marked "Plate Battery."

Make certain that all battery leads are connected to the proper terminals and that the polarities are not reversed. Connect the telephones, or amplifier unit, to the terminals marked "Output." Turn the rheostat wheel to the "off" position and place the vacuum tube in the socket. The rheostat may now be rotated to 2.

Operation

To tune the receiver to a given wavelength, the Antenna Inductance Switches and the Grid Variometer must all be adjusted to that wavelength, and the Wavelength Range Wheel set in the position indicating the upper limit of the wavelength band in use.

The figures opposite the contacts of the Antenna Inductance Switches represent the number of turns in the antenna circuit. Divide the wavelength desired by 14 to find the approximate number of turns to use.

The Plate Variometer Dial controls the regenerative action and its proper setting for spark signals is best determined by advancing the dial until the signal is of maximum audibility without distortion. For C. W. signals, the dial must be advanced beyond this point, i. e., until oscillations occur—a condition easily recognized by a soft hissing sound in the telephones. The Coupler should be set at 50 for preliminary tuning and finally adjusted to tune out interfering signals.

As many signals are inaudible until the regenerative action takes place, it is advisable to adjust the

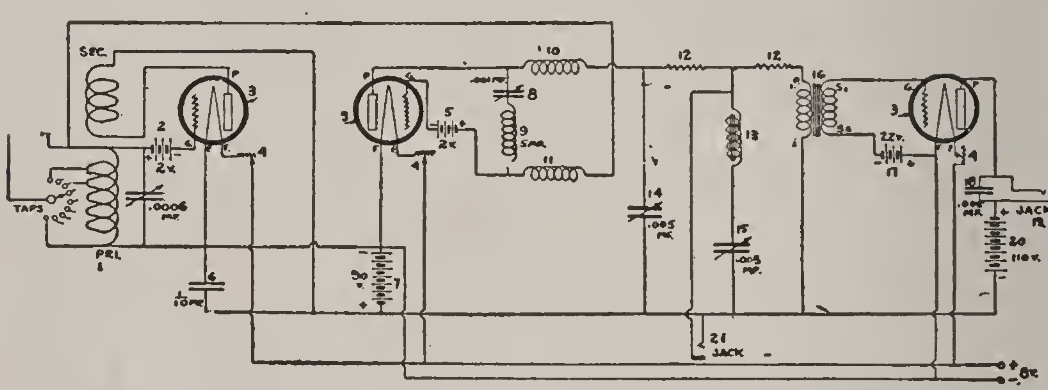


Fig. 66—Super Regenerative Receiving Set

Grid and Plate Variometers simultaneously, and make final adjustment of Antenna Inductance for maximum signal strength. The tangent-wheel verniers are indispensable in accurately turning all weak signals, especially C. W. and telephones.

Location of Faults:

(a) If adjustment of Plate Variometer fails to profuse regeneration, adjust filament current, plate voltage, or both.

(b) If adjustment of Plate Variometer produces regeneration but no appreciable increase in signal strength, adjust Antenna Inductance, Coupling, or both.

(c) If vacuum tube filament fails to light, or flickers, remove the tube and clean the end of its four contacts with a file or sand-paper.

(d) Grinding noises are caused by:

1—Faulty Connections.
2—Defective Plate Batteries.
3—Defective Vacuum Tubes.

Unlike static disturbances, these noises persist when the antenna is disconnected, and they may be elimi-

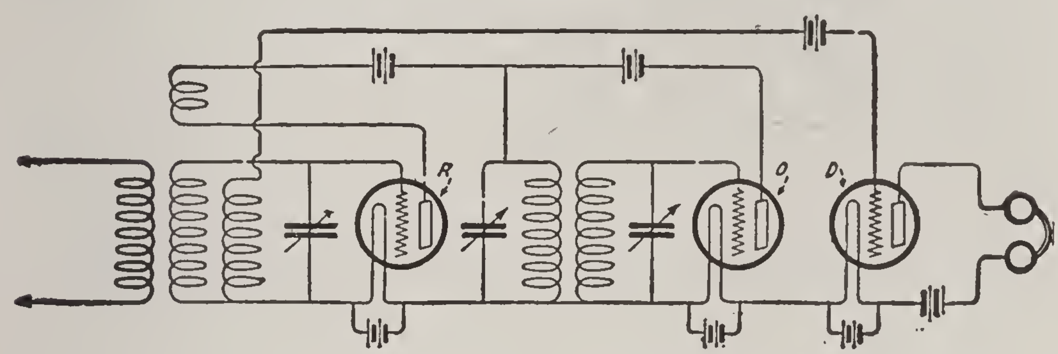


Fig. 67—Circuit for Reception of Modulated C. W. Signals

nated by tightening binding posts, cleaning the ends of the vacuum tube contacts, or replacing defective tubes or batteries.

Type CR-3

The operation of the Type CR-3 is essentially the same as the CR-8, with the exception that the detector is not included in the set. Four terminals are provided for externally connecting the detector unit. The combination of the Type CR-3 Receiver with the Type Rork detector-amplifier represents a complete receiving station equipment, the detector-amplifier unit being also available for use with other receiving circuits.

The Type CR-8 Receiver in combination with the Type Rork Two-Stage Amplifier unit is a complete station equipment in which the two stages of amplification are available for use with other receiving circuits.

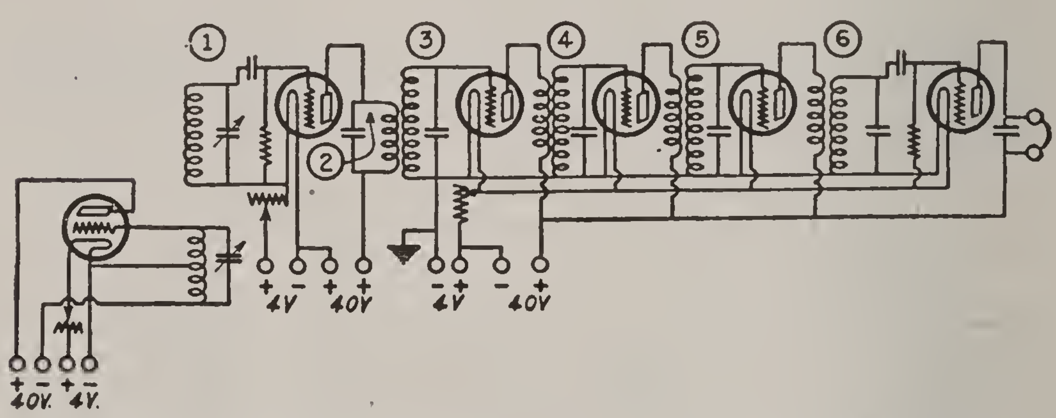


Fig. 68—Armstrong High Frequency Amplifier Circuit

INSTRUCTIONS FOR THE INSTALLATION AND OPERATION OF GREBE INTERMEDIATE-WAVE REGENERATIVE RECEIVERS

Installation

The receiver should be placed in a position convenient for operating control. Connect the Antenna and ground leads to the terminals so marked. Connect a 6-volt storage battery to the terminals marked "Filament Battery." (Connect two 22½-volt battery units in series). Connect the junction of these batteries to the terminal marked "Detector." Connect the ends of these batteries to the remaining terminals marked "Amplifier."

Make certain that all the battery leads are connected to the proper terminals and that the polarities are not reversed. Connect the telephone terminals to one of the plugs supplied with the set.

Turn all three rheostat wheels to the "off" position and place the vacuum tubes in the sockets. Insert the telephone plug into the jack marked "Detector," and turn the detector rheostat wheel to 2.

Operation

Combinations of antenna inductance and antenna series capacity as indicated by the Inductance Switch and the Condenser Dial, result in the wavelength shown for these combinations on the Wavelength Chart. The Tickler Dial controls the regenerative action and its proper setting for spark signals is best determined by advancing the dial until the signal is of maximum audibility without distortion. For C. W. signals the dial must be advanced beyond this point, i. e., until oscillations occur, a condition easily recognized by a soft hissing sound in the telephones.

As many signals are inaudible until regenerative action takes place, it is advisable to adjust the Condenser and Tickler Dials simultaneously. The Vernier Wheels are essential in accurately tuning all weak signals, especially C. W. and telephones.

After tuning and detector adjustments have been made, the telephone plug may be changed to the First Stage Amplifier position and the corresponding rheostat adjusted for maximum signal strength. The same procedure is followed in adjusting the second stage. When it is desired to use a loud-speaker this instrument should be connected to the terminals marked "loud-speaker," and the telephone plug inserted into the second stage just far enough to light all three filaments.

When it is desired to use the amplifier section in conjunction with external tuning and detector apparatus, connect the output of the external detector to the other plug supplied with the set. Also connect the filament leads of the external detector to the terminals marked "external filament." Thus, when the plug is inserted into the jack marked "External Detector," the automatic control device will cause the external filament to be lighted and the filament of the detector tube in the CR-9 to be extinguished.

Location of Faults

(a) If adjustment of Tickler fails to produce regeneration but no appreciable increase in signal strength, adjust Condenser.

(b) If vacuum tube filaments flicker or fail to light remove the tubes and clean the ends of their contacts with a file or sand-paper. If this does not eliminate the trouble, it may be necessary to adjust the filament control blades of jacks.

Remove all plate battery connections before making these adjustments, to prevent short circuit resulting in the burning out of vacuum tube filaments.

(c) If both stages fail to product amplification, the trouble may be traced to faulty plate batteries, or reversal of the filament battery leads. Defective tubes cause the majority of other troubles. It is desirable to try the tubes in various combinations for detector, first and second stages.

Grinding noises are caused by:

1—Faulty connections.
2—Defective plate batteries.
3—Defective vacuum tubes.

Unlike static, these noises persist when the antenna has disconnected and they may be eliminated by tightening binding posts, cleaning the ends of vacuum tube contacts or replacing defective tubes or batteries. Type CR-5—The operation of the CR-5 Receiver is essentially the same as the type CR-9 with the exception that the amplifiers are not included.

The Type CR-5 Receiver in Combination with the Type Rork Two-Stage amplifier is equivalent to the Type CR-9.

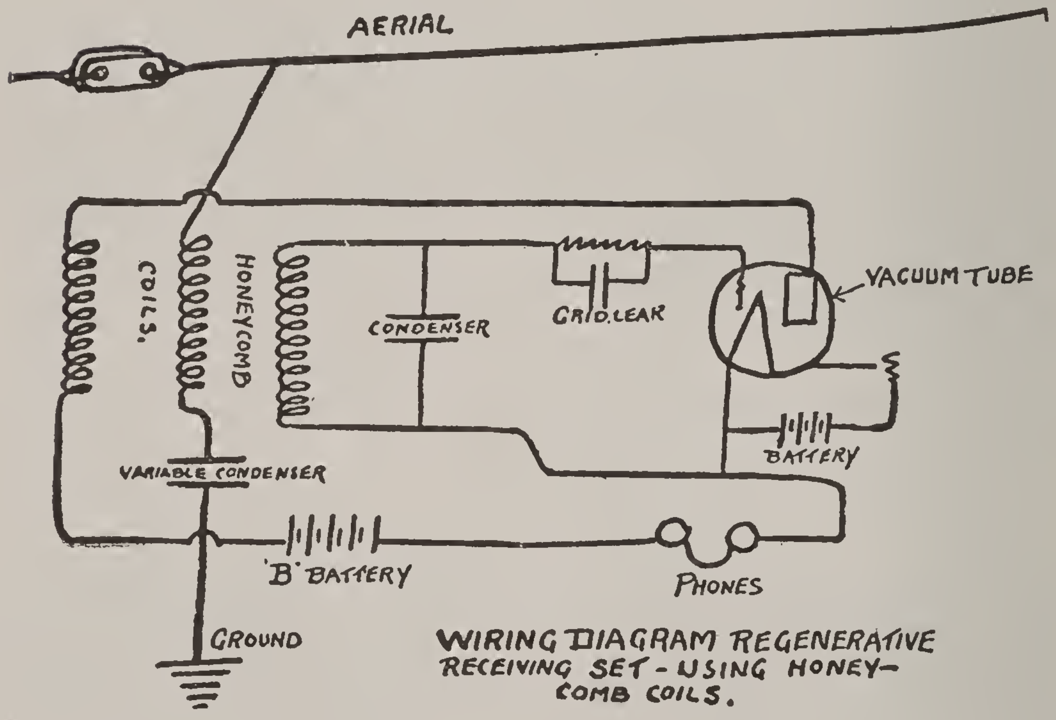

AERIAL
HONEYCOMB
COILS.
CONDENSER
GRID LEAK
VACUUM TUBE
BATTERY
VARIABLE CONDENSER
'B' BATTERY
PHONES
GROUND
WIRING DIAGRAM REGENERATIVE RECEIVING SET - USING HONEY-COMB COILS.

Fig. 69

TUNING METHOD FOR THREE CIRCUIT RECEIVERS

While excellent results may be obtained with approximate adjustments, the additional effort required for careful tuning is justified by the greatly improved reception, and in order to obtain maximum signals it is necessary to tune each of the three circuits to the wavelength of the desired signal. In all, there are five separate adjustments to be made.

1—Primary circuit (Antenna Inductance).
2—Secondary circuit (Grid Variometer).
3—Coupling (Coupler).
4—Plate circuit (Plate Variometer).
5—Detector (Vacuum tube).

Failure to make all the adjustments results in inaudibility of weak or distant signals, instability of audible signals, distortion of radiophone speech or music, due to improper amplification.

Tuning for Signals of Unknown Wavelength.

Set the grid variometer dial to correspond with the desired wavelength.

Set the coupler dial to either 50 position.

Starting from the zero position gradually increase the plate variometer dial to the point where oscillations occur. (This condition is recognized by a soft hissing sound in the telephones.)

Adjust the antenna inductance switches to a combination which causes the cessation of oscillations. If a Variable Antenna Series Condenser is used, adjust the switches to a combination which will cause the oscillations to cease upon rotation of the condenser dial to some point between 70 and 90.

The desired signal should now be audible in the telephones and final adjustments may be made with the grid variometer and coupler. The use of the tangent wheel verniers is essential is making these final adjustments.

Set the coupler on either 50 position.

Make approximate adjustment of the antenna inductance switches, setting them at a higher rather than a lower wavelength than is expected.

Using both hands, simultaneously rotate the grid and plate variometer dials over the entire scales. The dials should be rotated so as to keep the circuits or the verge of oscillating.

When the desired signal has been located on the grid variometer dial rotate the coupler dial toward zero until the signal is barely audible and then adjust the primary circuit.

Make a final adjustment on the Coupler dial.

TUNING METHOD FOR TWO CIRCUIT RECEIVERS

The tuning of this type of receiver is more simple than the three circuit type. Maximum signal is obtained only when the wavelength control circuit is adjusted to the same wavelength as the desired signal, and the tickler is adjusted to the point of greatest amplification.

Tuning for Signals of Known Wavelength.

Set the inductance switch for the desired wavelength range.

Set the condenser dial to the position corresponding to the wavelength desired.

Starting at zero gradually increase the Tickler dial reading to a position just below the oscillating point. (The oscillating condition is indicated by a soft hissing sound in the telephones.)

The desired signal should now be audible in the telephones and final adjustments may be made with the tangent wheel verniers.

Tuning for Signals of Unknown Wavelength.

Set the inductance switch in the position corresponding to the range in which the signal is expected.

Using both hands simultaneously adjust the condenser and tickler dials over the entire range, maintaining the proportion necessary to keep the receiver on the verge of the oscillating condition. If the signal occurs below 10 on the condenser dial, move the inductance switch to the next lower point, and if the signal occurs above 90, move the inductance switch to the next higher point.

SPECIAL TUNING INSTRUCTIONS

Spark Signals

The reception and amplification of spark signals will be most satisfactory when the regenerative action is controlled to a degree which will produce maximum amplification without causing an oscillating condition in the circuits. When the oscillating condition is reached, the tone of the spark signals will be destroyed and reception through interference will become almost impossible.

Modulated C. W. Signals

Modulated C. W. Signals, including I. C. W. Buzzer Modulated C. W. and Voice, may be received in a like manner, but a special condition may be obtained by allowing oscillations to take place in the receiver, producing the exact frequency of the incoming wavelength. This is known as the ''zero beat'' method and in this condition amplification is greatly increased due to the augmented feed-back of energy from the plate to the grid circuit. It is only possible to make use of this method while incoming frequency remains constant and its successful application requires considerable skill.

C. W.

In the reception of continuous waves the plate circuit feed-back is to be increased to a point where oscillations are constantly taking place and this condition must be maintained throughout the entire tuning operations.

Receivers Used as Wavemeters.

The wavelength of incoming signals or of any local oscillating circuit may be determined by noting the grid variometer dial setting. This applies to the CR-8 Receiver and the CR-3 Rord combination. Where the CR-3 Receiver is used in conjunction with non-standard detecting apparatus, the readings will be inaccurate. The wavelength of local oscillating circuits may be obtained with the CR-5 or CR-9 Receivers by shunting the antenna and ground binding posts, noting the Condenser dial reading.

Elimination of Interference

The most successful means for reducing spark interference while receiving modulated C. W. signals is the use of the zero beat method described above. This will cause the spark signal to become distorted and suppressed while greatly increasing the amplification of the desired signal.

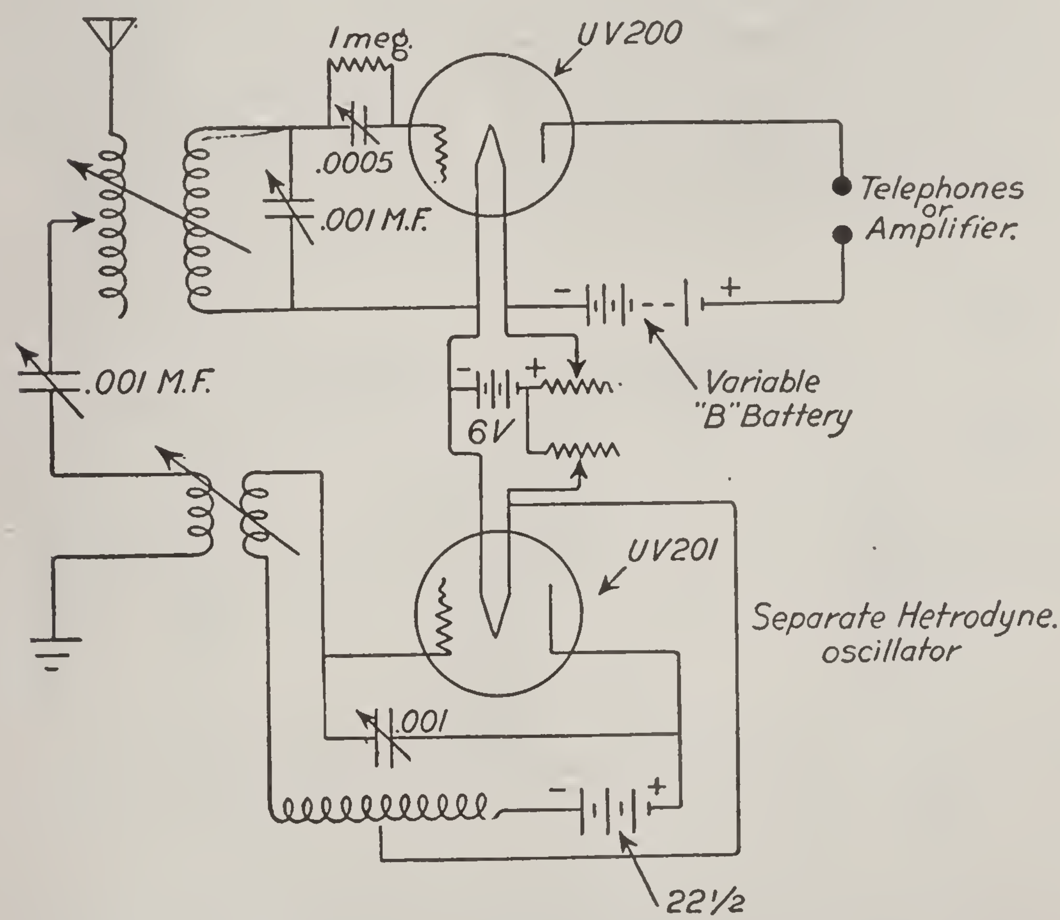


Fig. 70—Long Wave Receiver with Separate Hetrodyne

Eliminating interference from spark and modulated C. W. signals while receiving C. W. signals.

As the oscillating condition is a pre-requisite in the reception of C. W. signals, it follows that spark signals are more readily suppressed than are the modulated C. W. signals. Where the carrier wavelength of the modulated C. W. signal and the wavelength of the desired signal are almost identical it will only be possible to suppress the modulated C. W. signal is beyond audibility. In the Types CR-3 and CR-8 receivers, an additional freedom from spark interference is to be gained by the use of the coupling adjustment.

The elimination of C. W. signals while receiving spark signals is easily accomplished by reducing the plate variometer or Tickler dial setting until the oscillations cease, unless the C. W. station is very powerful and located nearby.

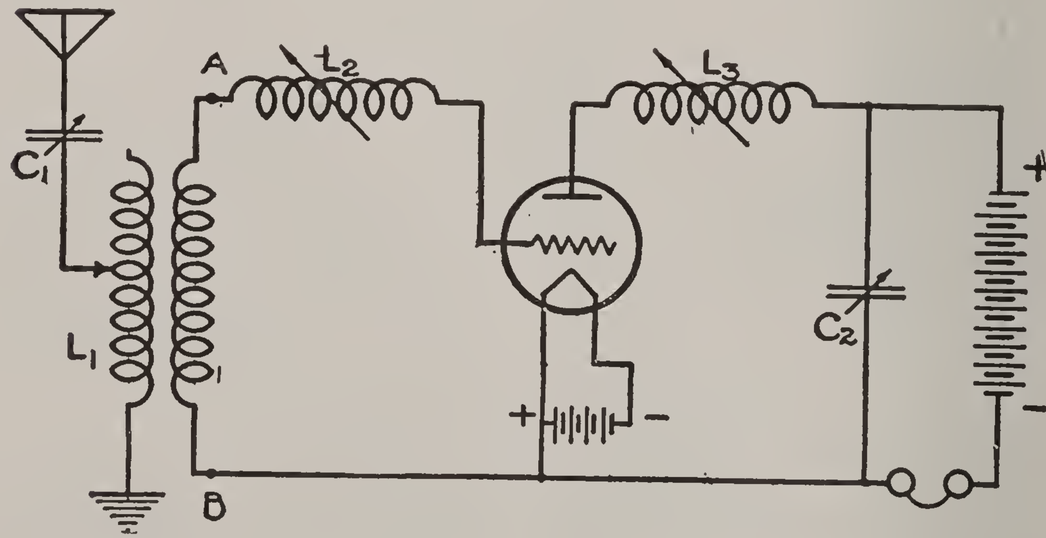


Fig. 71—Tuned Plate Regenerative Circuit, Using Variable Inductances

INSTALLATION OF DETECTOR AND TWO-STAGE AMPLIFIER

The Detector-Amplifier unit should be placed as close to the receiver as possible in order to avoid lengthy leads. The four terminals on the left are provided for externally connecting the amplifier with the receiver.

Connect a 6-volt battery to the terminals marked "Filament Battery."

Connect two 22½-volt battery units in series. Connect the junction of these batteries to the terminal marked "Detector." Connect the ends of these batteries to the terminals marked "Amplifier."

Make certain that all battery leads are connected to the proper terminals and that the polarities are not reversed.

Connect the telephone terminals to one of the plugs supplied with the unit.

Turn all the rheostat wheels to the "Off" position, and place the vacuum tubes in the sockets.

Insert the telephone plug in the jack marked "Detector" and turn the detector rheostat wheel to 2.

Operation

After tuning and detector adjustments have been made, the telephone plug may be changed to the 1st stage amplifier position and the corresponding rheostat adjusted for maximum signal strength. The same procedure is followed in adjusting the 2nd stage.

When it is desired to use a loud speaker, this instrument should be connected to the terminals marked "Loud Speaker" and the telephone plug inserted in the second stage jack just far enough to close the filament circuit of all three tubes.

When the amplifier section is used with external tuning and detecting apparatus, connect the output of the external apparatus to a telephone plug. Also connect the filament leads to the terminals marked "External Detector." Thus, when the plug is inserted in the jack marked "External Detector" the automatic control device will cause the external detector tube filament to light and the detector tube filament in the Rord will be extinguished.

Location of Faults

(a) If vacuum tube filaments flicker or fail to light, remove the tubes and clean the ends of the contacts with a file or sandpaper. If this does not eliminate the trouble, it may be necessary to adjust the automatic control jacks.

Remove all Plate Battery connections before making jack adjustments to prevent short circuit resulting in the burning out of vacuum tube filaments.

(b) If both stages fail to produce amplification, the trouble may be traced to faulty plate batteries, or the reversal of the filament battery leads. Defective tubes cause a majority of other troubles. It is desirable to try the tubes in various combinations for detector, 1st and 2nd stage.

Installation of Two-Stage Amplifier

Connect a 6-volt storage battery to the terminals marked "Filament Battery."

Connect two 22½-volt battery units in series; connect the ends of these batteries to the terminals marked "Plate Battery."

When this amplifier is used with the Grebe Type CR-5 or CR-8 Receiver, a connection may be made from the junction of the two 22½-volt batteries to the Plate Battery Terminal on the receiver. With this circuit a single plate battery is made to serve both units. No connection need be made to the "Plate Battery" terminal on the receiver as this circuit is completed through the positive side of the Filament Battery which is common to both Receiver and Amplifier. Connect the "Filament Battery" terminals of the receiver to the "External Filament" terminals of the amplifier. Connect the output or telephone terminals marked "Input" on the amplifier.

REGENERATIVE RECEIVING SETS

A regenerative, or feed back receiving set, is one in which the oscillations received from the aerial are regenerated by the action of the current in the vacuum tube.

The advantages of the vacuum tube set over the crystal set are many. It is much more sensitive, permits of finer tuning, and the tuning out of interference; through the regeneration in the vacuum tube the incoming signals are greatly amplified, and then one or more stages of amplification can be added to the set at will.

It is, naturally, the desire of all radio fans to own a regenerative receiving set, but the cost of same is generally more than they care to invest; however, by buying the various parts and assembling the set oneself the cost can be materially reduced. In fact, a vacuum tube set can be assembled in this way for approximately Thirty Dollars.

The inductance coil and tickler are the only parts of this set that I would suggest building. It will be found just as cheap to buy the other parts complete.

To make the inductance coil, secure 2 cardboard tubes, one 8 inches long by 3½ inches in diameter, the other 1½ inches long by 2¾ inches in diameter. First dry the tubes by placing in a warm oven for about an hour and then giving them, inside and out, a coat of shellac. On the larger tube wind about 6 inches of its length with No. 24 cotton covered wire, taking a tap off every tenth turn up to the 80th turn, and then a tap off every 40th turn after. This winding acts as the antenna tuning inductance. The tickler coupler winding is wound on the same tube and consists of two sections with 20 turns of wire in each section.

The flexible wires leading from the taps on the coil should be connected to a multipoint switch.

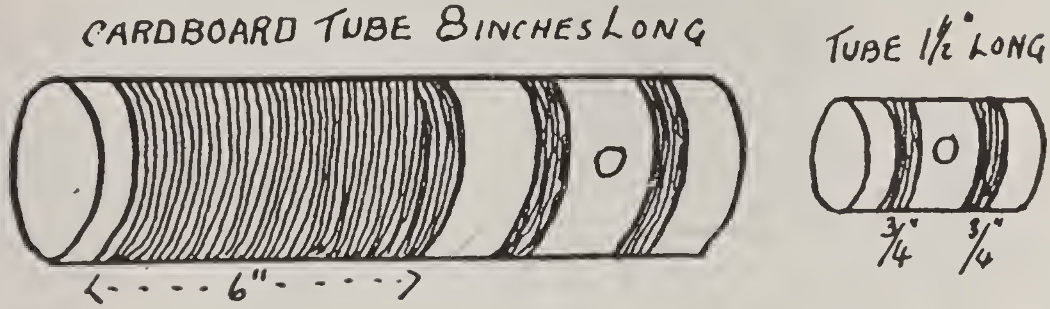


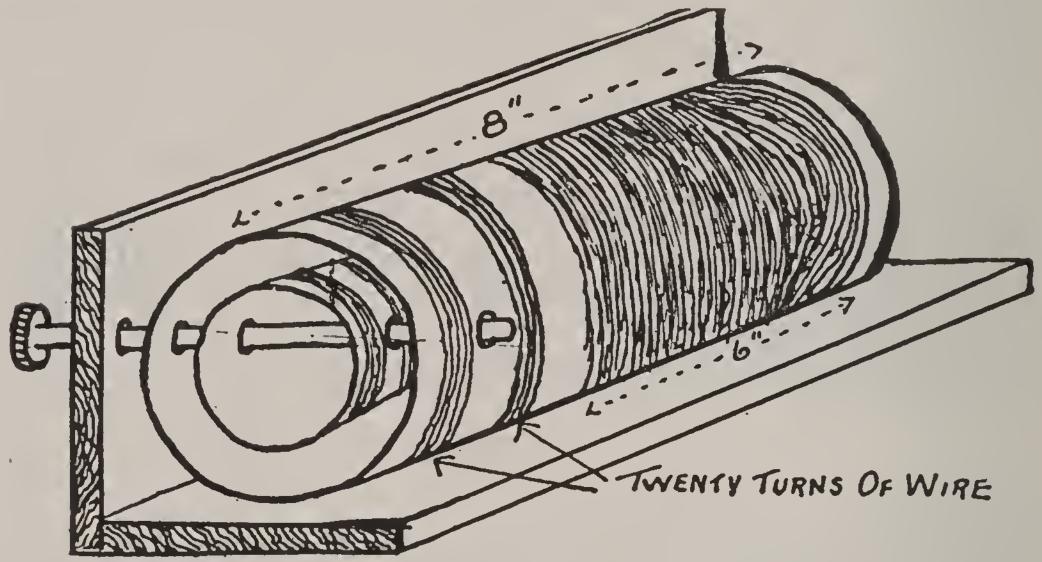
Fig. 72

On the smaller tube, wire should be wound as per the diagram; it is now necessary to mount the small tube so that it can rotate within the larger one, and this is best accomplished by running a shaft through the large tube, and mounting the smaller coil on this shafting, similar to the diagram.

The other parts necessary to complete the set will be a vacuum detector tube, vacuum tube socket, filament rheostat, variable condenser, grid condenser, grid leak, 22-volt battery, and a six-volt battery.

A regenerative set may also be made with the following parts: A set of honeycomb coils (A—primary, B—tickler, C—secondary), vacuum detector tube, variable condenser, grid leak, vacuum tube socket and adjustable filament rheostat, storage battery, "B" battery, head phones, binding posts, nuts and screws, a few feet of No. 18 wire and a Bakelite panel, to mount the whole affair on.

Still another set can be made by using a vario coupler, 2 variometers, vacuum tube, vacuum tube socket, filament rheostat, 6-volt battery, variable condenser, "B" battery, multipoint switch, Bakelite panel, wiring nuts and volts, binding posts.



SHOWING METHOD OF MOUNTING SMALL COIL INSIDE THE LARGER ONE SO THAT IT CAN BE ROTATED BY KNOB ON THE OUTSIDE OF PANEL

Fig. 73

Parts required for a two-step amplifier: 2 amplifying transformers, 2 amplifying vacuum tubes, 2 vacuum tube sockets, 2 adjustable filament rheostats, 1 single socket telephone jack, 1 double socket telephone jack, 1 telephone plug, panel of Bakelite, binding posts, nuts and screws, etc.

FIXED CONDENSER

Fixed condensers are used as shunts across the detector to intensify the incoming signals and to promit of fine tuning. To make a fixed condenser, first cut a number of strips of tin foil into sheets measuring 3 inches by 2 inches wide. Then lay two pieces of paraffined paper on a strip of cardboard measuring 3 inches long by 2 inches in width. On top of

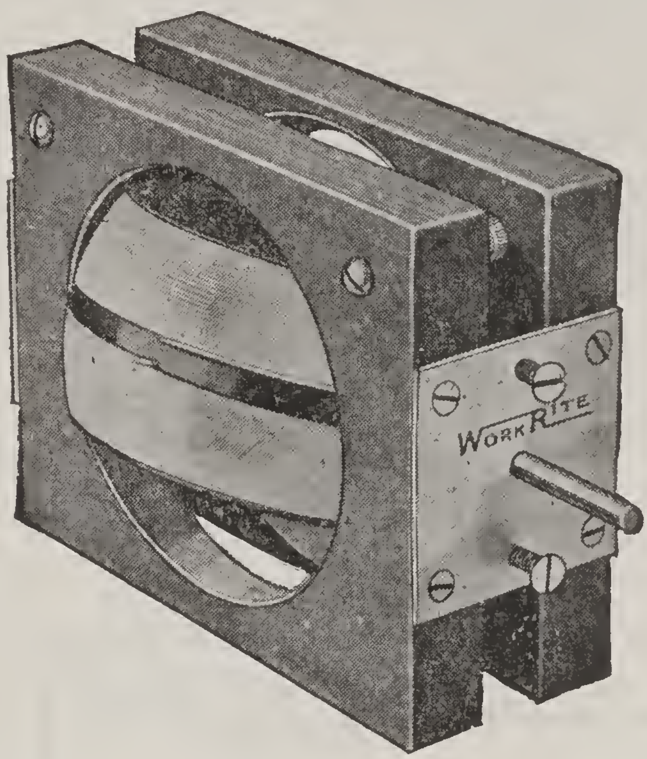


Fig. 74—Variometer

these sheets of paraffined paper lay one of the strips of tin foil, leaving about ½ inch projecting over the end of the paraffined paper. Now, place another sheet of paraffined paper over this, seeing that it coincides with the sheet of paraffined paper under it, and on top of this lay another strip of tin foil, this time letting it project ½ inch over the paraffined paper on the opposite end. And so on, the condenser being built with alternate layers of paraffined paper and tin foil, until the desired number of sheets have been built up. Place two pieces of paraffined paper on the top and over this a strip of cardboard, the same size as that at the bottom. The whole thing is then bound up with thread. Now, lay the condenser on a board fixing on two binding posts, so that they clamp down to the projecting ends of tin foil to the wood base. The condenser is then ready for use in the circuit.

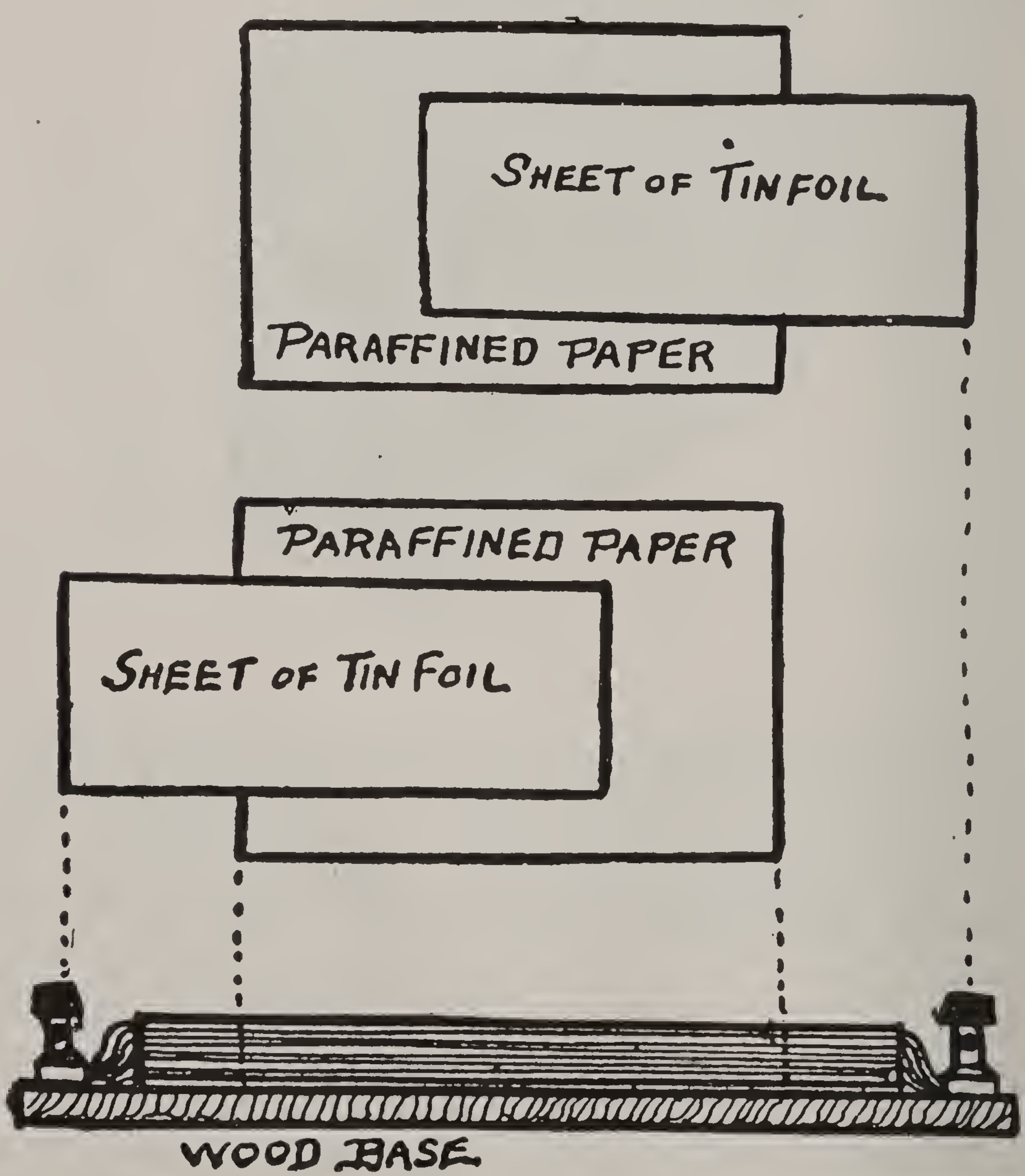


Fig. 75

THE VARIABLE CONDENSER

The variable condenser is an apparatus used in conjunction with the receiving set to make it capable of receiving weak signals. There are a number of types and models. The most common type consists of a number of metal plates separated from each other by an air-gap, or insulated from one another by sheets of mica, the whole being mounted in a circular case. One set of the plates are fixed, while the other set

Fig. 76

is mounted on an insulated spindle, which can be turned through an angle of 180 degrees, thus permitting of any required amount of interleafing of the plates.

There are other types on the market which use only two plates. The one illustrated on this page is made up of two plates, A and B. A is fixed; the plate B is free to move up and down, to or from plate A. The surface is covered with a thin circular sheet of mica C, and the plate B has secured to its underside a block of insulated material, which acts as a

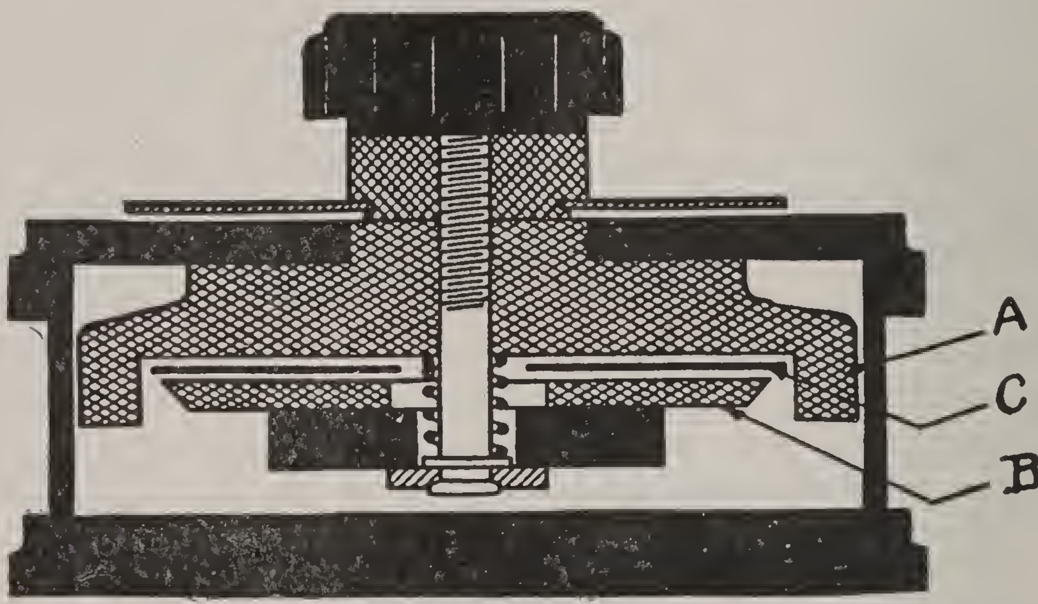
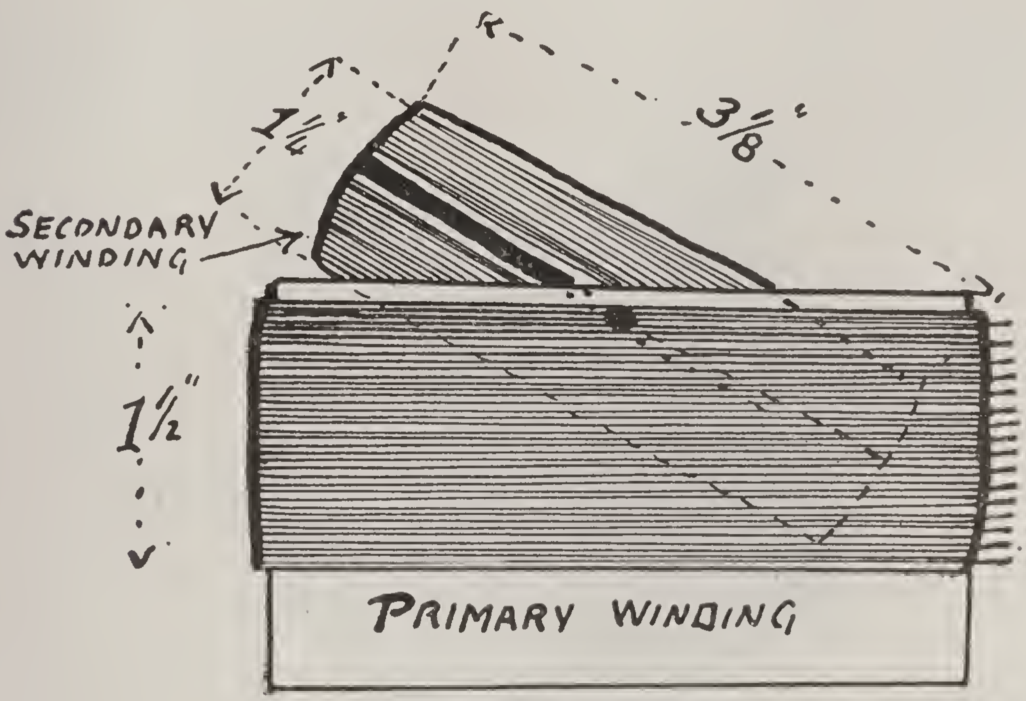


Fig. 77—Internal Construction of a Two-Plate Condenser

support for the guide rod and screw. The variation of the capacity is obtained by merely screwing the rod upward or downward on the shaft, which moves the plate B to or from plate A.

THE VARIOCOUPLER

An ideal receiving set is made up of two variometers and one vario-coupler. To make a vario-coupler, first thoroughly dry and coat with shellac two cardboard tubes, one about four and the other about three inches in diameter, then wind the larger tube with about 60 turns of No. 24 cotton-covered wire, taking a tap off every tenth turn of wire. Next, take the smaller cardboard tube and wind about 50 turns of No. 24 cotton-covered wire on this. The tubes now have to be mounted so that the small tube can rotate inside



VARIOCOUPLER.

Fig. 78

the larger one. The large coil acts as the primary, and the small coil as the secondary. The flexible wire leads from the taps on the larger coil now have to be connected to a multipoint switch, while one end of the large coil is connected to the aerial

VARIOMETER

A Variometer is a tuner that depends on the coupling between its two parts, which are connected together. It generally consists of one fixed and one movable coil, connected in series with each other, and mounted so that the coupling between the two coils can be varied and readily adjusted. The inductance of the combination is changed by varying the relative position of the coils. There are a number of different types on the market all meeting with more or less success. One of the best is the basket-weave type of winding on spherical forms. This type can be

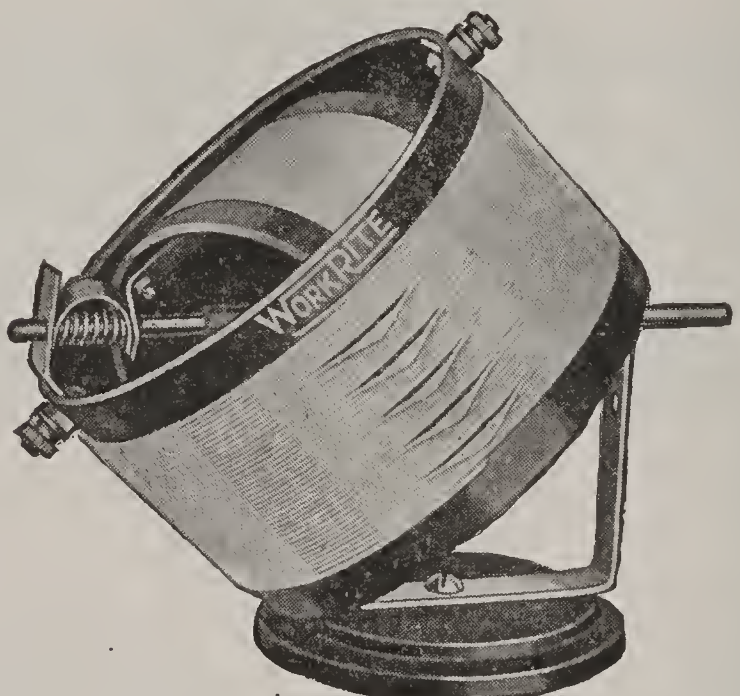


Fig. 79—180° Variocoupler

mounted in any desired position. The variometer should not be connected in series with the secondary of the loose coupler; this adds resistance to the circuit and weakens the signals. The working principles of a variometer are the same as an inductance, or tuning coil.

LOOSE COUPLER

A loose coupler is used in place of a tuning coil. With it, one can get a greater selectivity. It consists of 2 coils, the primary and the secondary, the secondary being so constructed that it will slide in or out of the primary.

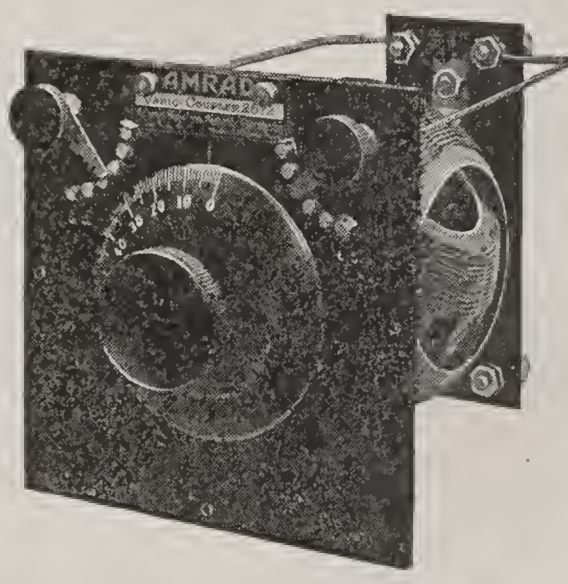


Fig. 80—Basketball Variocoupler

First, thoroughly dry 2 cardboard tubes, one about 8 inches long, by 4 inches in diameter, and the other about 7 inches long by 3½ inches in diameter. Wind the larger tube, which will act as our primary, with a layer of cotton covered wire, starting ½ inch from one end of the tube, and finishing ½ inch from the

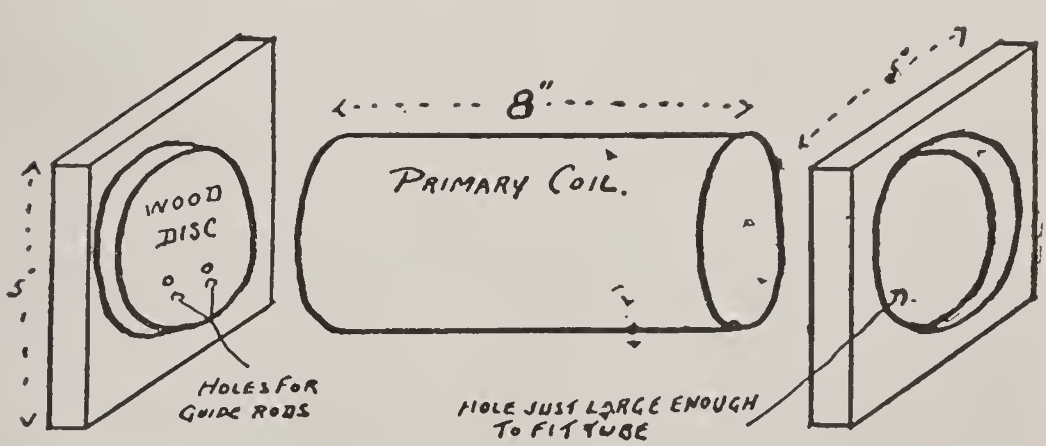


Fig. 81

other end. Now give the whole thing a coat of shellac, inside and out, and lay aside until dry. Take the smaller tube and wind this with No. 24 cotton covered wire, starting ½ inch from the end and finishing

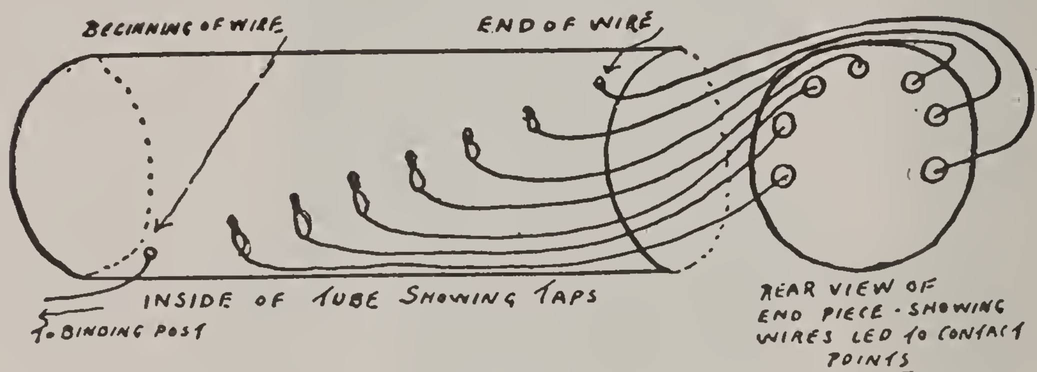


Fig. 82

½ inch from the other end. When winding this tube, which will be our secondary, it will be necessary to take a tap about every inch of winding. This is done by punching a small hole in the tube and pushing

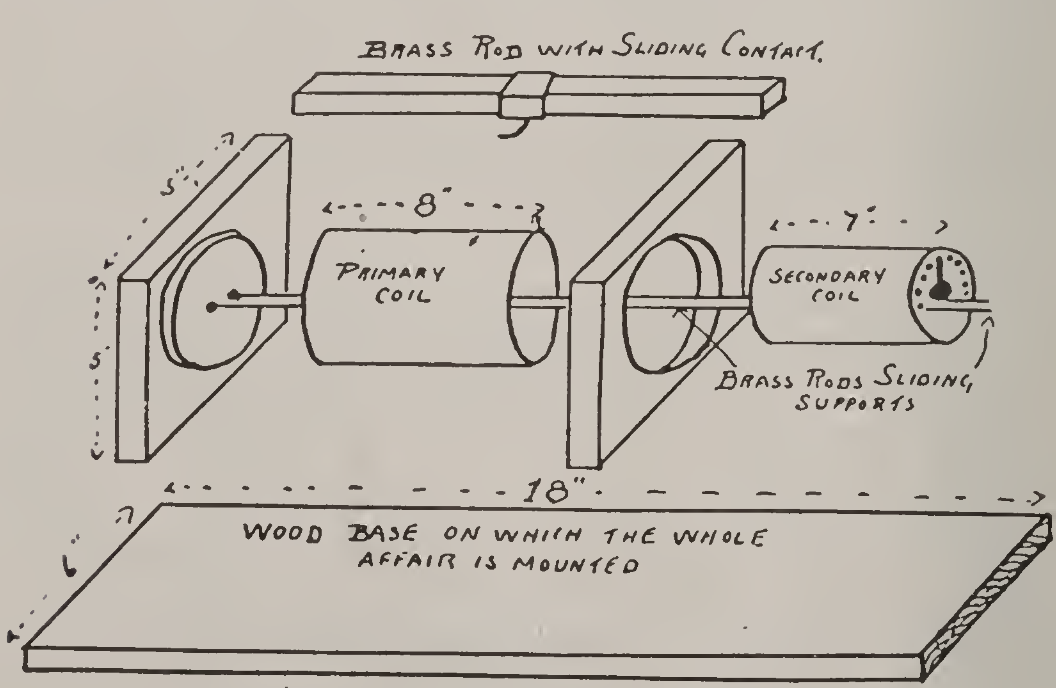


Fig. 83

the wire through, inside the tube, allowing us to make the taps from the inside, instead of the outside.

These taps are connected to contact points on the wood end piece, and the end of the coil should also be led to one of these contact points (see Fig. 82). The other end of the winding (the beginning), should be connected to the binding posts.

It will thus be seen that by rotating the adjustment handle on the end piece, that more or less of

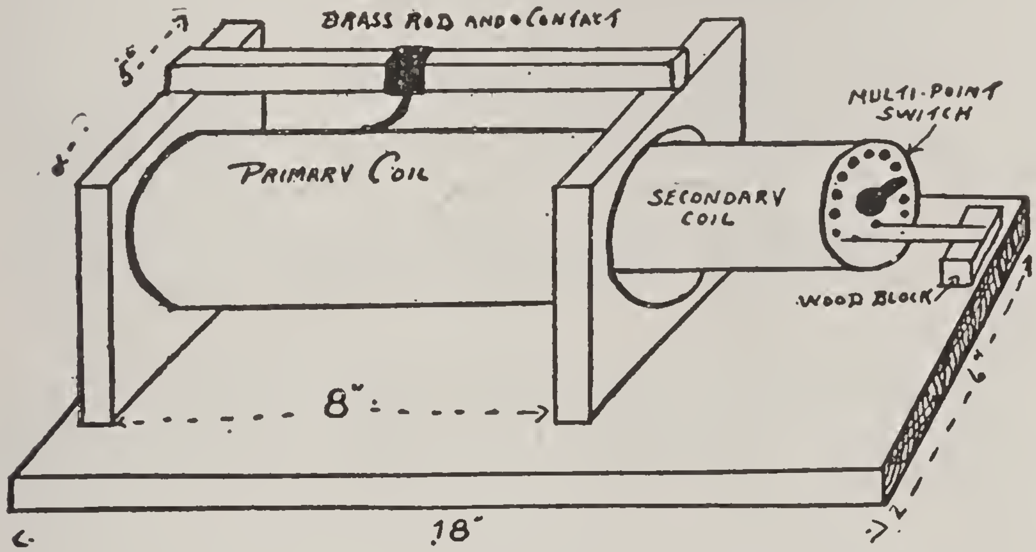


Fig. 84

the secondary winding can be cut in or out of the circuit.

Be careful when winding the coils that the wires are wound on both coils in the same direction.

We shall now need two pieces of wood about 5 inches square and a wood disc just large enough to fit into the end of the larger coil. One of the square wood pieces must have a hole cut out the center, 4 inches in diameter; we shall also need a wood base 18 inches long by 6 inches in width, 2¼ inches in brass rods, 17 inches long and one brass rod 8½ inches long.

Secure the wood disc onto the center of the end piece, then slip this into the end of the larger tube, the other end of the tube is slipped into the hole of the other end piece (Fig. 83).

Now secure the guide or travel rods by passing them through the secondary coil and then through the primary coil, and slip the ends into the two holes made for them in the wood disc; the other ends are secured to a small block of wood, which in turn is fastened to the wood base. The secondary coil is now pushed into the primary, and the whole affair mounted onto the base. The small brass rod with a sliding contact should now be mounted between the two end pieces over the primary coil in such a manner that the slider makes good electrical contact with the wiring of the coil.

The operation of this set is simple; push the secondary coil right into the primary, and tune as you would with an ordinary tuning coil; when the signal is heard, move the switch on the end of the secondary coil till you get maximum result. Then adjust the various condensers, to try and better the signal's strength. Next, slowly draw out the secondary coil and retune, repeat this process until you get the maximum signal strength.

DOUBLE SLIDE TUNER

First secure a cardboard tube about 8 inches in length, by 3½ inches in diameter. This tube should be placed in a warm oven for an hour or so, and then given 2 coats of shellac, wait till the first coat is hard and dry before applying the second. Next, wind the tube with No. 25 B & S gauge cotton covered wire, starting about ½ inch from one end of the tube, and finishing about the same distance from the other end. Now give the tube another coat of shellac (inside and out) and lay aside until dry.

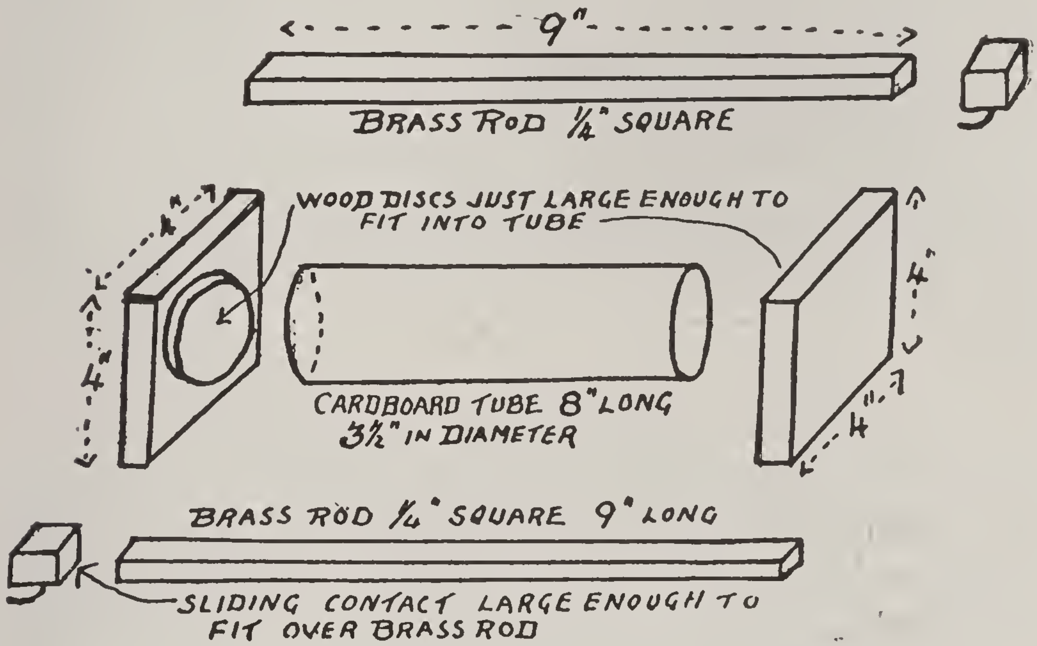


Fig. 85—Units of Double Slide Tuner

Next secure 2 pieces of wood about 4 inches square and ½ inch thick, and 2 wood discs just large enough to fit into the ends of the cardboard tube. First mount these discs in the center of the wood end pieces, and then slip the ends of the cardboard tube over the discs, then nail the tube onto the discs.

We shall now need 2 brass rods about ¼ inch square, by 9 inches long, and 2 sliding contact points. The contact points are placed on the rods (see diagram) and the 2 rods are fastened, one on the top, and one on the side of the coil, in such a manner that the sliding contact points can be worked along the whole length of the rods, making sure that the contact points make good electrical connection with the wire on the cardboard tube. It will be found necessary to scrape the wire where the sliding contact

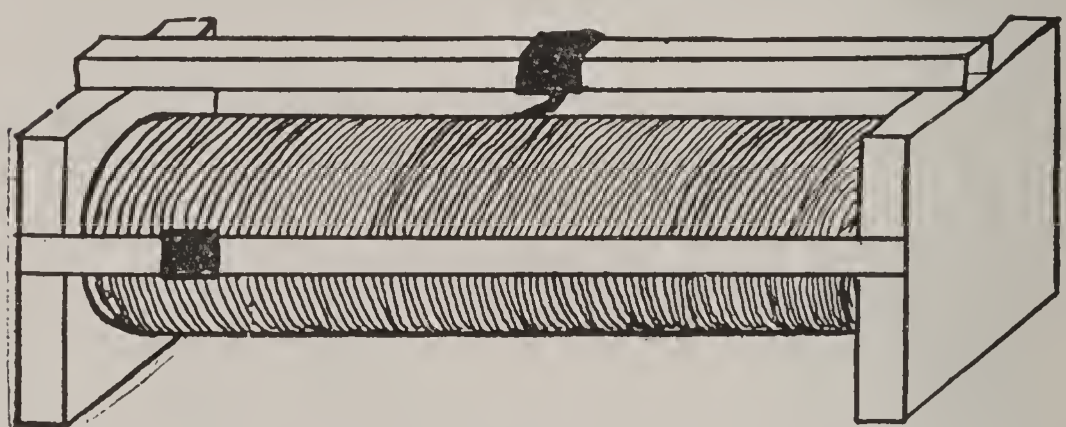


Fig. 86

points work to get good electrical connection. A simple hook-up is here given, showing how this tuner is connected into the circuit. The other apparatus necessary for the outfit consists of a variable condenser, a fixed condenser, and a crystal detector.

HOW TO MAKE A TUNING COIL

A simple tuning or loading coil consists of a cardboard tube, around which a wire is wound, and so arranged that more or less of this wire can be cut in or out of the circuit by means of a sliding contact point. To build the coil you will need the following: A cardboard tube 18 or 20 inches long and about 4 inches in diameter, 1½ lbs. of No. 24 copper wire, 2 brass rods a trifle longer than the cardboard tube and approximately $\frac{1}{4}$ inch square. Two wood discs, $\frac{3}{8}$ of an inch thick and just large enough to fit tightly into the ends of the cardboard tube, two wood pieces for ends, about $4\frac{1}{2}$ inches square and a wood base to mount the whole affair on. First wind the wire tightly around the whole length of the cardboard tube, leaving a free end of wire at each end of the tube. Care should be taken to space the winding evenly. Next, mount the two wood discs in the center of the two wood end pieces. Then slip the discs one into each end of the cardboard tube and mount the whole affair on the wood base. It is now necessary to mount the brass rods in such a manner that the sliding contacts on the rod makes a good

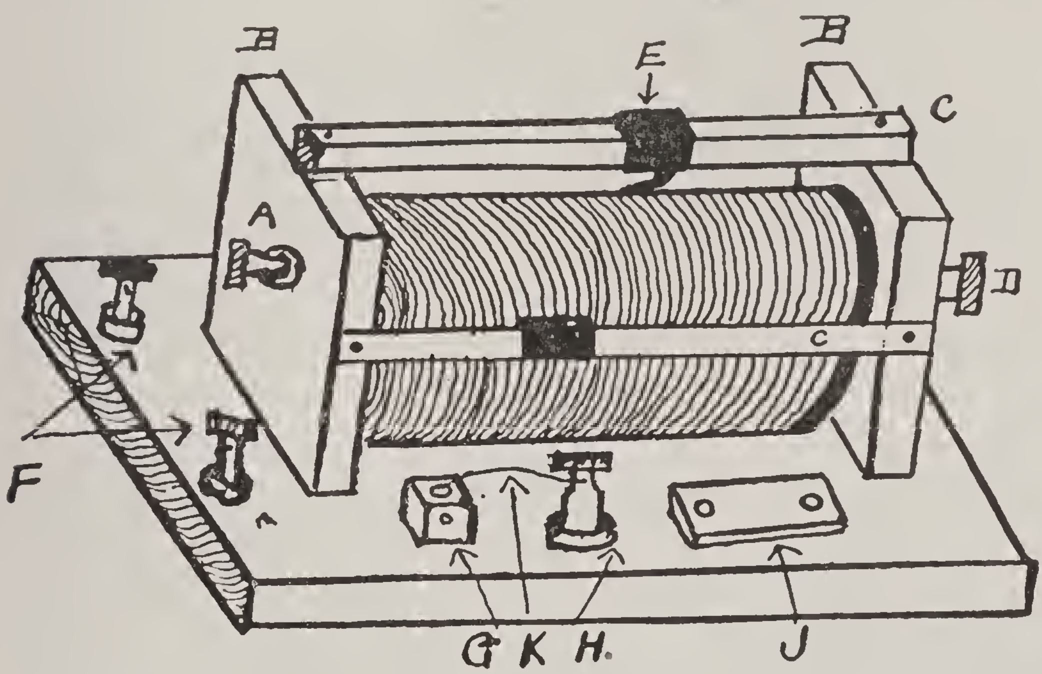


Fig. 87—A Complete Receiving Set on a Common Base

A—Connection to Aerial
C—Brass Rods
E—Sliding Contacts
G—Crystal and Holder
J —Fixed Condenser

B—Wood End Pieces
D—Connection to Ground
F—Phone Connections
H—Adjustable Catwhisker Holder
K—Catwhisker

contact on the wire windings of the coil. One end of the wire windings is attached to a binding post, while the other end is passed through a hole in the cardboard tube, so that it will be out of the way. It will be found advisable to dry all wood used in the building of radio apparatus, by leaving it for an hour or two in a warm oven, then giving it a coat of shellac. This will eliminate shrinking or warping of the wood. There are various makes of coils on the market and I do not think it advisable to go to the trouble of constructing one, as long as they can be bought so cheaply. A number of beginners, however, like to build their own, and it is for them that this article is written.

LOUD SPEAKERS

To make it possible for a number of people gathered together in one room to hear the concerts, etc., from one receiving set, a loud speaker must be employed. The loud speaker can be termed an instrument used to amplify radio signals. There are various types on the market all meeting with more or less success. A diagram of the "Telemegaphone" is here shown. A small coil of fine wire is placed in a circular air-gap between the poles of a very powerful electromagnet, and this coil attached to the diaphragm. The magnetic flux across this air-gap is constant, and the current is sent through the small coil. Whenever a current flows through the coil it is either attracted or repelled, according to the direction of flow through the coil, and the motion thereupon transmitted to the diaphragm. There are no pole pieces to interfere with motion, which may be as large as the

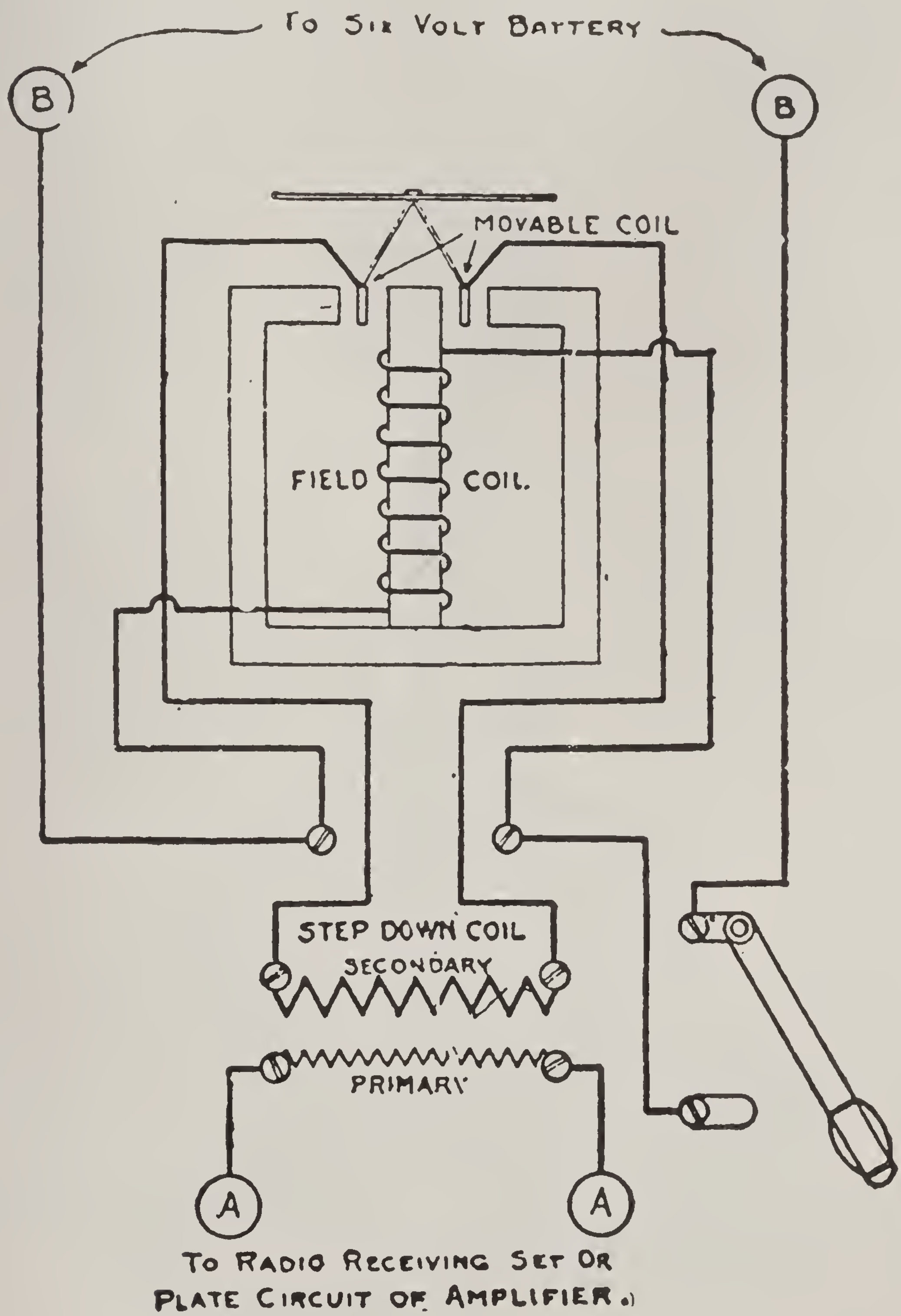


Fig. 88—Telemegaphone

elastic limit of the diaphragm. A large horn is attached immediately above the diaphragm, and the air column in that horn moved in accordance with the vibrations of the diaphragm. The "Vocaloud," another make of loud speaker, has met with great suc-

Fig. 89—Loud Speaker

cess. In this instrument, a balanced armature is employed, which is actuated by a magnetic field between four pole pieces, the field is caused to vary in accordance with the audio frequency component of incoming signal currents as the energy is passed through the single solenoid. The movement of the balanced armature is conducted to the mica diaphragm by a small connecting link.

Vocarola

The Westinghouse Vocarola is designed to be used with a set such as the type R.C. set. It is a scientifically designed sound amplifier and when connected in place of the telephones of the type R.C. set will deliver many times the volume of a pair of telephone receivers.

A diaphragm of aluminum with concentric circular corrugations is used in the telephone receiver of the Vocarola. The corrugations stiffen the diaphragm and prevents it from vibrating with nodal patterns. As a result there is only one free period. The Vocarola, therefore, gives an excellent quality of reproduction for the reception of both music and speech.

Victrola Attachment

The Westinghouse Victrola or Grafanola attachment employs the same telephone receiver as the Vocarola and is provided with an attachment which permits its replacing the reproducer of the phonograph and thereby utilizing the sound chamber of the phonograph.

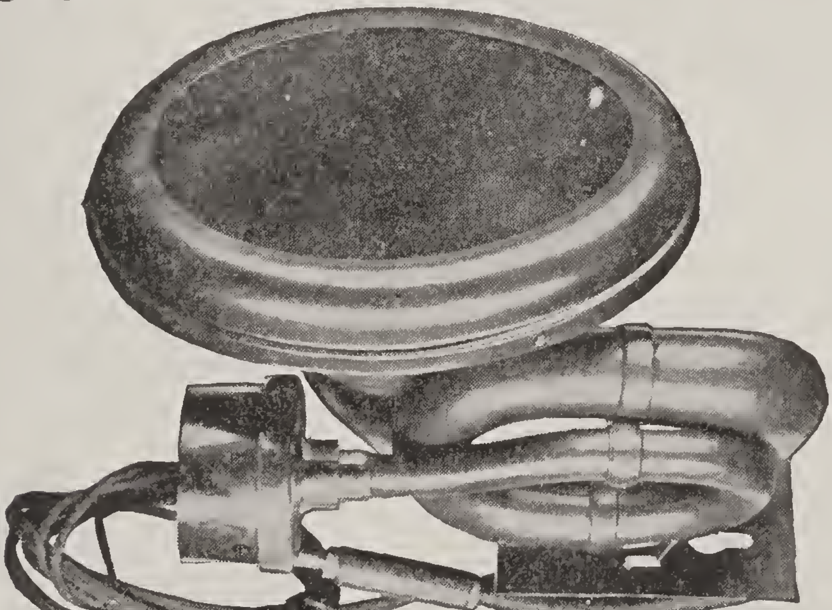


Fig. 90—Westinghouse Loud Speaker

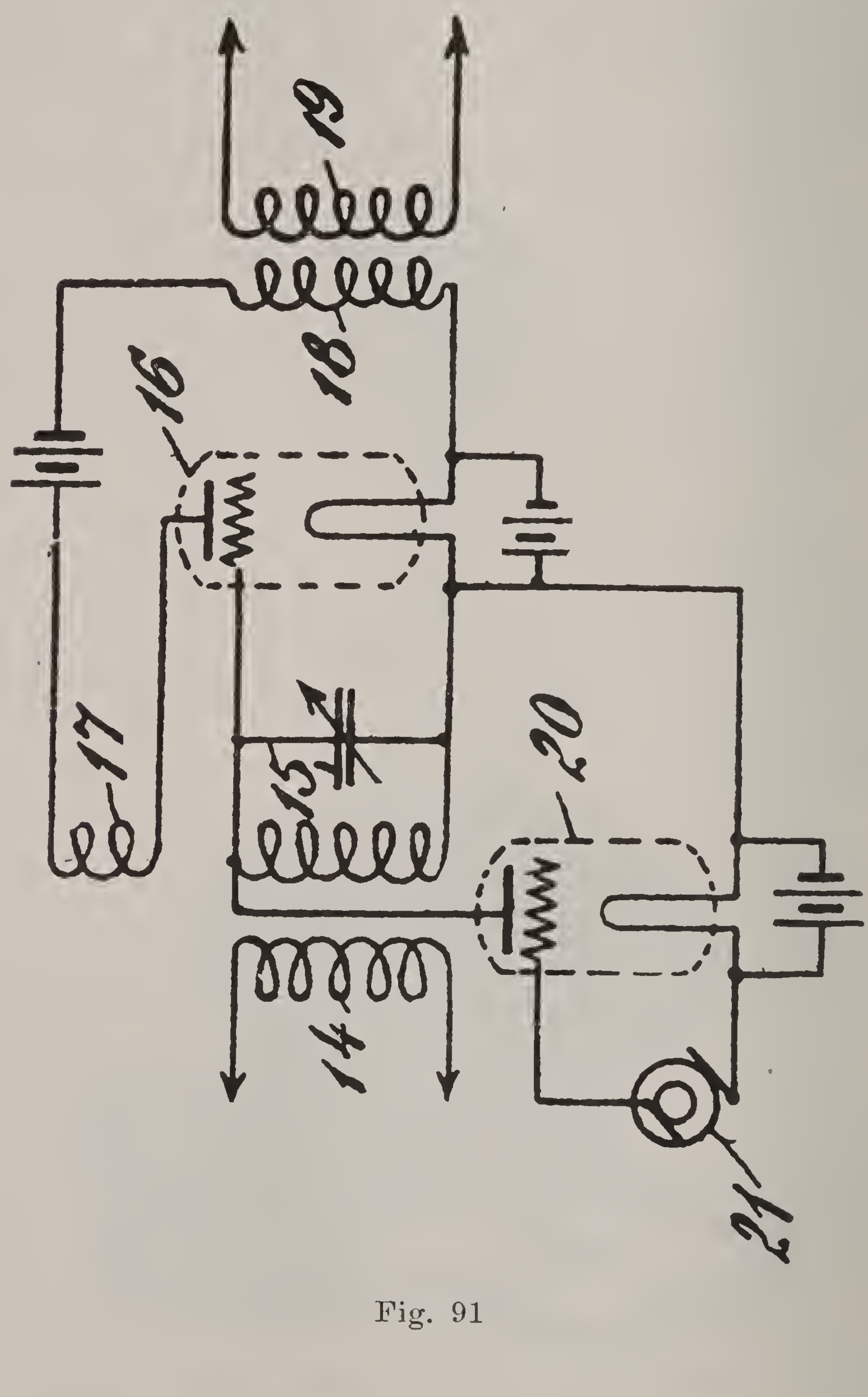


Fig. 91

ARMSTRONG SUPER-REGENERATIVE CIRCUIT

Major E. H. Armstrong, who is already well known to all radio fans throughout the world, is responsible for a new Super-Regenerative Circuit. A successful demonstration of this circuit was given by Mr. Armstrong at a meeting of the Institute of Radio Engineers on June 7, 1922. Only three tubes were employed with a loop aerial and the volume of sound received from Station WJZ, at Newark, N. J., was sufficient to fill the large meeting room in the Institute. During the demonstration Mr. Armstrong pointed out that the building was practically radio-proof against any ordinary receiving set, using an indoor loop aerial. To K. B. Warner, editor of Q. S. T. we are indebted for the following information on the Super-Regenerative Set.

As we all know from experience, oscillation represents the theoretical limit of amplification in our present-day receivers. How often, in approaching critical regeneration and hearing the signals build up enormously, have we wished that it might be possible to advance the regeneration just a little more, even one degree on the scale, without the bulb flopping into oscillation! The increase in amplification just below the oscillating point is amazing, and if only it could be squeezed a wee bit more how wonderful it would be! That is exactly what Armstrong's new scheme does—it extends the range of regeneration without oscillation, by means of a trick. We say a trick because the oscillating point is theoretically the limit

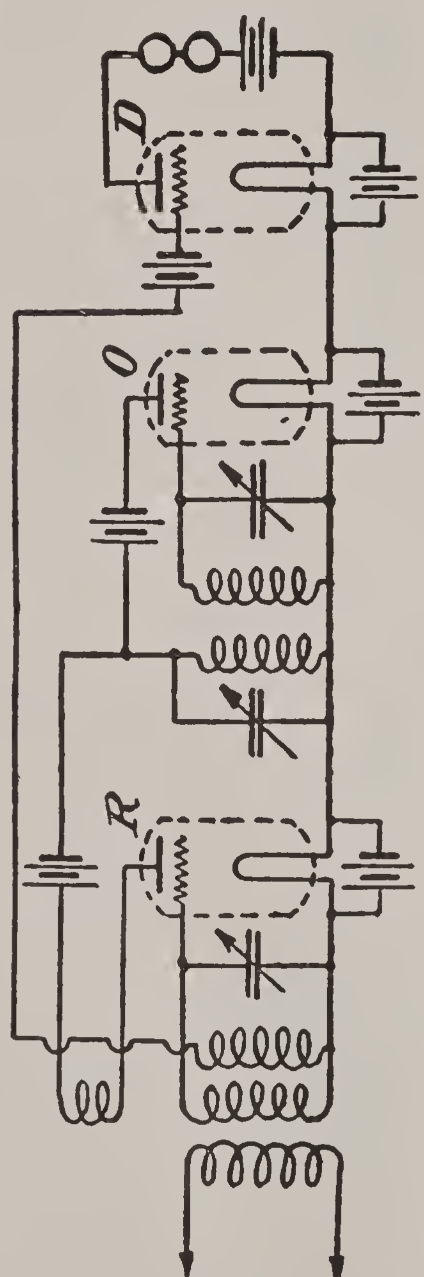


Fig. 92

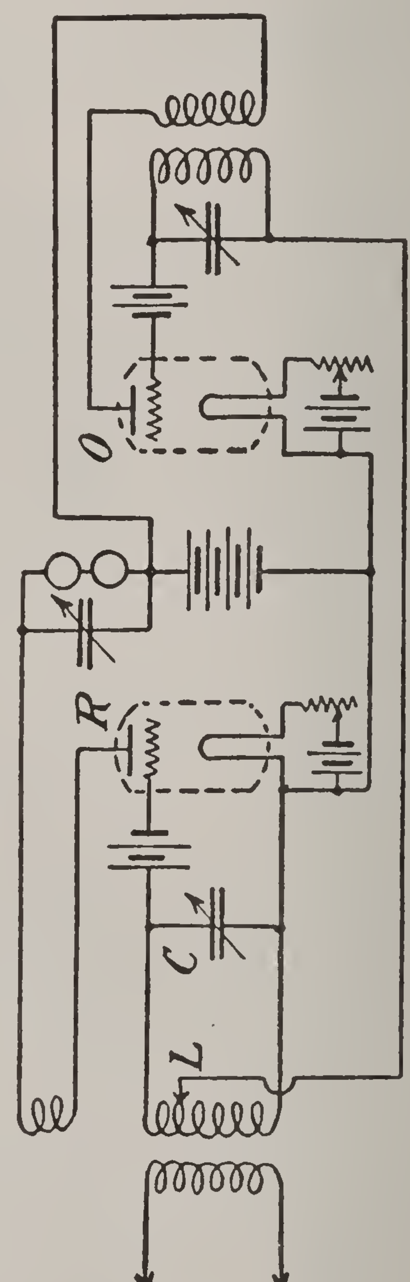


Fig. 93

but by an artifice this is got around and *any* amount of amplification may be obtained; and because it is in a field beyond the hitherto recognized limit, it is called *super-regeneration.*

Let us first study a few basic points regarding ordinary regeneration. As is well recognized, it consists of supplying energy by some process akin to feed-back in such a manner as to enforce the oscillations in the circuit, causing them to attain greater amplitude and thereby having the same effect as would the introduction of "negative resistance." That is, part of the positive resistance which the circuit normally would have seems to have been overcome, we say that by the use of regeneration its effective resistance has been lowered. Now, obviously, the "negative resistance" created by the feed-back may be not as great as the positive resistance, or it may just equal it, or it may be greater than the positive resistance. Let us examine each of these in turn:

When the negative resistance is less than the positive (which is the case in our regenerators of today), the oscillations in the circuit attain a steady amplitude of a value dependent upon the effective resistance; this amplitude is always finite, is reached in a finite time, and dies away to zero when the exciting e.m.f. is removed. Now when the negative and positive resistances are equal, the resultant effective resistance of course is zero. When an e.m.f. is impressed on such a circuit the current builds up at a rate dependent upon the voltage and certain other considerations and continues to rise as long as the e.m.f. is impressed. If it is impressed forever, the current reaches infinity; if for a finite time, then the oscillations have a finite amplitude; if at any time the exciting e.m.f. be removed, the oscillations continue forever at that same amplitude, for the circuit has no resistance. This is merely a theoretical case and cannot be attained in practice because of the imperfections of vacuum valves. Now when the negative resistance is greater than the positive the effective resistance of the circuit is negative and the free oscillations set up as the result of impressing an e.m.f. build up to a theoretical infinity regardless of whether or not the external e.m.f. is removed. The rate of the building-up progress is dependent upon the amplitude of the starting e.m.f., which in turn depends upon the ratio of the negative and positive resistance and will be greater if the negative resistance is increased. No oscillations will occur until an exciting e.m.f. is impressed, but once that takes place, no matter how small it be, the current builds up to infinity.

With this understanding of the regenerative effects in an audion circuit, note what Mr. Armstrong said:

"It is, of course, impossible with present-day instrumentalities to set up a system in which the negative resistance exceeds the positive without the production of oscillations in the system, since any irregularity in filament emission or impulse produced by atmospheric disturbances is sufficient to initiate an oscillation which builds up to the carrying capacity of the tube. It is, however, possible by means of various expedients to set up systems which avoid the production of such a paralyzing oscillation and which approximate the theoretical case in the use of a free oscillation to produce amplification. It is the purpose of this paper to describe a principle of operation based on the free oscillation which is quantitative and without a lower limit. This new method is based on the discovery that if a periodic variation be introduced in the relation between the negative and positive re-

sistance of a circuit containing inductance and capacity, in such manner that the negative resistance is alternately greater and less than the positive resistance, but that the average value of resistance is positive, then the circuit will not of itself produce oscillations, but during those intervals when the negative resistance is greater than the positive will produce great amplification of an impressed e.m.f.''

In other words, currents would increase to infinity and enormous amplification be possible if a non-oscillating circuit of negative resistance were available, but all such negative resistance circuits oscillate when excited. Mr. Armstrong accordingly sought and found a method whereby the effective resistance of ordinary regenerator may alternately be increased and decreased at a very rapid rate, whereby the negative resistance that obtains when the negative resistance is greater than the positive will serve to give great amplification and yet in the next instant when the positive resistance predominates its effect shall be such as to prevent oscillation. In still simpler words, the effect is much as if he had a rapid-action switch which fed alternately into the circuit a negative and positive resistance.

This scheme has all the benefits of radio frequency amplification *per se*, as it is a ''first power'' device, the amplitude of the effects depending upon the amplitude of the impressed e.m.f. Half of the time it is creating amplification (and the amplification when negative resistance predominates continues to rise even if the exciting e.m.f. is removed) and the other half of the time it is ''killing oscillation.'' There is no theoretical limit to the degree of amplification without oscillation—it is limited only by the carrying capacity of the tube. There is no reason why the very weak signal of an amateur station across the continent may not be fed into a 250-watt power tube and a quarter kilowatt of signal-modulated output made available if desired.

Now to secure this desired periodic variation in the ratio of the two resistances the negative may be varied with respect to the positive, the positive with respect to the negative, or both may be varied simultaneously, any one of the methods producing the super-regenerative condition. The rate of variation is an important matter and depends upon the nature of the received signals. At best the choice is a compromise, particularly in telephony, as the lower the frequency the greater the amplification and the higher the frequency the better the quality. For telephony this variation frequency must be above audibility, and the same applies for I.C.W. and spark telegraphy if the natural tone is to be preserved. If one does not care about losing the natural note of the signal, then a lower frequency may be employed with greater amplification and a signal like receiving a spark on an oscillating regenerator. For C.W. telegraphy, where an audio note is essential, the variation frequency may well be 500 or 1000 cycles, but this note would be the same for all C.W. signals and for better selectivity the variation frequency may be beyond audibility and a separate heterodyne used, thereby securing heterodyne selectivity and this system's super-amplification.

Fig. 92 shows a practical circuit in which the negative resistance is varied while the positive resistance is held constant. This circuit is recommended for C.W. and for spark, the latter presumably "on the mush."

Valve R, the super-regenerative amplifier, is a conventionally-arranged regenerator except that in its plate circuit is an inductance-capacity combination that is

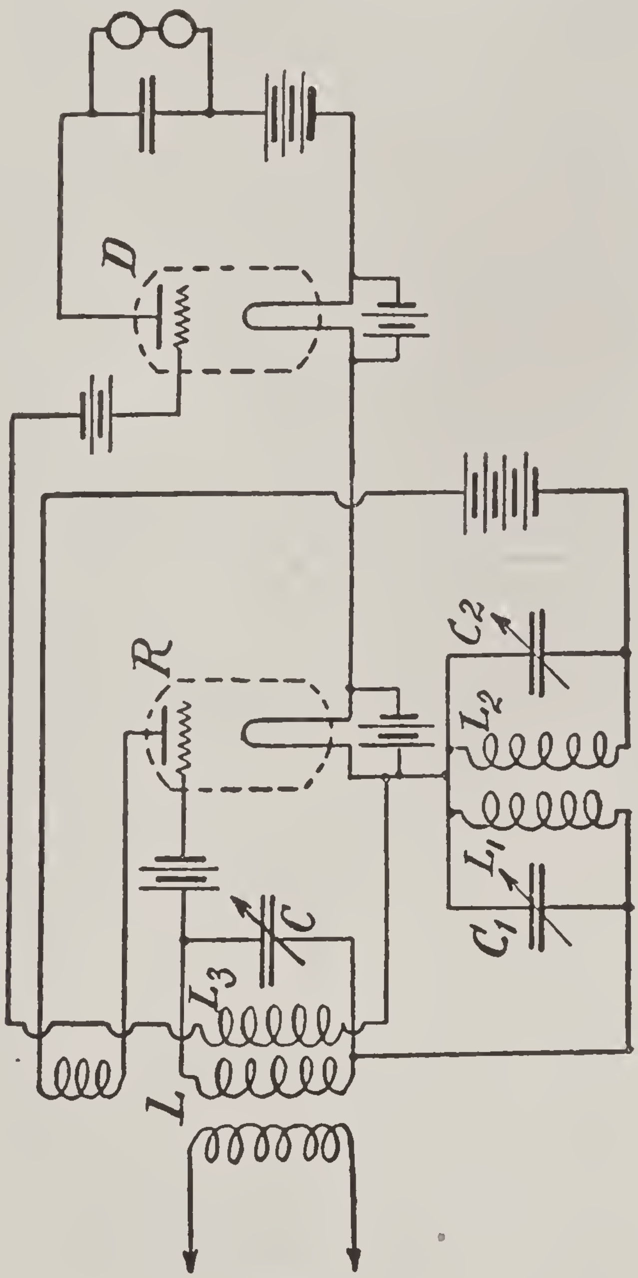


Fig. 94

likewise in the plate circuit of another tube O, the oscillator which creates the resistance variations. By O's action the normally-generated negative resistance of valve R's circuit is increased and decreased, and the frequency of the variation depends upon the oscillation constants of valve O. Generally this is at an audio rate, the inductances in O's circuit being of the order of 10 to 20 henries, and of course both tubes

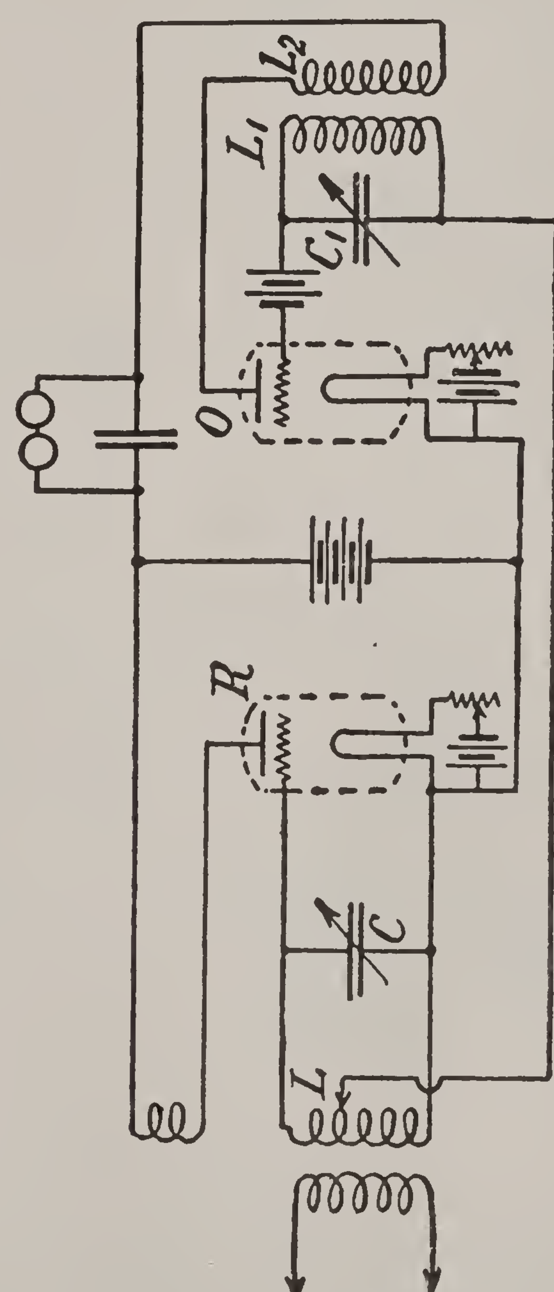


Fig. 95

have a big audio component in their currents. For this reason a third valve, a detector D, is coupled to the main radio-frequency inductances and the phones placed in its output circuit; but if a super-audible frequency is used in valve O the phones may be placed directly in the plate circuit of the amplifier R, and in that case, of course, sparks would be received on their natural note.

Fig. 93 illustrates the variation of the positive resistance with respect to the negative, and is a circuit more fitted to the reception of phone. The positive resistance of the regenerative amplifier-detector R is varied by means of an oscillating tube O, whose tuned circuit is completed back to filament via the inductance L of valve R and accordingly varies its effective resistance. When the grid of valve O is negative it has no effect and circuit R has normal resistance but when the oscillator grid becomes positive it practically shorts the inductance L and creates the effect of an excess of positive resistance therein. Although this circuit may employ an audio oscillator at O, it is customary to use it at a super-audible frequency, particularly for telephone reception.

Fig. 94 shows the third case in which both positive and negative resistances are simultaneously varied. For the real amateur who wants to have lots of fun with sixteen or so adjustments, Mr. Armstrong recommends this circuit. Although it is very critical of adjustment and extreme care is necessary to obtain the super-regenerative state, he says it produces more amplification than either Fig. 92 or Fig. 93. In Fig. 94 the amplifier R has a second feed-back circuit L_1C_1 and L_2 C_2 whereby it oscillates at some lower frequency. This does two things: (1) it creates a superimposed variation of the negative resistance generated in the plate circuit of R; and (2) at the same time it produces a variation in the positive resistance by varying the grid of valve R. The question of phase relationships between the positive and negative resistances is handled by a variation of the coupling between L_1 and L_2, and by adjustment of capacities C_1 and C_2, there generally being a disparity in their values. The separate detector D is necessary as a rectifier.

Mr. Armstrong uses hard tubes only, rectifying on the lower bend by virtue of a negative grid bias and without condenser and leak. When the variation frequency is above audibility the detection may be accomplished in the oscillating tube with still greater amplification, as shown in Fig. 95, but the circuit is harder to adjust. Its action is likewise difficult to explain but is somewhat as follows: incoming signals are amplified and become impressed upon the input circuit of the oscillator O, where they are rectified by virtue of the grid bias battery, producing two frequencies in the circuit; one at signal modulation frequency and the other at variation frequency (O's frequency, as determined by L_1C_1) with a super-imposed signal frequency component. This latter, being in tune with the valve O, is amplified by its regenerative action and then rectified, and hence heard in the phones

What anybody wants to cascade super-regenerators for we don't know, but Mr. Armstrong spoke about it. It seems tremendous reaction troubles are experienced when this is tried, but may be got around by a simple expedient: the second harmonic of the first amplifier valve is very strong, and if the input circuits of the second valve are tuned to this harmonic, reaction is avoided. Mr. Armstrong showed a diagram in which the two steps of super-regeneration had their positive resistance varied by a single tube generator as in Fig. 93, but with the second stage tuned to the second harmonic of the first stage.

The circuit diagrams above have contemplated coupling the super to the antenna by means of tuned circuits, but Mr. Armstrong says trouble is often experienced in this due to the fact that the free oscillations continue during the interval when the resistance is positive and re-excite the amplifier when the resistance becomes negative, with the result that the system oscillates. Accordingly he recommends that the tuning be done at one frequency and amplification at another, which of course is best accomplished by some super-heterodyne method. To accomplish this one would merely introduce an independent detector ahead of the super-amplifier and beat upon it with a separate heterodyne to create the amplifier frequency at which the super-regenerator (of whatever type) operates.

This system of amplification is free of interference from sparks—shock excitation is eliminated. In ordinary spark reception what is heard is a free oscillation produced by the shock of the forced oscillation representing the spark signal energy, but continuing long after the latter has ceased.

As far as concerns the reception of long-distance damped and modulated signals, super-regeneration so far has failed to live up to expectations. By this writing a great number of amateur experimenters have got into motion and slowly we are beginning to accumulate a fund of practical data acquired in the hard school of experience. Almost all of these experimenters have secured some measure of success but not of the order expected. In most cases absolutely terrific local signals have been obtained, and within say fifty miles of broadcasting stations the reception has been about all that could be desired; but when it has come to trying for long-distance 200 meter amateur spark telegraphy the attempts have been flat failures in every case which has come to our notice.

This is a sad disappointment. Let us look into the matter and see if any reasons can be found for this failure. In the first place if there are any signals present from nearby stations they will be amplified—never fear—to such a volume that the phones can't be worn for any length of time; that in itself precludes much DX work; one can't expect to fish for weak sparks two thousand miles away while a half-horsepower of sound energy from a sink gap ten miles away is being squirted in one's ears. Then again the super is full of strange noises and critical in its adjustments; doubtless these defects can be eliminated but so far they have handicapped operation. There is still another reason for this lack of success, however, and we believe it is the basic one. In his paper before the I.R.E. Mr. Armstrong presented oscillograms of the tube action. Let us quote from his paper:

"....*These oscillograms show phenomena which are in accordance with the explanations already given but, in addition, show evidence of self excitation. It has been stated in the preceeding pages of this paper that the basis of super-regeneration was the discovery that a variation in the relation between the negative and positive resistances prevented a system which would normally oscillate violently from becoming self-exciting. An examination of the oscil-*

lograms will show that this is not strictly true, as a free oscillation starts every time the resistance of the circuit becomes negative. It will be observed, however, that this free oscillation is small compared to that produced by the signal, and therein lies the complete explanation of the operation of the system.''

It seems to us that the above paragraph explains the trouble. Super-regeneration does not entirely prevent self-oscillation. As far as moderately strong signals are concerned, such as might be expected on a loop from a nearby station, the effect of these feeble local oscillations is entirely negligible—''and therein lies the complete explanation of the system.'' Now these weak locally-excited oscillations are initiated by some irregularity of operation of the tubes, such as a miniature volcanic eruption in the filament emission, and the original effect is of infinitesimal order, but it builds up rapidly during all of the period that the circuit resistance is negative. Although negligible in the case of strong signals it seems entirely reasonable to consider that the amplitude of this free oscillation might be very formidable when compared with a *weak* signal; in which case the effect of super-regeneration wouldn't obtain for the weak signal—in fact, a weak signal would actually encounter an oscillating tube!

We are not trying to find theoretical fault with the system. It's the other way about: the system has failed completely in DX spark reception and we are trying to find a theoretical reason why. The above would seem to answer the question. It may be possible by some innovation or even by a more skilled operation of the present circuits to eliminate the tendency toward self-oscillation but until that is done the system does not compare, for DX damped reception, with an amateur short-wave regenerative circuit with a soft detector and two steps of audio amplification, *even on the same loop!* Amplifications of signal strength from 100,000 to 1,000,000 times, perhaps, but increase in *receiving range,* no! We may be wrong, but as we view the matter today the chief appeal of this particular form of super-regeneration is going to be for loud-speaker reception of nearby broadcasts by the "cliff-dwellers" of big cities where it is impossible or undesirable to erect an outdoor aerial and where operation will be confined to short distances. As a result, the system has been dubbed "stupid-regenration."

We have been advised to use the super only on a loop. As a matter of fact it seems quite impossible on an aerial except under perfect atmospheric conditions. Strays and induction clicks and miscellaneous electrical disturbances are amplified to such an extent that a weak signal has no chance. The set must be operated on a loop and sheltered as completely as possible from stray electrical disturbances and atmospherics. Then if any strong signals are still picked up on the loop, the set will amplify them. That condition of course leaves very much to be desired.

Now to get over all this gloom, we have a pleasant surprise. The system is delivering the goods on C.W. telegraph reception in a most surprising manner. We say surprising, because here is a system designed not to oscillate but to regenerate, and to super-regenerate and still not oscillate, a system specifically designed for the reception of damped and modulated signals and supposedly incapable of C.W. reception without a separate heterodyne, and here it copies 'em like a charm.

Let us see if we can find an explanation for this unexpected C.W. reception. Frankly we don't know and are only guessing. 2BML believes it possible

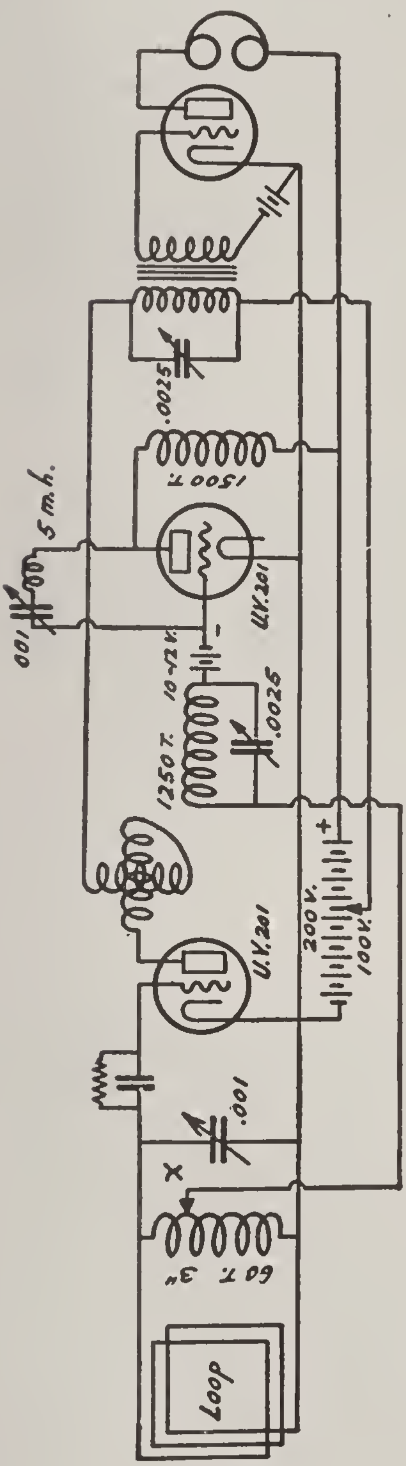


Fig. 96

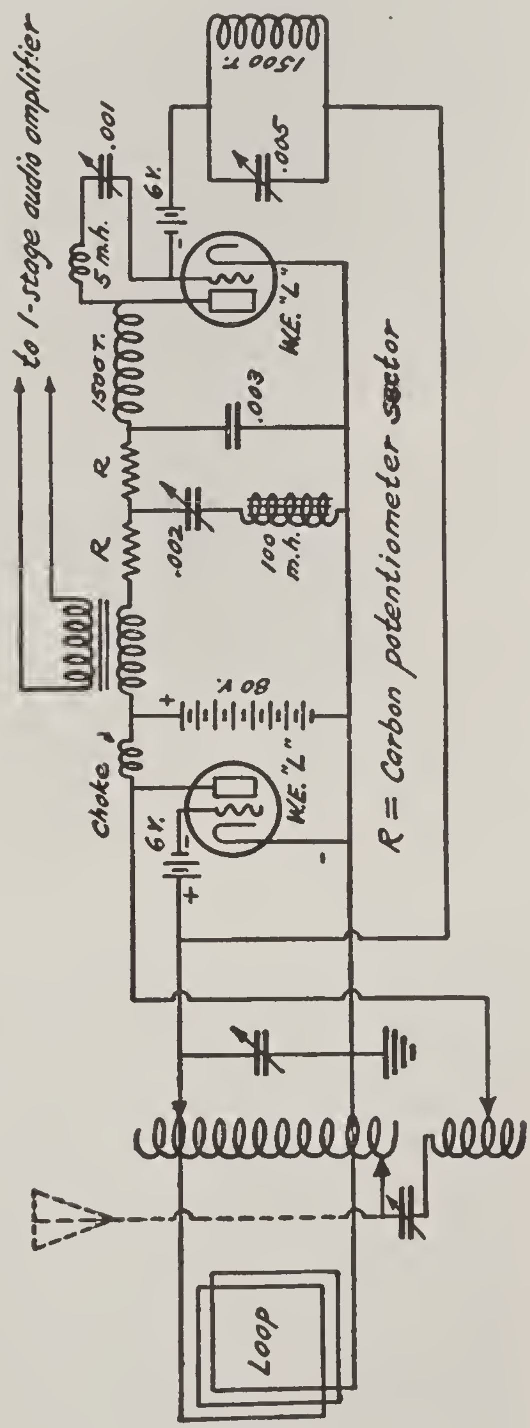


Fig. 97

that he is heterodyning the incoming C.W. signal with some harmonic of his super-audible variation frequency, producing beats which then of course are amplified in the normal super manner. 2XK, after slightly rearranging his circuit so that detection is accomplished in the first tube and after carefully selecting his tubes for their jobs, picks up C.W. by decreasing the *amplitude* of the variation-frequency energy by dimming the generator tube filament. When we consider that the superimposed variation frequency alternately increases negative resistance, permitting free oscillation, and positive resistance, chok-

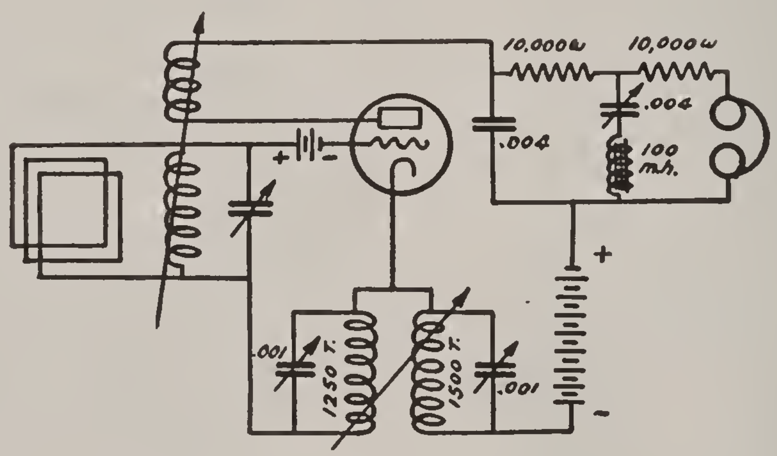


Fig. 98

ing off the oscillations, and that normally a rather considerable amount of energy is required of the variation generator, it seems that perhaps by dimming the generator filament the ratio of the negative periods to the positive periods would be increased to an extent which would permit the heterodyning of incoming C.W. signals without the regenerative amplifier actually being in unrestricted oscillation. Still another possibility of accounting for C.W. reception is that these same feeble locally-excited oscillations which exist throughout the periods of negative resistance heterodyne the incoming C.W. In any event we may say that through some attribute of one tube or the other, audible beats are produced which are then regeneratively amplified the same as telephone signals.

As evidence of the trend which amateur work is taking in the simplification of the armstrong circuits, consider Fig. 96, which has been used with considerable success. The first tube is caused to do the detection, and a condenser with leak is employed in-

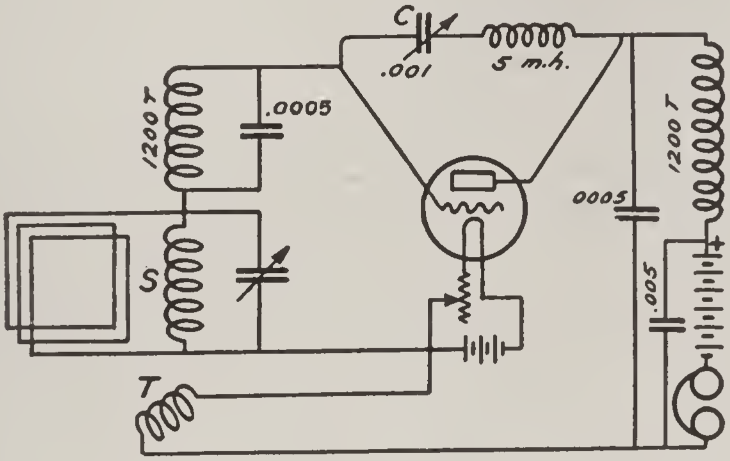


Fig. 99

stead of the C-battery; the regeneration is controlled by the ordinary plate variometer instead of the detested tickler; and the complicated and expensive filter-trap across the amplifier input (necessary to relieve the amplifier of the heavy component of variation-frequency energy) is simplified to a single large variable condenser across the inductance of the amplifier-transformer primary—it has to be tuned to the variation frequency, of course, but it eliminates the extra chokes, condensers, and resistances. The loop is still shown shunted across the pick-up inductance, an arrangement which seems to give greater stability. Notice variable contact X, which is decidedly to be recommended for control of the resistance variation introduced into the regenerative circuit.

Mr. R. B. Bourne of 2BML has succeeded in adapting the ubiquitous Reinartz Tuner to super-regeneration in the circuit shown in Fig. 97. 2BML has had excellent results in the reception of phones and DX 200 meter C.W. The set worked under disadvantages, as a loop was used in a radio shack entirely surrounded by a big counterpoise. 4DL in Palm Beach, Fla., C.W. was heard on the loop, and an amateur phone somewhere in South Carolina. Spark signals sound ''frazzled'' on this hook-up unless their decrement is very low. In fact this circuit is at its best in the reception of I.C.W., particularly 500-cycles-on-the-plate. 8AQO paralizes the phones at 2BML, and 1VQ, using one 5-watt tube with some form of grid modulation, has been heard 600 ft. from the phones on the equipment indicated. Of course it is possible that 2BML is experiencing some kind of an antenna effect from his counterpoise, but if that's all that is necessary to make the super work we will all be willing to operate our loops under our aerial. 1FS, by the way, gets good results by hooking his antenna to the grid side of his loop but using no ground connection.

The circuit of Fig. 98 is a one tube ''flivver'' circuit which has been given much publicity in newspaper radio columns. Nobody knows where it started. Nor why a filter should be necessary. It ''works,'' as far as giving distinct evidence of the presence of the super effect is concerned, but it is extremely hard to control the variation-frequency generation by means of the coupling between the two big honeycombs, and, in common with all the one-tube circuits on which we have received reports, the amplification is not satisfactory until the variation frequency is reduced to well within audibility, necessitating a separate detector. Then it works, but of course is no longer a one-tube circuit. For those interested in such circuits, Fig. 99, due to P. F. Godley, is of greater possibilities. The secondary S and its condenser are the regular closed circuit of a short-wave tuner, and the tickler T is the usual plate variometer but inductively coupled to S, for signal-frequency regeneration. The coupling at variation frequency is accomplished through the interelectrode capacity of the tube and controlled by condenser C, which should have a small choke of about 5 m.h. inductance in series with it to keep out the radio frequency.

Fig. 100 is a two-tube circuit plus an extra amplifier, the first tube being the regenerative amplifier, the second acting both as oscillator and as detector, and the third as an ordinary audio amplifier. It is this set which is shown in our photograph. Note the collector loop, which has a dozen turns 3 ft. square. The vario-coupler was provided so that the plate circuit might be back-coupled for regeneration by means of the tickler, and was an ordinary Grebe coupler with the rotor wound with double the usual number of turns for the tickler. Except for the lead running to the input circuit of the oscillator tube O, this first tube R is seen to be the familiar regenerative arrangement. The oscillator is tuned in both circuits to a super-audible frequency and to attain this has a 1250-turn duo-lateral coil shunted by a mica condenser of

.0025 mfds. in its grid circuit, and a DL-1500 in its plate circuit. The two duo-laterals are not electromagnetically coupled but, instead, the two circuits are

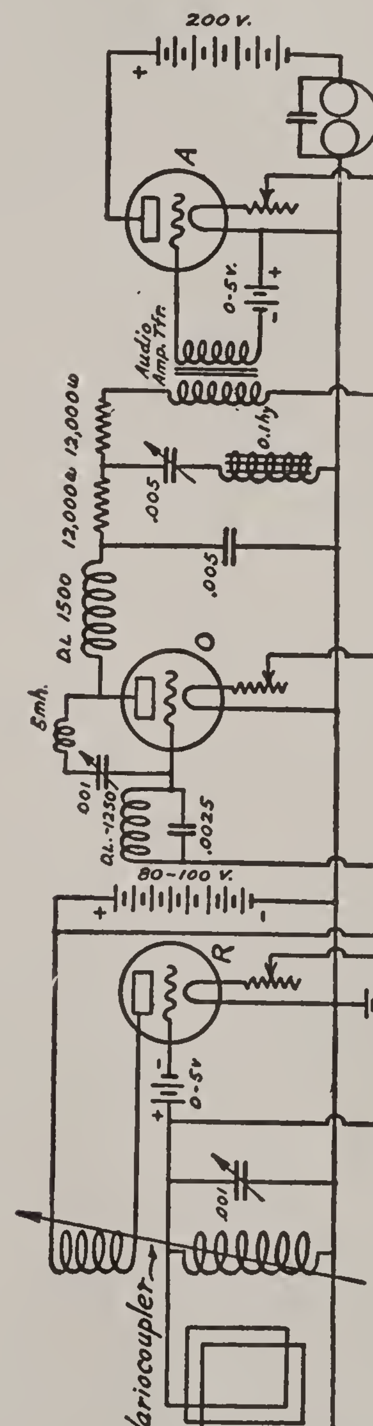


Fig. 100

statically coupled by means of the condenser C, a variable of .001 mfd. maximum, having in series with it a small inductance of 5 millihenries. This is a choke-coil and should be located close to the condenser C, which controls the amplitude of oscillations generated in the valve O. The small choke coil has little effect on the feed-back at the variation frequency but serves primarily to keep changes in the feed-back condenser from throwing the radio frequency circuits out of resonance with the incoming wave. As the radio circuits of valve R offer considerable impedance to the super-audible oscillations of valve O, a rather considerable power is necessary in the latter, and both R and O were 5-watt Western Electric power tubes with 90 volts on their plates.

Now if no audio-frequency amplifier is to be used, the phones may be connected across the fixed .005 mfd. condenser in the output circuit of the second tube. The amount of energy developed by the oscillator at the variation frequency, however, is sufficient to completely paralyze an audio amplifier if impressed on its grid, and a low-pass filter is necessary between the detector-oscillator and the amplifier to keep out the 12,000-cycle component and yet pass the signal frequency. Any form of such filter is satisfactory, the arrangement shown in the diagram consisting of two 12,000-ohm Lavite resistances, an air variable of .005-mfd. maximum and an iron-cored inductance of 0.1 henry being merely a make-shift built up of pieces of equipment Mr. Armstrong had at hand. The variable condenser is tuned to eliminate the variation frequency in the amplifier by providing a shunt path across the primary of the amplifying transformer of low impedance at the frequency to which it is tuned.

The amplifier valve was a Western Electric telephone repeater with 200 volts on its plate. An *additional* 200 volts is not essential; it might as well be supplied from an additional 110 volts and then connected to the same 90-volt battery that supplies the other tubes.

Hard tubes were used exclusively, it being impossible to maintain a stable adjustment with soft tubes. The grid of the first tube had a negative bias of 3 volts; this was merely to make the operation occur on the proper part of the characteristic curve and might as well have been attained by tapping off a different plate voltage for that tube, if any more convenient.

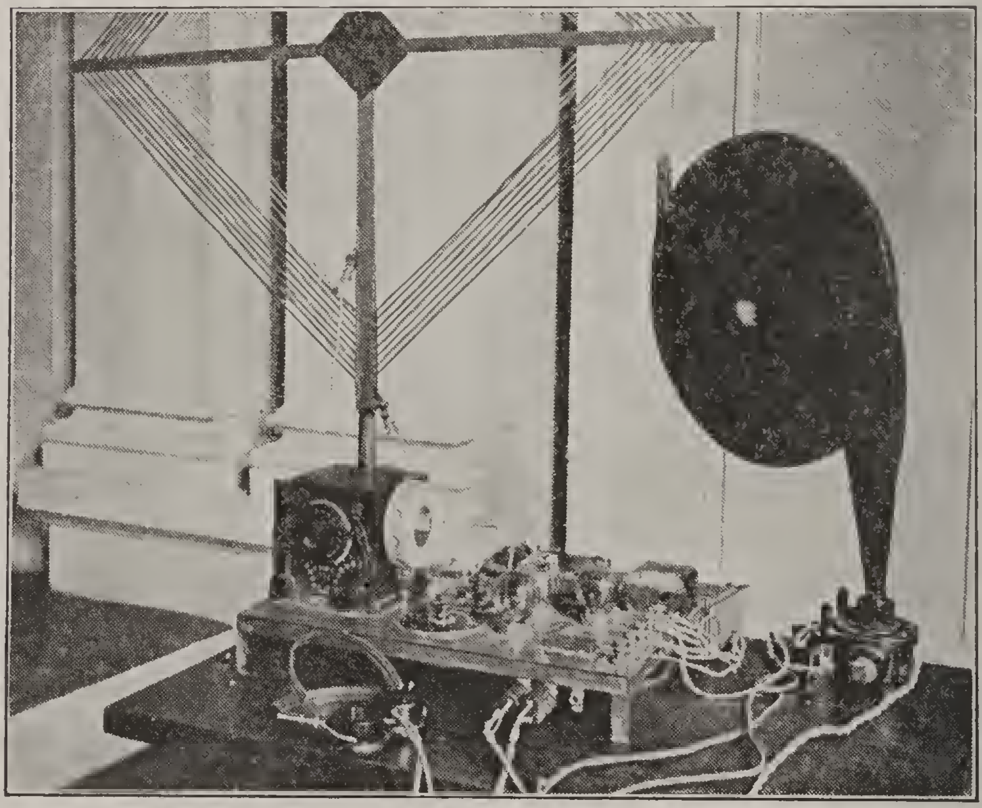


Fig. 101

TO BUILD A SUPER-REGENERATIVE RECEIVING SET

The parts required for a super-regenerative receiver are enumerated in the legend of Fig. 102, which is the best of these circuits to use.

This circuit was used very successfully with the super-regenerative receiver illustrated in this article. The constants used were as follows:

L-1	Stator of vario-coupler.
L-2	Vario-coupler with 100 turns on secondary
C-1	.0005 m.f. variable condenser
C-2	.001 m.f. variable condenser
C-3	.002 m.f. fixed condenser
L-3	D.L.-1250
L-4	5 mil-henry inductance coil
L-5	D.L.1500
C-4	.001 m.f. variable condenser
C-5	.005 m.f. fixed condenser
C-6	.005 m.f. fixed condenser
R-1, R-2	12,000 ohms non-inductive resistors
K-1	.1 henry iron-core choke coil
C-7	.002 m.f. fixed condenser
T-R	Audio frequency transformer—high ratio
C-8	.001 fixed condenser
B-1	100 volt plate battery
B-2	100 volt plate battery
B-3, B-4	Variable grid batteries
B-5	22½ volt grid battery

In the accompanying photographs one method of assembling this apparatus is shown. This arrangement was used with considerable success. It will be noted that the photographs show a variometer which is not indicated in the wiring diagram. This was used in the plate circuit of the first tube, to give a fine and simple control of the oscillation of this tube. This is not shown in the wiring diagram because, if the secondary of the vario-coupler is wound with 100 turns, the variometer is not required.

Most of the apparatus used in the super-regenerative receiver is quite familiar and its location will be recognized from the photographs.

Inquiries have been made concerning the choke coils and resistances in the filter circuit. These can now be purchased from radio dealers and it would be advisable to purchase the resistances. Almost any type of small iron-core choke coil can be used in the filter circuit. Final adjustments can be made by varying the capacities of the condenser in the filter circuit. The 5 mil-henry choke coil may consist of a D.L. 250 or 300 but it can be constructed by winding 210 turns of No. 28 S.C.C. wire on a form 5 inches in diameter. The length of the coil will be about 3¼ inches.

A suitable sized loop for the reception of 360 meters may be easily constructed on a frame 3-ft. square, by winding 7 turns of wire spaced about ¾-inch spart.

Western Electric "E" tubes are the best tubes to employ in this circuit as the results obtained with "E" tubes are greatly superior to other types. 100 volts should be used on the plate of the first two tubes and 200 volts on the last one. This is obtained by placing two 100-volt plate batteries in series with a center tap, as indicated in Fig. 102.

The use of grid batteries is essential to the operation of this circuit. The values of the grid voltages vary considerably, but are usually in the neighborhood of from 10 to 15 volts for each of the first two tubes and 22 volts for the last tube.

A set that will give good results can be assembled

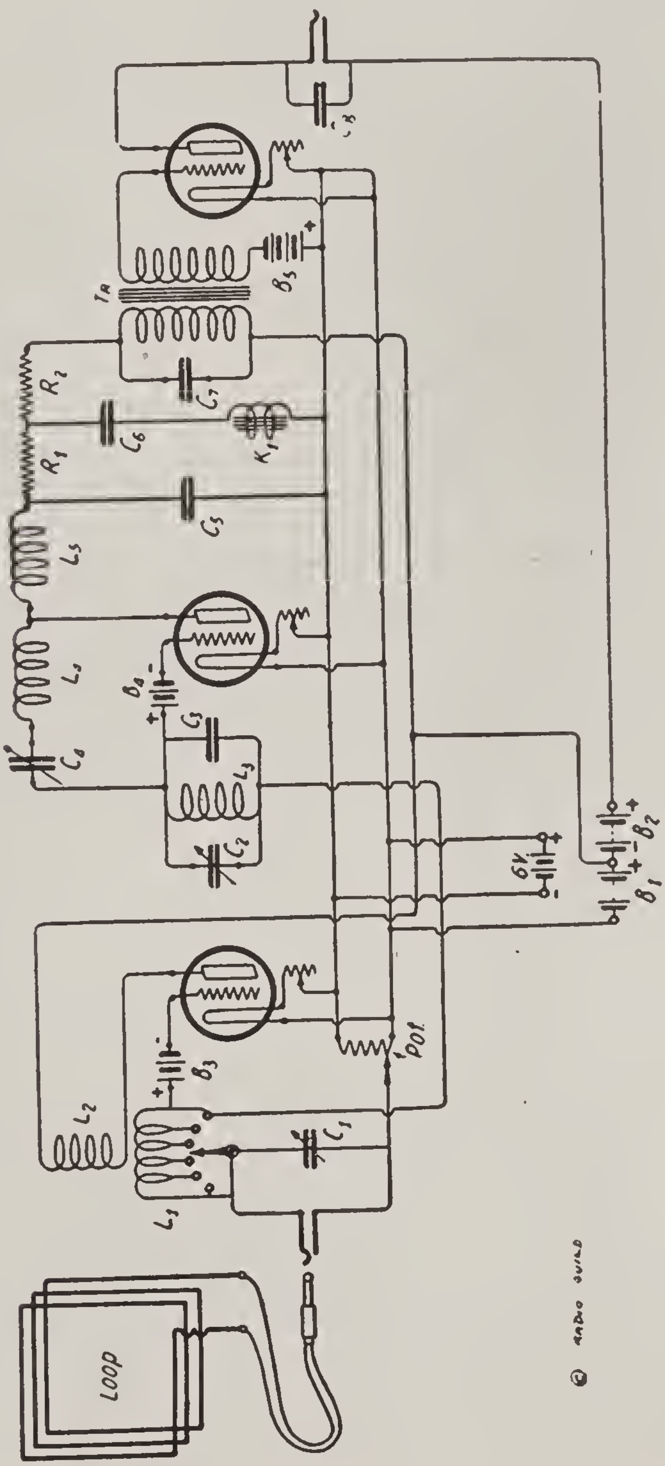


Fig. 102

by following diagram Fig. 103. The parts necessary are listed below with the same designations as shown in the photograph.

C_1—0.002 mfd. fixed condenser
C_2—0.001 mfd. variable condenser
C_3—0.0005 mfd. grid condenser and 2 meg leak
C_4—0.0005 mfd. fixed mica condenser
C_5—0.001 mfd. variable condenser
C_6—0.002 mfd. fixed mica condenser
L_1—Single layer solenoid as described
L_2—200-turn honeycomb coil
L_3—Variometer (one with high maximum and low minimum values of inductance)
L_4—1250-turn honeycomb coil
L_5—1500-turn honeycomb coil
L_6—Loop antenna as described
R_1 R_2 R_3—5-ohm rheostats
J_1—Double-circuit jack
J_2—Single-circuit jack
T—Audio-frequency amplifying transformer
V_1—Radiotron U.V.201
V_2—Moorhead or W.E. "J" tube (any hard tube will work)
V_3—Hard amplifier tube

The instruments are placed on a panel as clearly shown in Fig. 103.

The coil L_1 consists of a single layer solenoid of 60 turns with three evenly spaced taps brought out to binding posts for connection to the loop for adjusting the inductance where different sized loops may be used.

The set as it was first made used a 3 volt biasing battery in the grid circuit of the tube V_2, but the two binding posts for connecting this battery were shunted by a copper wire, it being found that the set worked just as well without any biasing batteries at all. The grid circuit of the tube V_1, contains the conventional condenser shunted by a grid leak. This is quite an advantage as two batteries are thus eliminated.

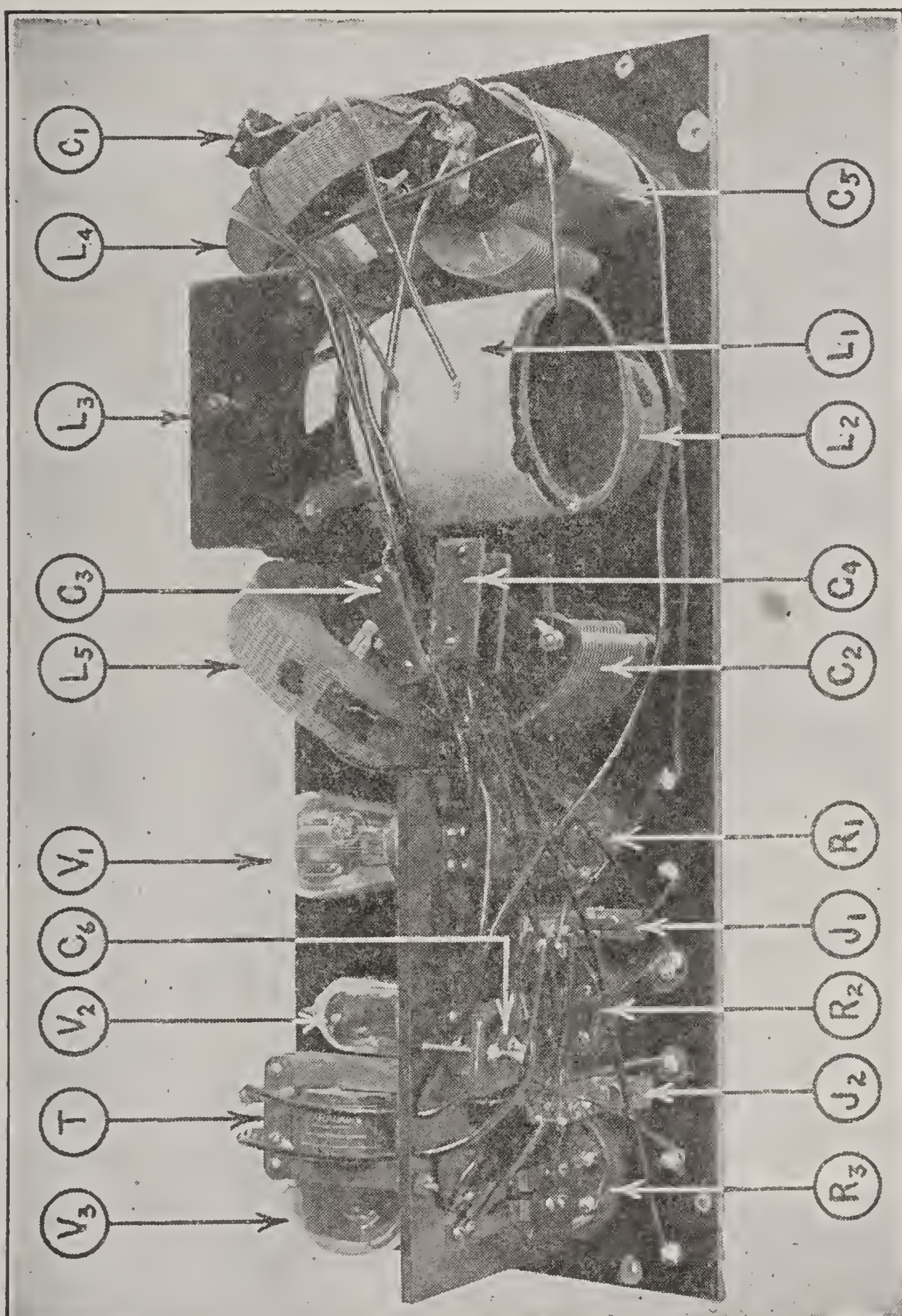


Fig. 103

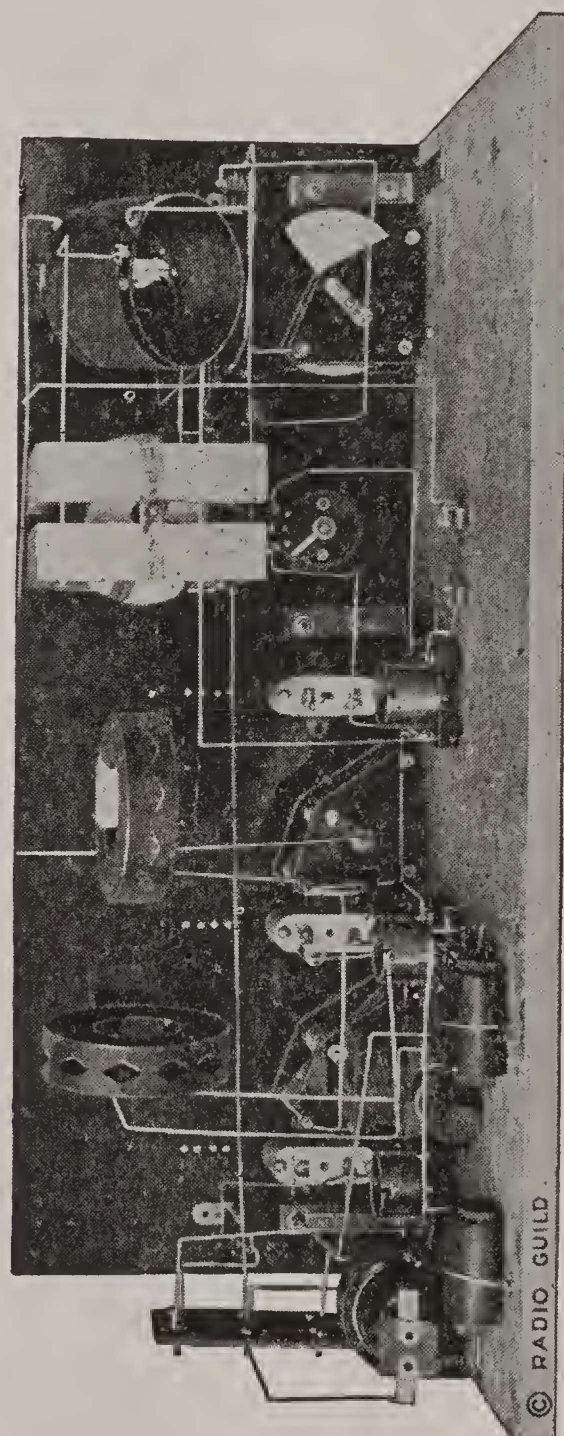


Fig. 104

The diagram fully illustrates the connections to the binding posts on the front of the panel. The binding posts in the diagram are arranged as looking at the front of the panel. The loop used was wound on a cross frame (30 inches across the arms) and consisted of fifteen turns spaced ½ inch between turns. Tubular braided wire was used as this was found to be far superior to any other wire for this purpose.

The lower left hand large knob controls the wave length (C_5), the top large knob controls the regeneration (L_3), and the right lower large knob controls the frequency of the tube V_2, (oscillator). For maximum amplification most of the capacity of this condenser (C_2) should be included in the circuit, but for the clarity of telephone signals and C.W. this will have to be forfeited a little by reducing the capacity considerably.

Of course we know that it has been generally understood that the super-regenerative circuit excludes C.W. because the oscillator tube stops the detector tube from oscillating, but nevertheless if the second tube filament is turned down to a rather critical point, the amplification is retained at a near maximum, and C.W. signals *can be received.*

The only explanation we can offer is that when the second tube filament is reduced in brilliancy, the amplitude of the oscillations generated by the tube is decreased, and their effect of stopping the detector tube from self oscillation at intervals is also reduced, thus allowing the detector to start oscillating at intervals between the slower frequency pulses of the second tube. This would produce an audio frequency beat when tuned properly with C.W. signals, which might at the same time be amplified, when its radio frequency component is fed back due to regeneration. This is only a theory, but the set actually picks up C.W. when in this condition very efficiently although with slightly different sounds than the ordinary regenerative set.

A different adjustment is required for spark—the filaments must be turned up higher; sparks at best sound mushy but can be read without difficulty although the true note is somewhat distorted.

For telephone reception the same procedure is gone through as for sparks, although the operator must make a choice between clarity of signals and degree of amplification. This adjustment is controlled by concondenser C_2; with the condenser set nearer the 0 setting the quality will be improved and with the condenser nearer the 100 setting on the scale, the amplification will be increased although interference from the oscillator frequency will be noted.

It will be noticed that in this circuit no filter is used except the by-pass condenser C_6, which is connected across the primary of the transformer T. This is all the filter necessary when using the first tube as the detector instead of the second tube as is ordinarily done.

STORAGE BATTERIES

The owner of a receiving set generally takes great care of the set itself and pays little or no attention to the battery. The battery must have attention if you desire maximum results from your set, and wish to save the life of your battery.

Care of the Battery.

In the proper care of a storage battery if the following things are remembered you will escape 75 per cent of your battery troubles:

First—Test the specific gravity of all cells with a hydrometer two or three times a month. If any of the cells are below 1200, the battery is more than half discharged, and it should be recharged.

Second—Pure water must be added to all cells regularly and at sufficiently frequent intervals to keep the solution at the proper height. Add water until solution is one-half inch above top of plates.

Never let solution get below top of plates.

Plugs must be removed to add water, then replaced and screwed on after filling.

The battery should be inspected and filled with water once every week in warm weather and once every two weeks in cold weather.

Do not use Acid or Electrolyte, only pure water.

Do not use any water known to contain even small quantities of salts or iron of any kind.

Distilled water or fresh, clean rain water only should be used.

Use only a clean vessel for handling or storing water.

Add water regularly, although the battery may seem to work all right without it.

In order to avoid freezing of the battery, it should always be kept in a fully charged condition. A fully charged battery will not freeze in temperatures ordinarily met.

Electrolyte will freeze as follows:

Sp. gr. 1,150, battery empty, 20 above zero F.

Sp. gr. 1,180, battery ¾ discharged, zero F.

Sp. gr. 1,215, battery ½ discharged, 20 below zero F.

Sp. gr. 1,250 battery ¼ discharged, 60 below zero F.

Therefore, it will be seen that there is no danger of the battery freezing up if it is kept at a specific gravity of from 1250 to 1300 and it should be kept as near 1275 as possible. Under no circumstances should acid or electrolyte be added to the cells to bring them up to the required specific gravity. Nothing but pure water must be put in the cells after the battery has been once placed in commission and the specific gravity must be kept up by charging only.

General Storage Battery Data

A storage battery, secondary battery, or accumulator, as it is variously called, is an electrical device in which chemical action is first caused by the passage of electric current, after which the device is capable of giving off electric current by means of secondary reversed chemical action. Any voltaic couple that is reversible in its action is a storage battery. The process of storing electric energy by the passage of

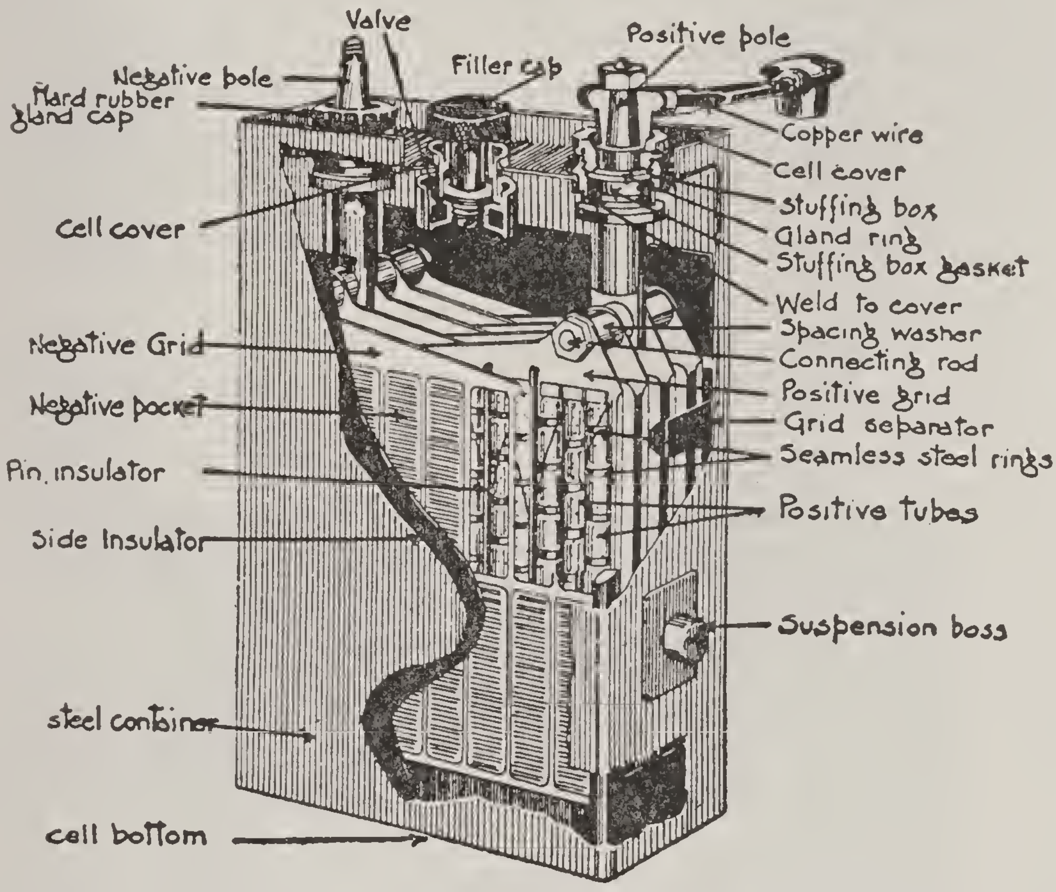


Fig. 105—Storage Cell of Nickel-Iron Type with Alkaline Electrolyte

current from an external source, is called charging the battery; when the battery is giving off current, it is said to be discharging. A storage battery cell has two elements or plates, and an electrolyte. The two plates are usually made of the same material, though they may be of two different materials. The material used in the construction of both plates of battery furnished is lead.

Polarity.—The terms positive and negative are employed to designate the direction of the flow of current to or from the battery; that is, the positive plate is the one from which the current flows on discharge, and the negative plate is the one into which current flows on discharge. In a lead battery the positive plate, on which the lead peroxide is formed, has a comparatively hard surface of a reddish-brown or chocolate color, while the negative plate, which carries the sponge lead, has a much softer surface of a grayish color.

Electrolyte.—The electrolyte used with the lead type of battery is always a diluted solution of sul-

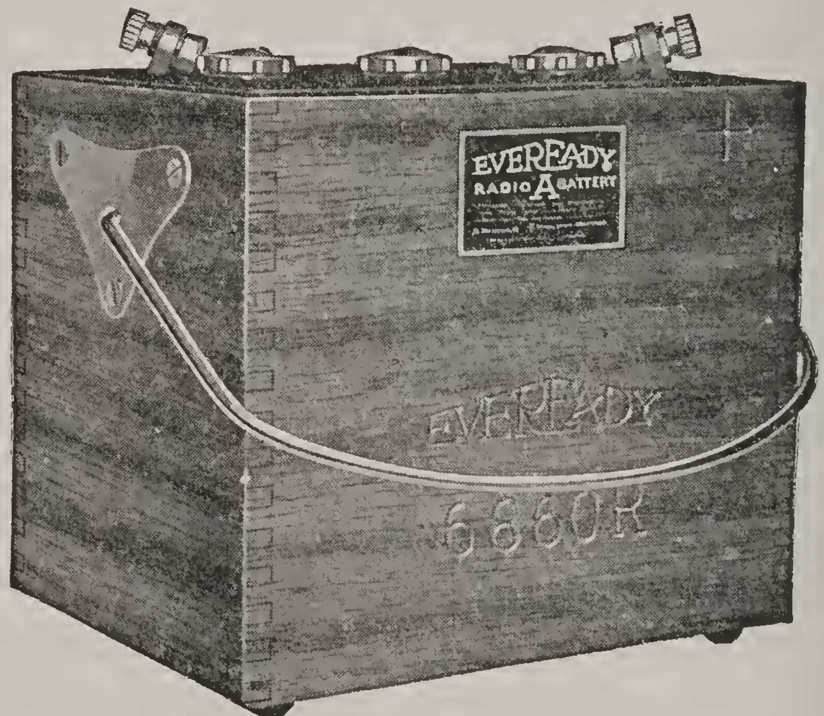


Fig. 106—"A" Battery

phuric acid. The specific gravity of the electrolyte when the battery is fully charged, varies from about 1.210 for stationary batteries to 1.300 for automobile ignition batteries and other portable batteries.

The proper specific gravity to use varies with the conditions, and the specific gravity may be found by the use of a hydrometer. When the cells of the battery shipped with this outfit are fully charged, the specific gravity of the electrolyte, as indicated by the hydrometer, should be 1275 to 1300 at 70 degrees F. The final density is the usual practice. None but sulphur or brimstone acid should be used. When diluting, the acid must be poured into the water slowly and with great caution.

Never Pour the Water into the Acid.—The specific gravity of commercial sulphuric acid is 1.835, and 1 part of such acid should be mixed with 5 parts (by volume) of pure water. Care should be taken that no impurities enter the mixture. The vessel used for the mixing must be a lead-lined tank or one of wood that has never contained any other acid; a wooden washtub or spirits barrel answers very well. The electrolyte when placed in the cell should come ½ inch above the top of the plates. Before putting the electrolyte in the cells, the positive pole of each cell should be connected to the negative pole of the next cell in the series and the whole battery of cells should be connected, through a main switch, to the charging source—the positive pole of the battery to the positive side of the charging source, and the negative pole of the negative side. After adding the electrolyte the battery should be charged at once or at least inside of 2 hours. A little pure water should be added occasionally to the electrolyte to make up for evaporation, and a small quantity of acid should be added about once a year to make up for that thrown off in the form of spray or that absorbed by the sediment in the cells. Do not use anything but pure distilled water in storage batteries because any impurities such as those commonly found in tap or well water will in a very short time absolutely ruin the battery.

Test of Specific Gravity.—The specific gravity of the electrolyte is the most accurate guide as to the state of charge of a leadtype storage battery. The test of the specific gravity is made by means of a hydrometer having a suitable scale for the type of cell to be tested. In all portable types of batteries, and ordinarily in vehicle batteries it is usually necessary to draw some of the electrolyte from the cell in order to test its specific gravity with the hydrometer, which should have a scale reading from 1150 to 1300.

Charging.—The normal charging rate is the same as the 8-hour discharge rate specified by manufacturers. The charge should be continued uninterruptedly until complete; but if repeatedly carried beyond the full-charge point, unnecessary waste of energy, a waste of acid through spraying, a rapid accumulation of sediment, and a shortened life of the plates will result. At the end of the first charge, it is advisable to discharge the battery about one-half, and then immediately recharge it. It is advisable to overcharge the batteries slightly about once a week, in order that the prolonged gassing may thoroughly stir up the electrolyte and also to correct inequalities in the voltages of the cells. If the discharge rate is very low, or if the battery is seldom used, it should be given a freshening charge weekly.

Indications of a Complete Charge.—A complete charge should be from 12 to 15 per cent greater in ampere-hours than the preceding discharge. The principal indications of a complete charge are: (1)

The voltage reaches a maximum value of 2.4 to 2.7 per cell, and the specific gravity of the electrolyte a maximum of 1275 to 1300 per cell. If all the cells are in good condition and the charging current is constant, maximum voltage and specific gravity are reached when there is no further increase for ¼ to ½ hour; (2) the amount of gas given off at the plates increases and the electrolyte assumes a milky appearance, or is said to boil.

Voltage Required.—The voltage at the end of a charge depends on the age of the plates, the temperature of the electrolyte, and the rate of charging; at normal rate of charge and at normal temperature, the voltage at the end of the charge of a newly installed battery will be 2:5 volts per cell or higher; as the age of the battery increases, the point at which it will be fully charged is gradually lowered and may drop as low as 2.4 volts. All voltage readings are taken with the current flowing; readings taken with the battery on open circuit are of little value and are frequently misleading. After the completion of a charge and when the current is off, the voltage per cell will drop rapidly to 2.05 volts and remain there for some time while the battery is on open circuit. When the discharge is started, there will be a further drop to 2 volts, or slightly less, after which the decrease will be slow. Cells should never be charged at the maximum rate except in cases of emergency.

Direction of Current.—The charging current must always flow through the battery from the positive pole to the negative pole. If it is necessary to test the polarity of the line wires when no instruments are available, attach two wires to the mains, connect some resistance in series to limit the current, and dip the free ends of the wires into a glass of acidulated water, keeping the ends about 1 inch apart. Bubbles are given off most freely from the negative end.

Discharging.—Heavy overcharging rates maintained for a considerable time, are almost sure to injure the cells. The normal discharge rate should not be exceeded except in case of emergency. The amount of charge remaining available at any time can be determined from voltage and specific-gravity readings. During the greater part of a complete discharge, the drop in voltage is slight and very gradual; but near the end the falling off becomes much more marked. Under no circumstances should a battery ever be discharged below 1.7 volts per cell. and in ordinary service it is advisable to stop the discharge at 1.75 or 1.8 volts. If a reserve is to be kept in the battery for use in case of emergency, the discharge must be stopped at a correspondingly higher voltage. The fall in density of the electrolyte is in direct proportion to the ampere-hours taken out, and is therefore a reliable guide as to the amount of discharge.

Miscellaneous Points

Restoring Weakened Cells.—There are several methods of restoring cells that have become low: (1) Overcharge the whole battery until the low cells are brought up to the proper point, being careful not to damage other cells in the battery; (2) cut the low cells out of circuit during one or two discharges and in again during charge; (3) give the defective cells an individual charge. Before putting a cell that has been defective into service again, care should be taken to see that all the signs of a full charge are present.

Sediment in Cells.—During service, small particles

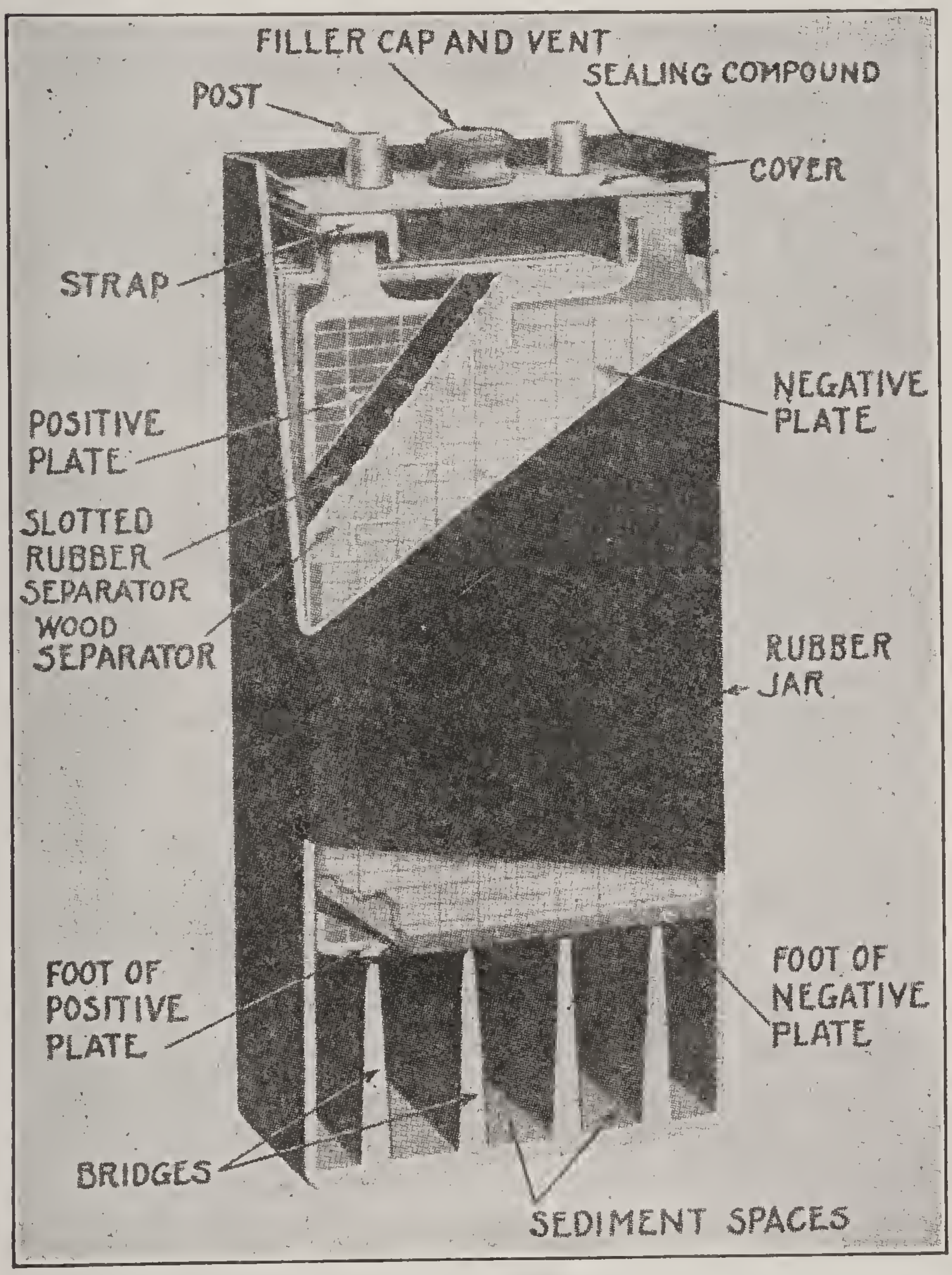


Fig. 107—Storage Cell, Lead Plate, Acid Electrolyte Type

drop from the plates and accumulate on the bottom of the cells. This sediment should be carefully watched, especially under the middle plates, where it accumulates most rapidly, and should never be allowed to touch the bottom of the plates and thus short-circuit them. If there is any free space at the end of the cells, the sediment can be raked from under the plates and then scooped up with a wooden ladle or other non-metallic device. If this method is impracticable, the electrolyte, after the battery has been fully charged, should be drawn off into clean containing vessels; the cells should then be thoroughly washed with water until all the sediment is removed, and the electrolyte should be replaced at once before the plates have had a chance to become dry. In addition to the electrolyte withdrawn, new electrolyte must be added to fill the space left by the removal of the sediment; the new electrolyte should be of 1.3 or 1.4 sp. gr. in order to counteract the effect of the water absorbed

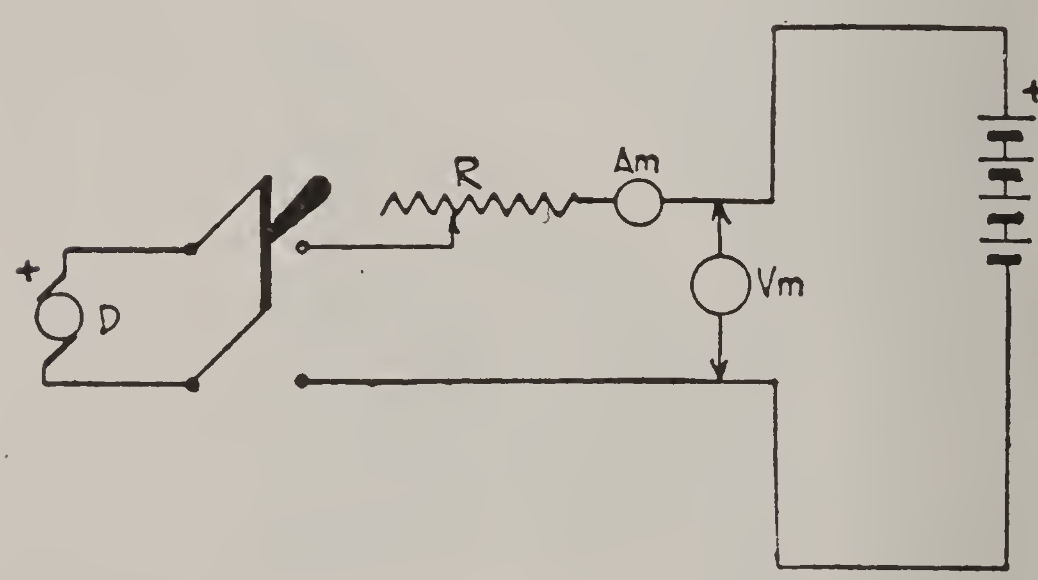


Fig. 108—Storage Battery Charging Circuit

by the plates while being washed. If at any time any impurities, especially any metal other than lead or any acid other than sulphuric acid, gets into a cell, the electrolyte should be emptied at once and the cells thoroughly washed and filled with pure electrolyte.

Idle Batteries.—If a battery is to be idle for, say, 6 months or more, it is usually best to withdraw the electrolyte, as follows: After giving a complete charge, siphon or pump the electrolyte into convenient receptacles, preferably carboys that have previ-

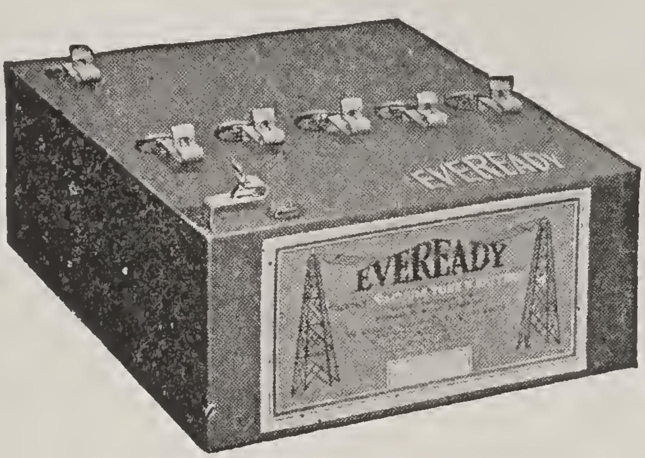


Fig. 109—"B" Battery

ously been cleaned and have never been used for any other kind of acid. As each cell is emptied, immediately refill it with water; when all the cells are filled, begin discharging and continue until the voltage falls to or below 1 volt per cell at normal load, and then draw off the water.

Putting Battery into Commission.—To put an idle battery into commission, first make sure that the connections are right for charging; then remove the water, put in the electrolyte, and begin charging at once at the normal rate. From 25 to 30 hours continuous charging will be required to give a complete charge.

Sulphating.—Lead sulphate is practically an insulator. Some of this material is formed in all lead-sulphuric-acid storage cells on discharge and is reconverted to lead oxide or lead peroxide on recharging the cell. If present in excessive quantities, the sulphate adheres to the plates, especially the positive, in white soluble patches, preventing chemical action, increasing the resistance of the cell, and causing unequal mechanical stresses that may buckle the plates. The most frequent causes of sulphating are overdischarging, too high specific gravity of electrolyte, and allowing the battery to stand for a considerable length of time in a discharged condition.

GENERATOR TROUBLES, THEIR CAUSES AND REMEDY

Methods for Locating and Repairing Break in the Armature of Generator.

A break in an armature must be located by the fall of potential method, which means that a current must be sent through the armature and the voltage tested across the various segments. First disconnect all the leads from the armature and lift all brushes except one on each pole, then connect the battery to these brushes through the resistance and ammeter shown in Fig. 111, connect the detector to one brush, and then to each segment in turn with a wire from the other terminal of detector until the break is located.

If the two wires from the detector are connected to the segments that the brushes are standing on, a deflection will be seen caused by a fall of voltage through the coils. If we gradually draw the movable wire over the segments toward the other brush, the deflection will gradually fall to zero, providing it is on the side on which the break does not occur (Fig. 111). If however, the wire is drawn over the segments on the other side, the deflection on the instrument will remain constant until the failing segment is reached, when the deflection will drop to zero as the wire passes over the break.

Instead of moving the testing wire around the commutator, a course that might not always be convenient, it could be held stationary against the commutator, say a few segments from one of the brushes, and the armature gradually pulled around till the break appeared.

In this case on the unbroken side a constant deflection will be obtained till the break passes a brush, when the needle will fall to zero. On the other side there will be no deflection till the break passes one of the brushes. So long as the break is between the movable testing wire and the brushes to which the

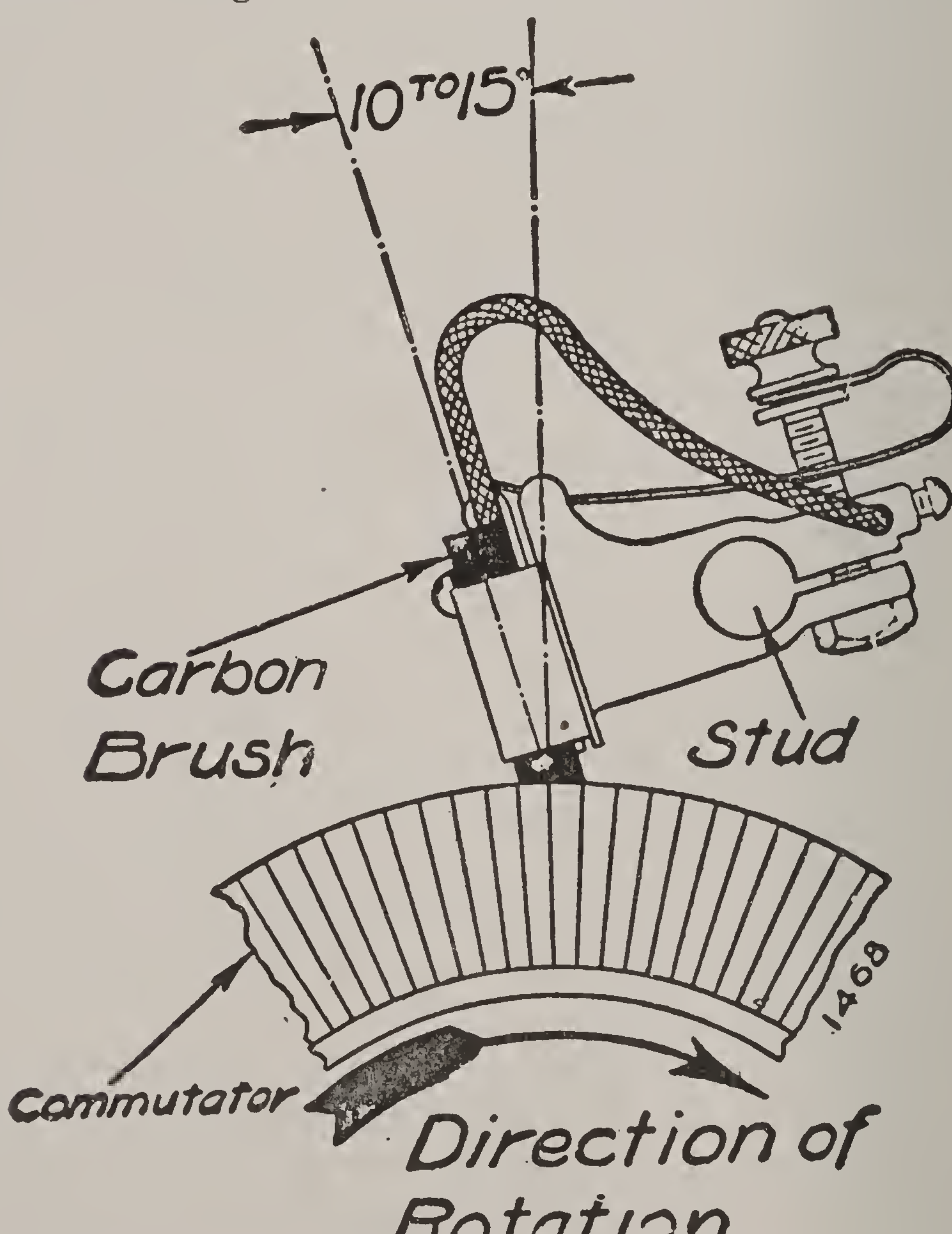


Fig. 110—Correct Method of Setting Brushes

detector is connected, there is a deflection; but not when the break is between the fire brushes and the testing wire. If the instrument gives a good reading between two adjoining segments, it will show a much larger reading across a break.

If a millivoltmeter is available, the matter is somewhat simplified, as a small current is sufficient for testing, such for instance as the current taken by an incandescent lamp. If, therefore, the armature be connected to a source of supply through a lamp, a millivoltmeter will give a good deflection across a break. Millivoltmeter is the instrument used as a shunted ammeter in conjunction with various law resistances called shunts; when used as a millivoltmeter in the manner above described, it is used alone, the armature itself taking the place of the shunt (Fig. 112).

Having found the broken section it must be examined till the actual break is discovered. In the case of a winding, the bad section can be taken out and a new one put in without much difficulty. In the case of a formed wound drum, it is generally an inaccessable bottom wire that breaks. In this case it is usual to strip the armature till the break is reached; this is not always necessary. Having found the defective section, cut out as much as can be got at, that is the conductors on the surface of the core or in the slots. Leave the end crossing wires in, but with the ends separated and rewind the section with the end crossings on top of the others.

Overheating of the Armature

Several causes will cause overheating of the armature, the most common being—overload, grounds, eddy currents in the core, eddy currents in the conductors, short-circuit in the coils, sparking at the commutator, heat conducted from the bearings, low insulation. If the excessive heating is uniform over the whole armature, the machine is overloaded.

Should one or two of the coils be overheated, the trouble is due to a short circuit in the winding. If the core is hotter than the coils, the trouble is due to excessive eddy currents in the laminations, caused by the core rubbing up against one of the pole faces, or it may be caused by a number of the laminations being short-circuited, the slots having been filed too much when the core was built. Heating due to eddy currents either in the armature core or the conductors, cannot be remedied by the projectionist, the maker of the machine should be immediately notified. The test is to run the generator on open circuit and take note of the rise in temperature. To test for a ground in the windings, first disconnect the generator from the circuit, and then run it up to normal speed. Using an ordinary test lamp, touch the opposite brushes to make sure you have the voltage.

Then connect the lamp terminals between the generator frame and the poles. Should there be a ground the test lamp will either glow or light. The cause of the ground should then be located and removed.

Locating Grounded Coil

To locate a grounded coil is a difficult job, and should not be undertaken by anyone who is not familiar with electrical apparatus.

The armature should be removed from the field and set on trestle, a current (not to exceed the normal current of the dynamo) should be passed through the armature from any one of the commutator segments to the shaft. A compass should be held near the conductors, and the needle will be deflected in a certain direction due to the flow of current. If the armature is slowly turned round, till such time as the compass needle reverses, this will indicate the proximity of the grounded coil.

Low insulance (insulation resistance) between the core and the armature winding, is generally caused by the presence of moisture, and often accompanied by vapor arising from the armature. This can be reme-

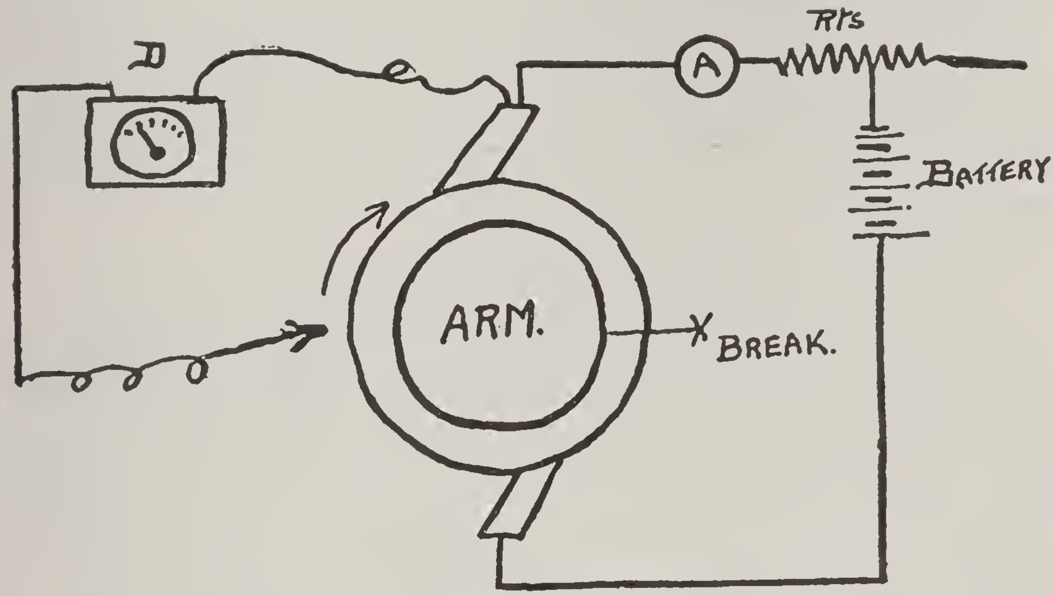


Fig. 111

died by baking the armature in an oven at a temperature of about 200° F, or by running the machine unloaded for a few hours and sending a small current round the windings.

The short circuiting of the coils is generally accompanied by heavy sparking and a smell of burning may be caused by copper dust, oil on bits of solder lodged between the commutator arms.

Locating Short-Circuited Coil

To locate a short-circuited coil, use the same method to locate break in armature. It is best to test between each pair of segments, remembering that the readings will all be alike when connected across the good coils, and that a variation in the reading points to a fault.

The remedy for a short circuited coil is to strip the damaged parts and rewind.

A temporary repair job can be accomplished by disconnecting the short circuited coil from the commutator arms, and then bridging the arms, thus cutting out the defective coil.

Should the short circuiting of the coils be due to copper dust, oil, etc., between the commutator arms, all that will be necessary will be to dislodge the foreign substance.

Overheated Bearings

A hot bearing may result from one or more of the following causes: Insufficient lubrication, faulty lubrication, grit or other foreign matter in the bearings; armature not centered with respect to pole pieces; side pull due to magnetic pull on armature; end pressure of collar against the bearing—due to machine being out of line, with its driving shaft, or to want of alignment in engine; to a bent armature shaft; shaft rough or cut, etc., etc.

Only the best of oil, free from sediment and grit should be used for lubrication (the ordinary machine oil supplied and used on the projector is too thin for this class of work) all the oil cups should be kept clean and filled, the oil rings should be watched to see that they carry the oil up to the shaft.

When the heating of a bearing is due to the presence of dirt or grit, it should be cleaned with some thin oil or kerosene. If kerosene is used do not forget to use a good lubricant directly after the cleansing.

The bearing caps should just be tight enough to run freely, without any side play. If a bearing is too tight the oil cannot get through as the oil passage remains full. The same thing occurs if the oil passages become choked with dirt or grit.

Do not tighten up the bearing caps with pliers, as sufficient pressure can be brought to bear with the finger and thumb. After tightening up the caps the armature should revolve freely, and when in motion the armature should come gradually to rest. Should the armature stop quickly the bearings are too tight.

A bent shaft will cause the armature to rub pole

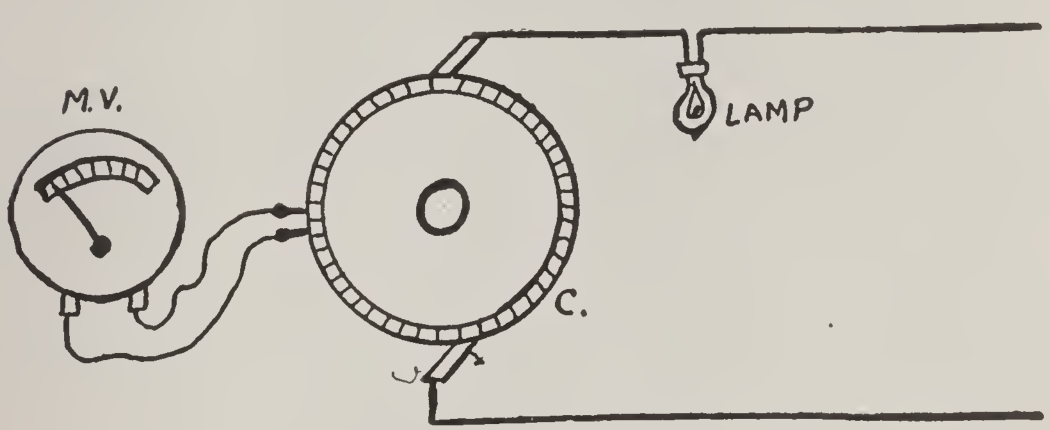


Fig. 112

pieces, and thus produce sparking, vibrations and overheating. To overcome this it will be necessary to remove the armature from the machine and have the shaft straightened in what manner is most handy. It may be found necessary to withdraw the shaft from armature before this can be accomplished.

A rough shaft may be caused by dirt, grit or overheating. The roughness, if not excessive, can be taken out by the use of a little emery cloth, but care should be taken to remove all grit and filings when the job is finished. If the roughness is so great that it cannot be taken out with the use of emery cloth, it will be necessary to remove the armature, and smooth up the shaft in a lathe, using a very fine file and emery cloth.

Noise in a generator can be laid to one of the following causes: Bent or broken shaft; armature out of balance; brushes grinding commutator; armature hitting pole pieces; loose bearings. All screws and bolts should be periodically gone over and any loose one tightened. If the noise is due to the armature not being properly balanced, the makers of the machine should be notified, as this is due to faulty construction of the generator.

A grinding or squeaking noise from the brushes can sometimes be stopped by the application of a very little vaseline to the commutator. If, however, the noise continues, the brushes should be removed and examined to see that a "hard place" has not developed. Should this be the case, the brushes should be filed down past the "hard place" and then replaced in the holders.

In the event of a short-circuit a fuse would naturally blow, and all generators should be fused up as near the terminals as possible.

A series-wound generator would spark and pull the engine up. It would not give any current to the arc.

A compound-wound generator would spark and show a drop in voltage.

A shunt-wound generator would lose its field and would not excite till such time as the short was removed.

When a generator is overloaded, the temperature of the armature will rise, and heavy sparking of the brushes will also result. If the machine is run without removing the overload, the insulation of the armature may be destroyed.

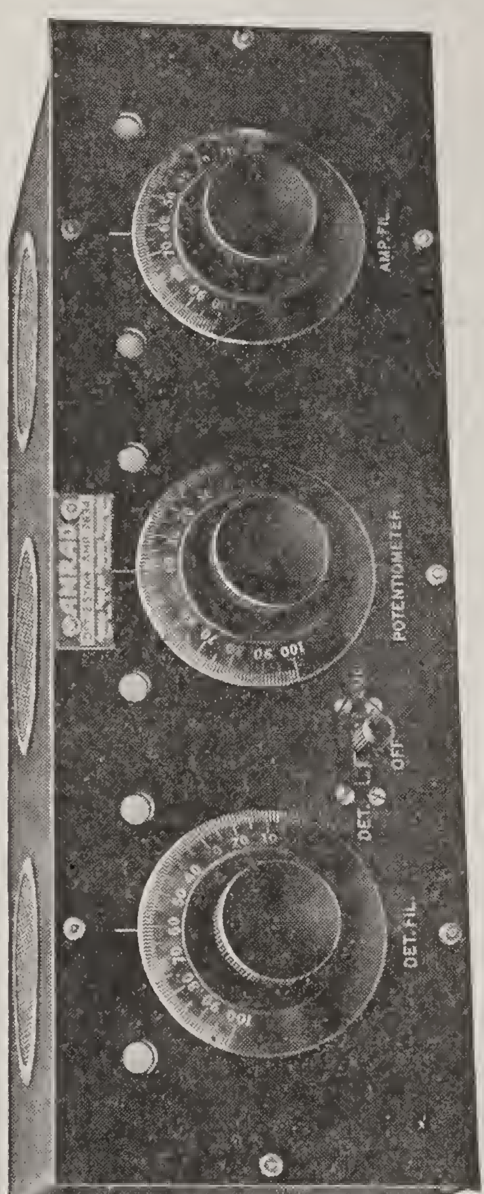


Fig. 113

MOTOR TROUBLES AND REMEDIES

Sparking may be due to overload, wrong position of brushes, broken coil, weak field, and to any of the causes named for dynamos.

Sparking

Symptom. Intermittent Sparking. On a varying load, in which the work comes on at the beginning or end of each cycle, and then falls off during the remainder of the cycle, a motor often sparks just as the peak load comes on.

The cause is the heavy current taken at the instant of maximum load, which distorts and weakens the effective field and shifts the neutral point. This weakening of the field results in a still larger current in the armature, aggravating the evil.

Remedy. Add a compounding coil on the motor to assist the shunt, or exchange the motor for a compound-wound one, or one with interpoles.

Failure to Start

(1) *Symptoms.* Motor does not start. Little or no current passes on closing the D.P. switch and pushing starting handle over.

Probable Causes. Brushes not down. Switch not making contact in the jaws. Starting switch not touching the contacts. Fuse broken. Controller fingers not touching contact plates. Break in series coil (if a series motor). Terminal loose. No current on mains.

If the no-volt release coil excites, or if a long arc is observed on breaking circuit, it indicates that the shunt field gets its current and the probable cause of the failure to start is that the shunt is connected in series with the armature owing to two of the leads from the starter being reversed.

Remedy. Trace out the connections or use testing set.

Failure to Start

(2) *Symptom.* Motor does not start, but takes excessive current. Fuse or overload cut-out acts.

Cause. It is assumed the motor is not overloaded; this can be tested by taking load off and trying to start motor light. If a shunt motor there may be a short circuit in connecting cables or in field coil; or in armature; or a break in field coil.

Remedy for broken field. If field excites when brushes are up, but not when they are down, the symptoms point to a short circuit in or across armature, or brushes.

Examine brushes for short circuit to frame, for copper dust, oil, or broken down insulation.

Then disconnect armature and excite field. Move armature round quickly by hand. A drag will be felt as the short circuited coils pass the holes. If the armature can be driven at a fair speed by belt, with the field excited, the short-circuited coils will warm up and can probably be located in this way.

If the above symptoms occur with a series-wound motor, the cause may be a short in the field or armature, but not a break.

A fairly common cause is incorrect connecting up.

Another cause, particularly with machines that have been dismantled, is incorrect polarity of the field coils. Thus if the coils are connected up so that they are all of the same polarity, the effect is the same as with a broken field wire as the field is completely neutralized. If only one of the field coils is reversed in a four-pole motor, the motor would probably not start and would in any case take an excessive current.

Remedy. Test the coils for polarity.

Incorrect Speed

A certain amount of speed adjustment may be obtained by altering the position of the brushes. Moving the brushes backwards from the neutral point has the effect of increasing the speed, whilst moving them forward reduces the speed.

Excessive Speed

Symptom. Motor starts, then speed gradually increases till motor runs at very excessive speed. This only occurs when a motor starts light or on a very light load such as a loose pulley.

Cause. If shunt or compound motor. Shunt coil connected in *series* with armature instead of in parallel.

On first switching on, the magnets excite, as the armature is stationary and allows the full shunt current to pass the coils. As the armature speeds up it puts a back emf in the circuit, gradually reducing the current passing and thus weakening the field. The faster the armature goes the weaker the field becomes. A short circuit in the shunt might produce same result if motor starts absolutely light.

Remedy. Connect up the shunt.

Fuse Blows

Symptom. Motor starts and runs up to its proper speed, but fuse or overload acts on putting load on.

Cause. This is a sign of overload. Probably belts too tight, bearings tight or dry.

If the fuse blows while starting up there may be be a ground on the motor. This should be tested. If the starter is provided with shunt sector the fuse may blow while starting up, owing to a bad contact to this sector, due either to dirt or to a hollow place in the metal.

In the case of a compound-wound motor a cross connection or leakage between the series and shunt windings will cause the fuse to blow if the cross is in a position that the shunt is practically short circuited by the series.

Starter Overheats

Symptom. Motor starting against load takes excessive current. Last few coils of resistance overheat (probably smoke or get red hot). Fuse or overload acts, or motor sparks.

Cause. Overload; or starter too small.

When a motor starts against a load having considerable inertia, such as heavy line shaft with several large pulleys and tight belts, or against a heavily flywheeled machine, time must be given for it to get up speed. If the starter is moved over the contacts more quickly than the motor can accelerate, an excessive current will pass, causing the motor to spark. The starter must be put on more slowly and this will cause it to heat up unless it has been liberally rated.

Remedy. Exchange starter for one having more margin, that is one which permits of starting up slower. This does not mean a starter for a large H.P.

Starts Suddenly

Symptom. Motor does not start nor take current till most of resistance is cut out, then takes rush of current and starts suddenly.

Cause.—A break in the starting resistance. *Temporary Remedy.* Connect the contacts where breaks occurs, until resistance can be repaired.

Wrong Direction

Symptom. Motor runs in wrong direction.

Remedy. Reverse armature or field connections, whichever is easier, but not both.

In a compound-wound machine both the shunt and series coil must be reversed if the field be reversed; but if the machine be provided with interpoles these must be treated as part of the armature and must therefore not be reversed when the field is reversed.

More Reverses

Symptom. Motor starts up and runs correctly on light load. On an overload, or reduced voltage, motor reverses and runs backwards.

Cause. This applies to a compound-wound motor, with the series or compound coil connected up in opposition to the shunt coil.

Remedy. Reverse the series coil.

Flashing

Symptom. Severe sparking or flashings apparently all round the commutator; overheating of the armature and burning of the insulation between a couple of the segments.

Cause. The cause of the above is a broken wire in the armature winding.

Remedy. If the broken end cannot be located and repaired easily, the armature must be stripped until the break is found and the section re-wound. A temporary repair can sometimes be made sufficiently to enable the motor to continue working, by joining across the two segments on each side of the burnt mica with a short piece of copper wire, the wire being laid on the ears of the commutator and sweated in with a soldering iron. This practically converts two segments into one, and the motor will run in this way quite satisfactorily. If the commutator lugs are not readily accessible, a copper pin may be driven hard down between the two segments in a part not under the brushes.

Flashing Over

Symptom. On an overload and sometimes on a normal load a motor will flash from the brushes to a part of the commutator or to the rocker, and blow the fuses. This is more liable to happen with a weak field.

Cause and Remedy. The cause is that the motor has too much forward lead, and the brushes should be moved back a little.

REGULATIONS FOR THE INSTALLATION OF AERIALS

a. Antennae outside of buildings shall not cross over or under electric light or power wires of any circuit carrying current of more than 600 volts, or railway trolley or feeder wires, nor shall it be so located that a failure of either antenna or of the above mentioned electric light or power wires can result in a contact between the antenna and such electric light or power wires.

Antennae shall be constructed and installed in a strong and durable manner and shall be so located as to prevent accidental contact with light and power wires by sagging or swinging.

Splices and joints in the antenna span, unless made with approved clamps or splicing devices, shall be soldered.

Antennae installed inside of buildings are not covered by the above specifications.

b. Lead-in wires shall be of copper, approved copper-clad steel or other approved metal which will not corrode excessively, and in no case shall they be smaller than No. 14 B. & S. gauge except that approved copper-clad steel not less than No. 17 B. & S. gauge may be used.

Lead-in wires on the outside of buildings shall not come nearer than four (4) inches to electric light and power wires unless separated therefrom by a continuous and firmly fixed non-conductor that will maintain permanent separation. The non-conductor shall be in addition to any insulation on the wire.

Lead-in wires shall enter building through a non-combustible, non-absorptive insulating bushing.

c. Each lead-in wire shall be provided with an approved protective device properly connected and located (inside or outside the building) as near as practicable to the point where the wire enters the building. The protector shall not be placed in the immediate vicinity of easily ignitible stuff, or where exposed to inflammable gases or dust or flyings of combustible materials.

The protective device shall be an approved lightning arrestor which will operate at a potential of 500 volts or less.

The use of an antenna grounding switch is desirable but does not obviate the necessity for the approved protective device required in this section. The antenna grounding switch, if installed, shall, in its closed position, form a shunt around the protective device.

d. The ground wire may be bare or insulated and shall be of copper or approved copper-clad steel. If of copper, the ground wire shall be not smaller than No. 14 B. & S. gauge, and if approved copper-clad steel, it shall be not smaller than No. 17 B. & S. gauge. The ground wire shall be run in as straight a line as possible to a good permanent ground. Preference shall be given to water piping. Gas piping shall not be used for grounding protective devices. Other permissible grounds are grounded steel frames of buildings or other grounded metallic work in the building and artificial grounds such as driven pipes, plates, cones, etc.

The ground wire shall be protected against mechanical injury. An approved ground clamp shall be used wherever the ground wire is connected to pipes or piping.

e. Wires inside buildings shall be securely fastened in a workmanlike manner and shall not come nearer than two (2) inches to any electric light or power wire unless separated therefrom by some continuous and firmly fixed non-conductor making a permanent separation. This non-conductor shall be in addition to any regular insulation on the wire. Porcelain tubing may be used for encasing wires to comply with this rule.

f. The ground conductor may be run inside or outside of building. When receiving equipment ground wire is run in full compliance with rules for Protective Ground Wire, in Section d., it may be used as the ground conductor for the protective device.

REQUIREMENTS OF NATIONAL ELECTRICAL CODE-RADIO INSTALLATION

Where an indoor aerial is used, no special safeguards are necessary, but where the aerial is placed outside the building, a ground wire should be carried from the aerial in the most direct line to the ground. This wire should not be smaller than No. 8 B. & S. gauge. Should it not be possible to make a suitable ground connection outside the building, then the ground wire should be lead into the cellar of building through a lead-in insulator and connection made to the water main. Do not under any circumstances connect the ground wire to a gas pipe. The lead-in wire from the aerial to the receiving set should be protected by one of the approved types of lightning arrestors now on the market. This arrestor should be installed on the lead-in wire outside the building.

A. Aerial conductors must be installed and constructed to prevent accidental contact with the conductors carrying a current over 600 volts. Aerial supports must be constructed and installed in a strong and durable manner. Aerial wires leading from same to ground switch must be mounted firmly on approved insulating supports which may be constructed of wood, not iron pin, or brackets equipped with porcelain knobs or petticoat insulators. Insulators must be so installed as to maintain the conductors at least five inches clear of the surface of the building wall. In passing the aerial conductor through the side of the building a continuous tube or bushing must extend five inches beyond the surface of the walls on both sides. The porcelain tube will not be approved in this case. Ground switches shall be mounted so that the current carrying parts will be at least five inches clear of the building walls and located preferably in the most direct line between the aerial and the point of ground connection. The conductor from the ground switch to ground connection must be securely supported.

B. Aerial conductors must be effectively and permanently grounded at all times when the station is not in operation, by a conductor the periphery of the cross section of which is not less than three-quarters of an inch. The ground conductor must be of copper or other metal which will not corrode excessively under existing conditions. Where ground conductor is over twenty-five feet in length it shall be insulated throughout its entire length in a similar manner to wires attached to aerial conductors. Ground connections should be made in accordance with the requirements as set forth above, except where variations from these requirements may be allowed by special permission in writing from the Board of Fire Underwriters.

C. In radio stations used for receiving only the ground switch may be replaced by a similarly mounted and grounded short (one-eighth inch or less) or vacuum type lightning arrestor. The current carrying parts must be five inches from the building.

D. Where the aerial is grounded as specified in sections *A* and *B* the switch employed to join the aerial to the ground connection must be a knife switch, the blade of which must have a periphery of less than three-quarters of an inch so that when open the current carrying parts to which the aerial and ground connection wires are attached will be separated at least by five inches. The base of the switch must be of a material suitable for high frequency service. Slate will not be approved.

E. When supply is obtained direct from street service the current must be installed in metal conduit or armored cable. In order to protect the supply system from high potential surges there must be provided two condensers, each of not less than one-half microfarad capacity and capable of withstanding 600-volt tests in series across the line with mid-point grounded. A capacity fuse not larger than ten amperes capacity must be connected between each condenser and the line wire connected to it. Each condenser must be protected by a shunting fixed spark gap of one thirty-second of an inch separation or less. Another way of protecting the supply system from high potential surges is by means of two incandescent lamps connected in series across the line with the mid-point grounded.

F. Transformer, voltage reducers, keys and similar devices must be of types specially designed for the service.

U. S. RADIO LAWS AND REGULATIONS

The owner of an amateur radio transmitting station must obtain a station license before it can be operated if the signals radiated therefrom can be heard in another state; and also if such a station is of sufficient power as to cause interference with neighboring licensed stations in the receipt of signals from transmitting stations outside the state. These regulations cover the operation of radio-telephone stations as well as radio-telegraph stations.

Station licenses can be issued only to citizens of the United States, its territories and dependencies.

Transmitting stations must be operated under the supervision of a person holding an *Operator's License* and the party in whose name the station is licensed is responsible for its activities.

The Government licenses granted for amateur stations are divided into three classes as follows:

Special Amateur Stations known as the "Z" class of stations are usually permitted to transmit on wave lengths up to approximately 375 meters.

General Amateur Stations which are permitted to use a power input of 1 kilowatt and which cannot use a wave length in excess of 200 meters.

Restricted Amateur Stations are those located within five nautical miles of Naval radio stations, and are restricted to ½ kilowatt input. These stations also cannot transmit on wave lengths in excess of 200 meters.

Experimental stations, known as the "X" class, and school and university radio stations, known as the "Y" class, are usually allowed greater power and also allowed the use of longer wave lengths at the discretion of the *Department of Commerce.*

All stations are required to use the minimum amount of power necessary to carry on successful communication. This means that while an amateur station is permitted to use, when the circumstances require, an input of 1 kilowatt, this input should be reduced or other means provided for lowering the antenna energy when communicating with near-by stations in which case full power is not required.

Malicious or wilful interference on the part of any radio station, or the transmission of any false or fraudulent distress signal or call is prohibited. Severe penalties are provided for violation of these provisions.

Special amateur stations may be licensed at the discretion of the *Secretary of Commerce* to use a longer wave length and higher power than general amateur stations. Applicants for special amateur station licenses must have had two years' experience in actual radio communication. A special license will then be granted by the *Secretary of Commerce* only if some substantial benefit to the science of radio communication or to commerce seems probable. Special amateur station licenses are not issued where individual amusement is the chief reason for which the application is made. Special amateur stations located on or near the sea coast must be operated by a person holding a commercial license. Amateur station licenses are issued to clubs if they are incorporated, or if any member holding an amateur operator's license will accept the responsibility for the operation of the apparatus.

Applications for operator's and station licenses of all classes should be addressed to the *Radio Inspector* of the district in which the applicant or station is located. *Radio Inspectors'* offices are located at the following places.

First District........................Boston, Mass.
Second District ....New York City
Third District.......................Baltimore, Md.
Fourth District.......................Norfolk, Va.
Fifth District.....................New Orleans, La.
Sixth District..................San Francisco, Cal.
Seventh District.....................Seattle, Wash.
Eighth District......................Detroit, Mich.
Ninth District.......................Chicago, Ill.

No license is required for the operation of a receiving station, but all persons are required by law to maintain secrecy in regard to any messages which may be overheard.

There is no fee or charge for either an operator's license or a station license.

A GLOSSARY OF RADIO WORDS AND THEIR DEFINITIONS

A. C. ALTERNATING CURRENT. A current that changes its flow of direction a given number of times a second, according to the construction of the alternator.

ACCELERATION. Rate of change of velocity.

ACCUMULATOR. A storage battery.

ACLINIC LINE. The line that represents the magnetic equator.

ACOUSTICS. The science of sound.

ACTINIC RAYS. The rays at the violet end of the spectrum.

ACTINOMETER. A photometer; a meter for measuring the sun's rays.

ACTUAL HORSEPOWER. The exact useful power given out by a machine; found by subtracting the power used by the machine itself from the indicated horsepower.

ADAMANT. A substance of extreme hardness such as the diamond.

ADJUSTABLE CONDENSER. A condenser, any part of which may be cut in or out of the circuit; thus varying its capacity.

ADMITTANCE. One ohm has an admittance of one mho; the reciprocal of impedence.

AERIAL. A system of wires used to radiate or receive energy in the form of electro-magnetic waves. The wires should be strung clear of, and insulated from all surrounding objects.

AEROMETER. A meter for measuring the tension of the air.

ALIGN. To place or form in line.

ALLOY. A mixture of two or more metals.

ALTERNATOR. An alternating current dynamo.

ALTERNATING CURRENT. See A. C.

ALUMINUM. A light malleable white metal. Specific Gravity 2.6. (A conductor of electricity.)

AMALGAM. An alloy, part mercury.

AMMETER. An instrument used to measure the flow of current, and connected in series in the circuit.

AMPERE. The unit of current strength.

AMPERE HOUR. The quantity of electricity passed by a current of one ampere in one hour;
One ampere flowing for one hour;
Two amperes flowing for one-half hour;
One-half ampere flowing for two hours, all equal one ampere hour.

AMPLIFIER. An instrument to increase the volume of a receiving signal. There are a number of different types on the market such as vacuum-tube, magnetic, etc.

ANCHOR BOLTS. Bolts used to fasten machines to their foundation.

ANCHOR GAP. A spark gap used to disconnect the detector when using the transmitter.

ANEMOMETER. A meter for measuring the direction and velocity of the wind.

ANEROID BAROMETER. An instrument for measuring atmospheric pressure.

ANGLE OF DECLINATION. Variation of a compass; the angle of error of the magnetic compass.

ANGULAR VELOCITY. The speed of a revolving or turning body.

ANNULAR. Having the form of a ring; ring shaped.

ANODE. Positive terminal of a conducting current.

ANTENNA. A receiving aerial.

ANTI-FRICTION METAL. A tin, lead alloy like Babbitt Metal.

ANTI-INDUCTION CONDUCTOR. A conductor so made that it avoids induction effects.

ANTI-SPARK DISCS. Discs made of Ebonite used to assist in preventing sparking on Bradfield tube.

APERIODIC. Not tuned.

APERTURE. An opening of any description in a partition.

ARC. The arc between the two carbon electrodes slightly separated.

ARC RECTIFIER. An apparatus used to change Alternating Current to Direct Current.

AREOMETER. An instrument for finding the specific gravity of a fluid.

ARMATURE. A collection of pieces of iron designed to be acted on by a magnet; a part of a generator.

ARMATURE BORE. The space within which the armature revolves.

ARMATURE COILS. The wires wound on the core of the armature.

ARMOR CABLE. Wire enclosed in a metal protective covering.

ARTIFICIAL MAGNET. A piece of iron or steel that has been magnetized.

ASBESTOS. A fibrous variety of ferro-magnesium silicate. A non-conductor of heat, and fireproof.

ASBESTOS COVERED WIRE. A cable of very fine strands of copper wire all twisted together and covered with an asbestos covering.

ATMOSPHERE. Air, a mixture of gases.

ATOM. The smallest division of a substance.

ATTENUATE. To make thin; to lessen the force of.

AUDION. A relay operated by electrostatic control of currents flowing across a gaseous medium; consists of a heated filament, a grid electrode and a metal plate all enclosed in a highly evacuated bulb.

AUDIOMETER. A meter for measuring the strength of incoming signals.

AURORA BOREALIS. A luminous display and electrical phenomenon seen in the heaven in the northern hemisphere.

AUTOMATIC. Self-acting.

AUTOMATIC TRANSMITTER. A transmitter operated by running a paper tape between small metal wheels.

AUTOMATIC TRANSFORMER. A transformer provided with one coil instead of two, part of the coil being traversed by the primary and part by the secondary current.

AUXILIARY ANODE. The third element of the amplifier.

A. W. G. American Wire Gauge.

B. A. British Association.

B. and S. W. G. Brown and Sharpe Wire Gauge.

B. W. G. Birmingham Wire Gauge.

B. X. Metal tubing containing twin conductors each insulated from the other and both wires wrapped so as to completely fill the tubing.

BABBITT METAL. An anti-friction metal.

BALANCE, ELECTRIC. Wheatstone bridge.

BALANCING SET. A dynamo used in a three wire system to balance the electromotive force.

BALANCE WHEEL. A fly wheel; a wheel added to machines to prevent too sudden variations in speed.

BALL AND SOCKET JOINT. A joint in which spherical object is placed within a socket made to fit it.

BALL BEARING. A bearing whose journal works upon a number of metal balls and thus reduces friction.

BALLISTICS. The science dealing with the velocity, path and impact of projectiles.

BALLISTIC GALVANOMETER. A galvanometer used for measuring short duration currents. Used for measuring a condenser discharge.

BAR MAGNET. A straight bar of steel with both ends magnetized.

BAROMETER. A meter for measuring the pressure of the atmosphere.

BARS, COMMUTATOR. The bars of copper or bronze, making up the segments of a commutator of a dynamo or motor.

BARRETTER. A thermal detector.

BASE PLATE. The plate used as a foundation.

BATTERY. A combination of elements for the production of storage of electrical energy.

BATTERY, DRY. An open circuit battery containing solified zinc oxychloride of gelatinous silica.

BATTERY GAUGE. A small galvanometer for testing batteries and connections.

BEARING. The support on which the moving part of a machine rests.

BEARING SURFACE. The surface of bearing parts which are in mutual contact.

BEAUMES HYDROMETER. A hydrometer named after its maker; used to measure liquids lighter than water.

BED PIECE. The frame carrying a dynamo or motor.

BERNE BUREAU. Bureau of the International Telegraph Union at Berne, Switzerland.

BICHROMATE CELL. Two carbon plates immersed in a solution of sulphuric acid, bichromate of potash and water.

BIFURCATION. Spreading into two branches.

BILLI CONDENSER. A variable tubular condenser.

BINDING POSTS. Metal fixtures fitted to receive the ends of wires and thus make electrical contact.

BISMUTH. One of the elements that is a conductor of electricity.

BOARD OF TRADE UNIT. An English standard, 1,000 watt hours, equal to one and one-third horse power; written B. O. T.

BLIND FLANGE. A plate used to cover an orifice.

BLUE STONE. Crystallized copper sulphate.

BOLOMETER. An apparatus similar to Wheatstone Bridge.

BORE. The interior diameter of a cylinder.

BOOSTER. A dynamo used to raise the pressure of another dynamo.

BRADFIELD INSULATOR. A leading-in insulator; an ebonite tube fitted with ebonite spark discs made to prevent rain running down and making a ground connection.

BRASS. An alloy of seven parts copper and three parts zinc.
BRAZING. The process of joining metals together.
BRAZING METAL. An alloy of tin and zinc.
BREAKER. A switch or other device for opening a circuit.
BRONZE. An alloy of copper, tin and lead.
BROWN AND SHARPE GAUGE. A wire gauge of American standard.
BRUSH. A rod of carbon held in a holder and pressed against the commutator.
BRUSH HOLDER. An adjustable clamp into which the brushes are fixed and then held against the commutator.
BRUSH, WIRE. A brush made of rolled wire gauze.
B. T. U. British Thermal Unit.
BUFFING WHEEL. A wheel covered with leather and mounted so it can be rotated; used for polishing.
BUS BAR. A heavy copper conductor used on distribution boards.
B. W. G. Birmingham Wire Gauge.
CABLE—A heavy electrical conductor highly insulated.
CALL BELL. A bell used to attract the attention of the person called.
CAM. A revolving disc rotated on a shaft or spindle and shaped to give a variable motion to the driven element.
CAM FRICTION. The friction between the cam and the element it actuates.
CANADA BALSAM. A gum used in cementing lenses. Obtained from balsam fir.
CAPACITY. The extent of space; power of containing.
CARRYING CAPACITY. The capacity of an electrical conductor to carry current without overheating.
CARBON. One of the elements; exists in three forms—charcoal, graphite and diamond. It is used as an electrical conductor, for arc lamps and incandescent lamp filaments. The carbons used for arc lamps generally have a core of soft powder carbon.
CARBORUNDUM. An artificial silicate of carbon produced under very high temperature; often used as crystal detector.
CARTRIDGE FUSE. A safety device; fuse wire enclosed in a cardboard tube with metal ends.
CASCADE. A number of Leyden jars connected in series.
CATHODE. The terminal of an electrical circuit.
CAT WHISKER. The fine wire used on a crystal detector.
CENTIGRADE. A thermometer scale; freezing point 0°; boiling point 100°.
CENTIMETER. Unit of length, 0.3937 inch.

CENTRAL STATION. A point from which current is sent out.

CENTRIFUGAL FORCE. The force which draws a body constrained to move in a circular path, away from the centre of rotation.

CHARACTERISTICS OF SOUND. A, pitch; b, loudness; c, quality.

CHARGE. A quantity of electricity at rest, measured by units of quantity such as the coulomb.

CHECK UNIT. Generally called lock nut, a nut placed over another nut on the same bolt to lock the main nut in place.

CHLORIDE. A non-inflammable gas, Atomic weight 4.90. Specific Gravity 1.4.

CHOKE COILS. Coils of wire wound on an iron core sometimes called induction coils.

CHRONOSCOPE. An instrument for measuring very short intervals of time.

CIRCUIT. The path through which the current flows.

CIRCUIT-BREAKER, AUTOMATIC. A device, a circuit.

CIRCUIT, CLOSED. A circuit closed so as to give the current a continuous path.

CIRCUIT, OPEN. A circuit with its continuity broken, as by the opening of a switch.

CIRCUIT-BREAKER, AUTOMATIC. A device that automatically breaks the circuit in case of overload.

CIRCUIT, GROUNDED. A circuit where the return wire is done away with so that the earth completes the circuit, as in wireless work.

CIRCULAR MIL. Unit of area, the area of a circle whose diameter is one mil.

CLEAT. A wood, porcelain or composition support for wires.

CLOCKWISE. A machine or other device that runs in a right hand direction; that travels as do the hands of a clock.

CLOTH WHEEL. A polishing wheel.

CLUTCH. A device for engaging or disengaging two pieces of shafting.

CODE, CIPHER. A code of prearranged words, letters or signs.

CODE, TELEGRAPHIC. An alphabet made up of dots and dashes.

COIL. A series of rings or turns of wire.

COIL, INDUCTION. Built the same as a transformer; has a laminated iron core and a primary and secondary coil.

COIL, RESISTANCE. A coil of some poor conducting metal wire such as German silver. Used to offer resistance to the flow of current. A rheostat.

COINCIDE. Two or more articles that occupy the same place in space.

COLLET. A metal ring used to retain metallic packing in a stuffing box.

COMMUTATOR. That part of a dynamo which changes the direction of the current.

COMPASS, RADIO. An apparatus used to find the location of a radio transmitting or broadcasting station.

COMPOUND. A mixture of two or more elements.

COMPOUND WOUND GENERATOR. A dynamo giving a constant electromotive force, on account of having its field magnet winding partly in shunt with current generated.

CONDENSER. An appliance for storing up electrical energy, made of a number of thin sheets of tin foil laid on top of each other and separated from each other by an insulator. Condensers in multiple will increase the total capacity. Condensers in series will decrease total capacity.

CONDENSER, ADJUSTABLE. A condenser, part of which may be cut in or out of the circuit, thus varying its capacity.

CONDUCTANCE. The conducting property of any material.

CONDUCTOR. Anything that will permit the passage of electricity—a wire.

CONDUCTIVIT -. The reciprocal of the ohm. Unit is the Mho, (Ohm written backwards).

CONDUIT. A metal pipe through which electrical conductors are run.

CONTACT, ELECTRIC. A contact between two conductors giving a continuous path for the current.

CONTACT BREAKER. Any appliance for quickly opening or closing a circuit.

CONSTANT LOAD. A load whose pressure is steady and invariable.

CONTINUOUS. Uninterrupted, without break or interruption.

CONTINUOUS CURRENT. Direct current. A current that always runs in the same direction. The opposite to alternating current.

CONTINUOUS WAVES. Waves whose amplitude are constant. Waves produced by frequency multiplying transformers.

CONVERTER. An electric machine or apparatus for changing the potential difference of an electrical current.

COPPER. A metal; one of the elements; a good conductor of electricity.

CORE. The iron centre of a transformer, on which the primary and secondary coils are wound.

CORE DISCS. Thin metal discs used in building up armature cores, etc.

COTTER PIN. A headless split pin.

COUPLING WAVES. The two waves produced by coupling the oscillating circuits.

CORROSION. Chemical action which causes destruction of metals, usually by oxidation or rusting.

CORRUGATED. Formed with a surface consisting of alternate valleys and ridges.

COULOMB. The practical unit of quantity of electricity. It is the quantity passed by a current of one ampere intensity in one second.

COUNTER CLOCK WISE. A machine that runs from right to left, the opposite direction to the hands of a clock.

COUPLING. The connection of two oscillating circuits.

CRATER. The depression that forms in the positive carbon of a voltaic arc.

C. P. Abbreviation for Candle Power.

CRYSTAL DETECTOR. A detector using a crystal and thin metal wire to rectify a number of oscillations.

CURRENT. A current of electricity is supposed to flow from the positive pole of a generator, through the various appliances in the circuit and back to the generator through the negative pole. The unit of current strength is the ampere.

CURRENT, ALTERNATING. A current that is continually changing both its strength and direction. A current that changes its flow of direction so many times a second according to the construction of the alternator. These changes are called cycles.

CURRENT, DIRECT. A current that always flows in the same direction. The opposite to Alternating Current.

CURRENT FREQUENCY. The number of times alternating current changes its flow of direction in a second. These changes are called cycles.

CURRENT, INDUCED. A current produced in a conductor by induction.

CURRENT, NEGATIVE. The current which deflects the needle to the left in a single needle telegraph system.

CURRENT, POSITIVE. The current which deflects the needle to the right in a single needle telegraph system.

CURRENT REVERSER. Some appliance, generally a switch for changing the direction of a current in a conductor.

CURRENT, SECONDARY. The current induced in the secondary coil of a transformer or induction coil.

CUT-OUT. Either a fuse or a magnetic control arranged to open a circuit should the circuit be overloaded.

CYCLE. A term given to the alternation of an alternating current circuit.

DASH COIL. An induction coil for jump spark ignition.

DAMPING. The weakening of amplitude in a train of electro magnetic waves owing to resistance and radiation from an oscillating circuit.

D. C. Direct Current. (See "Current, Direct")

DEAD BEAT. Where the moving indicator of measuring instruments comes to a reading quickly, without the indicator oscillating.

DELTA GROUPING. A way of connecting up three phase windings in the form of a triangle.

DETECTOR. An apparatus that changes the oscillations received by the aerial into audible sounds.

DETERIORATION. The state of growing worse.

DEVIATION. Divergence from a course.

DIAPHRAGM. A thin iron disc in the telephone receivers which is thrown into motion by electric impulses and changes the vibrations to audible sounds.

DIELECTRIC. A non-conductor of electricity.

DIFFRACTION. The bending of electro magnetic waves around the earth's curvature.

DIMMER. An adjustable choking coil used to regulate the intensity of electric incandescent lamps.

DIRECT CURRENT. A current of uniform strength that always flows in the same direction.

DIRECT COUPLING. A coupling where the inductance coils of both currents are directly connected.

DIRECTION. The direction of an electric current is supposed to be from the positive pole to the negative pole of the circuit.

DIRECTION FINDER. See Radio Compass.

DIRECTIVE AERIAL. See Bellini Aerial.

DIRECT LOOSE COUPLING. A coupling where two inductance coils, though directly connected, are at a distance from each other, or a coupling where only a few turns are common to both circuits.

DIRECT TIGHT COUPLING. A coupling where one circuit has its inductance formed by tapping off a number of turns from the coil actually employed as inductance in the other circuit. Also called Direct Close Coupling.

DISC CONDENSER. A variable condenser with its two sets of plates composed of semi-circular inter-leafing metal vanes, separated by insulating discs or air; the whole being mounted in a circular case, one set of vanes is fixed, the other mounted on an insulated spindle is capable of being turned through an angle of 180 degrees, thereby permitting of any desired amount of interleafing of vanes; thus regulating the amount of capacity.

DISCHARGE. To dissipate electric energy from a condenser or battery.

DISTANCE SPARKING. The distance between electrodes which a spark from some source will jump.

DISTRIBUTION BOX. A metal box or cabinet containing a distribution panel together with fuses, switches, etc.

DOUBLE POLE SWITCH. A switch with two knife like blades, able to break both the positive and negative wires of a circuit.

DOWNLEAD. The wire connecting the aerial to the instruments.

DRY CELL. An enclosed battery used for open circuit work.

DUPLEX. Twofold, working two ways.

DYNAMICS. The mechanics of moving forces or motion, the reverse of static.

DYNAMO. A machine used to convert mechanical energy into electrical energy.

DYNE. Unit of force.

DYNOMETER. A meter for measuring mechanical force.

EARTH. Generally refers to a connection to the earth. An accidental grounding of a conductor.

EBONITE. Vulcanized India rubber; a non-conductor of heat and electricity.

ECONOMIZER. A step-down transformer.

EFFICIENCY, MECHANICAL. The rate between the work performed and the energy expended by the machine in performing it.

ELECTRICITY. An unknown power; a powerful physical agent which manifests itself mainly by attraction and repulsion; also by luminous and heating effects, by violent commotions, by chemical decompositions and many other phenomena. The word was first used by Dr. Gilbert in England during the Sixteenth Century.

ELECTRICS. Certain substances can be electrified by friction.

ELECTRODE. The terminal of an open electric circuit.

ELECTRODYNAMICS. Electricity in motion.

ELECTROLYSIS. The breaking up of a compound into its elements by the use of an electric current.

ELECTRIC HORSE POWER. 746 watts are equal to one unit of Electric Horse Power.

ELECTROLYTIC DETECTOR. A fine wire making contact with an electric light.

ELECTRO MAGNET. A mass of iron magnetized by winding around it several coils of copper wire. The softer the iron the more easy it is to magnetize. Hard metals retain their magnetism longer.

ELECTRO MOTIVE FORCE. Another term for electric pressure or voltage.

ELECTROSCOPE. Apparatus for detecting static charges of current.

ELEMENT. There are about seventy-five known elements. Is an original form of matter that cannot be divided into constituents by any process.

EMBOSSER, TELEGRAPH. A receiver which embosses telegraphic paper tape.

EMERGENCY APPARATUS. A second generator set that can be used in case of trouble.

EMERY WHEEL. A machine used for grinding.

E. M. F. Electro Motive Force. Voltage. Pressure.

ENERGY. Capacity of acting; energy may be mechanical, electrical, chemical, physical, etc. Unit of energy is the ERG.

ENERGY, ELECTRIC. Unit is the volt coulomb or volt ampere.

EQUIDISTANT. Placed at equal distance from the same point.

EQUIVALENT, ELECTRO-CHEMICAL. The weight of a substance set free by one coulomb of electricity.

ERG. The unit of work. The amount of energy expended in moving a body through one centimeter against a resistance of one dyne.

ETHER. A name given by Huygens to the medium that fills all space and matter.

EXCITER. A dynamo used to excite the fields of a generator.

FAHRENHEIT. A thermometer scale. Freezing point is 32°. Boiling point, 212°.

FATHOM. A measure of length; six feet.

FARAD. Practical unit of capacity.

FEEBLY DAMPTED. A train of oscillations with many complete oscillatory motions.

FEEDER. A main wire or set of wires.

FEEDER, NEGATIVE. The wire connected to the negative pole of a generator.

FEEDER, NEUTRAL. The wire connected to the middle or neutral point in a three-wire system. The wire common to both generators.

FEEDER, POSITIVE. The wire connected to the positive pole of a generator.

FIELD MAGNETS. Electric magnets that produce the magnetic field in which the armature of a generator rotates.

FIELD REGULATOR. A variable resistance.

FLATS. Commutator segments worn to a lower level than other segments.

FLAT TUNING. The considerable adjusting of tuning without altering the strength of the signals.

FLUX. A compound used in soldering.

FOOT POUND. The resistance equal to one pound moved upwards one foot.

FORCE. May be defined as the rate of change of momentum.

FREAK. The increasing or decreasing of range of signals that periodically happens to a receiving set.

FREQUENCIES, RADIO. Radio frequencies are very high, sometimes as high as 1,500,000 cycles per second.

FUNDAMENTAL WAVELENGTH. Ordinary wavelength of a circuit.

FUSE. A short length of fusable wire introduced into a circuit as a safety device.

FUSING POINT. The temperature at which metals melt and become liquid.

GALENA. A crystal sulphide of lead. When heated becomes lead sulphate. Used as a thermo-electric detector.

GALVANIZED IRON. Iron with a coating of zinc to prevent rusting.

GALVANOMETER. An instrument for measuring current strength and direction of current in a circuit.

GAP. An opening by breaking or parting.

GAP MICROMETER. A gap to protect apparatus from overloads.

GASKET. A ring or washer used for packing or insulating.

GAUGE. An instrument to measure size or capacity.

GAUZE WIRE. A pliable wire cloth made of very fine strands of wire.

GEISSLER TUBE. A vacuum tube having its electrodes in bulbs.

GENERATOR. An apparatus for maintaining an electric circuit.

GERMAN SILVER. Alloy of nickel and copper with a percentage of zinc. Used in resistance frames, rheostats, etc.
GOLD. One of the elements; a conductor of electricity.
GONIOMETER. An instrument for measuring angles.
GRAM. The unit of weight. Equal to 15.43 grains.
GRAPHIC TELLURIUM. A crystal rectifier.
GRAPHITE. A soft form of carbon, used as a lubricant.
GRAVITY. The attractive force of the earth.
GRID. A frame of wire gauze found between the plate and filament of a vacuum tube. Perforated lead plate used in storage batteries.
GRID LEAK. A form of rheostat to permit excess grid charges to escape to an external source.
GROUND. The contact of an electrical conductor with the ground or with some other conductor not in the circuit.
GROUND CLAMP. A strip of copper for making an easy and secure connection with a water pipe, etc.
GROUND WIRE. The wire leading from the aerial to the ground. The wire used as a return wire of the circuit in wireless work.
GUN METAL. A compound of nine parts copper and one part tin.
GUTTA PERCHA. The hardened juice of the Isonandra Gutta, used as an insulator.
GUY ROPES. Ropes or wires used to steady the aerial supports.
HAND OR WING NUT. A nut with flanges allowing it to be tightened by hand.
HEAT. A physical kinetic form of energy.
HELIOGRAPH. A mirror for reflecting flashes of light, generally the Sun's rays; used in signal work.
HELIX. A coil of wire.
HENRY. Unit of inductance.
HERTZIAN WAVES. Ether waves.
HIGH FREQUENCY. A current with a very great number of alternations per second.
HIGH FREQUENCY SLIDING INDUCTANCE. Two metal bars connected by a sliding brass clamp used for making final adjustment in closed oscillatory circuits.
HIGHLY DAMPED TRAIN. A train with few oscillations.
HONEY-COMB COIL. A tuning coil. A set of three coils—primary, secondary and tickler; the primary coil being placed between the other two.
HORSE POWER. A unit of rate of work. Equal to the raising of 33,000 pounds one foot in one minute. Equal to 746 watts.

HORSE POWER HOUR. One horse power exerted for one hour.

HORSE SHOE MAGNET. A steel bar shaped like a horse shoe with its ends magnetized.

HUMIDITY. The dampness in the atmosphere which varies with the temperature.

HYDROELECTRIC GENERATOR. A generator driven by a turbine.

HYDROMETER. An instrument used to test the specific gravity of a fluid. Used for testing the discharge of storage batteries.

HYPOTHESIS. Taken for granted. Assumed for the purpose of argument.

HYSTERESIS. A reluctance when a change of condition is taking place in a circuit.

IMPEDANCE. The total opposition of a circuit, due to reactance and resistance to a varying circuit.

IMPEDANCE COIL. Another name for induction coil, an iron core around which is wound a coil of wire.

INCANDESCENCE, ELECTRIC. The heating of a conductor to a white heat.

INCH. The twelfth part of a foot. A measure of length.

INCLINATION. A tendency from the true horizontal or vertical direction, as in the case of the compass needle.

INDUCTANCE. The induction of a current in a non-electrical body from an electrified or magnetized body, without metallic or electrical connection.

INDUCTION COIL. A transformer; an apparatus for changing low voltage to high voltage.

INDUCTIVE COUPLING. The coupling of two oscillatory circuits by arranging the inductance coil of one circuit into the lines of force of the other circuit.

INDUCTIVE LOOSE COUPLING. A coupling without metallic contact and where the inductances are well apart.

INDUCTOR. A step-down transformer.

INERTIA. Property of matter at rest.

INSULATING TAPE. A prepared tape to cover and insulate ends of wires when making joints, etc.

INSULATOR. Any material that will not allow the passage of electricity through it, except under very great pressure.

INTENSITY. The strength of a current, expressed in amperes.

INTERFERENCE. Where more than one set of electro magnetic waves arrive in such a manner as to nullify each other.

INTERMITTENT. Acting at intervals.

INTERSECTION. The place where two wires cross each other.
INVERTED "L" AERIAL. An aerial that is tapped at one end by the lead in wire.
IRON. A metal; one of the elements.
JAMMING. QRM. Interference from other stations.
JIGGER. An oscillation transformer.
JOULES. Unit of electrical work. Volt coulomb.
JOURNAL. That part of a shaft or spindle which rotates in the bearings.
KEY TRANSMITTER. An easily controlled switch which allows the operator to rapidly make and break the primary circuit.
KILOWATT. One thousand watts. Written K. W.
KNIFE SWITCH. A switch with knife like blades, used on circuits carrying high amperage.
LAG SCREW. A wood screw with a square head.
LAMINATED. Made up of a number of fine sheets.
LATERAL FORCE. Force proceeding from the side.
LAW OF MAGNETISM. Like poles repel one another. Unlike poles attract each other; positive pole attracts negative, etc.
LEADING-IN INSULATOR. An insulation tube used in the walls or roof through which the lead-in wi e from aerial runs.
LEAKAGE. A loss of current due to oor insulation or other causes.
LENZ LAW. An induced current always tends to stop the current which produces it.
LEYDEN JAR. A static condenser.
LIGHT. Light waves travel at the same rate of speed as electro magnetic waves; 186,000 miles per second. Light is merely ether vibrations.
LIGHTNING ROD. A metal rod connected with the earth, used on buildings as a safety device.
LINES OF FORCE. Imaginary lines showing the direction of attraction and repulsion in a field of force.
LINK FUSES. A link of fusable metal, introduced into the circuit as a protective device.
LOADING COIL. A single slide, tuning coil.
LOCAL CURRENTS. Currents within the metal parts of a generator.
LOCK NUT. A nut placed over another nut on the same bolt to hold the original nut in place. A check nut.
LODESTONE. An iron ore which possess the properties of a magnet. Also known as Magnetite.

LOG DECREMENT. The hyperbolic log of reciprocal of the ratio of the first amplitude to second amplitude in a train of waves.
LOOP AERIAL. A frame around which several turns of wire are wound.
LOOSE COUPLING. A coupling without metallic contact or where the inductances are well apart.
LOST MOTION. The motion in a machine that produces no useful results.
LOW FREQUENCY. A current whose alternations are low per second.
LUBRICANT. Anything used to help diminish friction between two or more working parts; like oil, graphite, etc.
LUGS. Metal wire terminals.
MAGNET. A piece of iron or steel that has the property to attract or repel other pieces of metal.
MAGNET COIL. The coil over an iron core in an electric magnet.
MAGNETIC FIELD. The field or space over which the magnet exerts its influence.
MAGNETIC FLUX. The lines of force which flow from a magnet; magnetic induction.
MAGNETIC FORCE. Force at any point in a magnetic field.
MAGNET HORSE SHOE. A bar of steel shaped like a horse shoe with both ends magnetized.
MAGNETIC LIMIT. The temperature beyond which a metal cannot be magnetized.
MAGNETIC SELF INDUCTION. A magnet tends to repel its own magnetism and weaken itself by self-induction.
MAGNETITE. A natural magnetic iron ore. Lodestone.
MAGNETO. A small generator.
MAKE AND BREAK CURRENT. A current continually broken and started again as is the action in an induction coil.
MALLEABLE. Capable of being worked into shape.
MANGANESE BRONZE. An alloy of copper, tin and ferromanganese ore.
MANGANESE STEEL. An alloy of steel and metal manganese.
MARCONI FILINGS COHERER. A glass tube containing fine metallic filings used as a detector.
MEGAPHONE. An instrument used to help make the voice audible at a distance.
MEGOHM. One million ohms.

MERCURY. A metallic element liquid at ordinary temperature; also known as quicksilver.
METER VOLT. An instrument for measuring the pressure or voltage of a circuit. Connected in multiple on your line.
METER AMPERE. An instrument for measuring the flow of current.
METER WATT. An instrument for measuring the wattage. Volts times amperes.
MHO. Unit of Conductivity. The word ohm spelled backwards.
MICA. A mineral more or less transparent and used as an insulator.
MICANITE. A manufactured insulator made of mica.
MICRO. One millionth.
MICROFARAD. Unit of capacity.
MICROHM. One millionth of an ohm.
MICROMETER. An instrument for measuring small distances like the thousandth or ten thousandth part of an inch.
MICROMETER SPARK GAP. An adjustable spark gap used in the aerial circuit.
MICROPHONE. An apparatus to magnify sound.
MIL CIRCULAR. A unit of area. The area of a circle whose diameter is one mil.
MIL FOOT. A unit of resistance. A wire one foot long with a diameter of one mil.
MILLIMETER. A unit of length. One thousandth part of a meter.
MINIMUM. The least quantity.
MOLECULE. The smallest part of an element that can exist alone.
MOLYBDENITE. A sulphide of Molybdenum. Used as a detector.
MORSE RECEIVER. A receiver named after S. F. B. Morse.
MORSE INKER. An instrument that records the received message on a traveling paper tape.
MOSCISKI CONDENSER. A condenser in the form of a glass tube with a metal foil coating.
MOTOR. A machine to convert electrical energy into mechanical energy.
MOTOR GENERATOR. A combined motor and generator; a generator driven by a motor.
MOTOR SERIES. A motor whose armature windings and field windings are in series.
MULTIPLE. Multiple connection is that in which each lamp draws its supply direct from the mains and is not de-

pending on any other lamp or set of lamps for its supply. Lamps in parallel with each other. The opposite to series.

MUTUAL INDUCTION. The introduction of an electrical pressure in a circuit, by another circuit not directly connected to it.

NATURAL CURRENTS. Earth currents.

NATURAL WAVELENGTH. The natural length of wave produced by the aerial's own capacity and inductance.

NEGATIVE. The opposite to positive. The pole to which the current seems to flow.

NEGATIVE CHARGE. One of the two electric charges, the opposite to positive.

NEUTRAL WIRE. The middle wire of a three wire system. The wire that is common to both dynamos.

NICKEL SILVER. An alloy of nickel, copper and zinc. German silver used in making resistance coils.

NICKEL STEEL. Steel with the addition of a small percentage of nickel.

NON-CONDUCTOR. Any material that will not conduct electricity.

NON-INDUCTIVE CIRCUIT. A circuit possessing a very small inductance.

NOTCH WIRE GAUGE. A gauge with notches for measuring wire.

OHM. Unit of electrical resistance. The resistance offered by a column of pure mercury, 106.3 centimeters in length by one square millimeter in cross section at a temperature of zero centigrade.

OHM'S LAW. The fundamental principle on which all electrical mathematics are worked. The current in amperes is equal to the voltage divided by the resistance in ohms. The resistance is equal to the voltage divided by the current in amperes. The voltage is equal to the resistance in ohms times current in amperes. Thus with two known quantities you can always find the third unknown.

OHMIC RESISTANCE. True resistance.

OSCILLATING CURRENT. An alternating current of high frequency.

OSCILLATOR HERTZIAN. A device for producing oscillations.

OSCILLATORY INDUCTION. Induction produced by action of an oscillatory discharge.

PAPER CONDENSER. A condenser made with tin foil and paraffin paper.

PARTITION INSULATOR. A leading-in insulator.

PERIOD. Time required to produce and complete one wave; time required to complete one cycle of an alternating current circuit.
PERIPHERY. The circumference of a circle.
PERMANENT MAGNET. A magnet that will retain its magnetism away from the source of magnetism.
PHENOMENON. An unusual occurrence.
PHONETRON. A trade name for a type of amplifying telephone receiver. Consists of an enclosed electro-magnetic solenoid producing an annular field in which an armature coil is suspended from the apex of a conical diaphragm. The magnet requires a current of 2½ amperes at a pressure of 6 volts.
PHOSPHOR BRONZE. A very hard alloy of copper, tin and phosphorus.
PLUNGER. A movable core used with a solenoid to be drawn in an oil bath when the coil is excited.
POLARITY. Pertaining to the poles of a circuit; the positive and negative.
POLARIZATION. The changing of a voltaic cell by depriving it of its proper pressure.
POLYPHASE. More than one phase. Multiphase.
POSITIVE POLE. The pole from which the current is supposed to start on its journey around the circuit.
POTENTIAL. The pressure of an electric charge.
POTENTIOMETER. An arrangement for determining potential difference.
POUNDAL. British unit of force.
POWER. Activity; rate of doing work.
PRIMARY COIL. The coil of a transformer that is connected to the source of supply.
PRIMARY COLORS. Red, yellow, blue.
PRIMARY POWERS. Water power; wind power; tide power; power of combustion; power of vital action.
PRIMARY TUNING INDUCTANCE. A variable inductance in the primary closed oscillatory circuit.
PROPAGATION. The traveling of electro-magnetic waves over the earth's surface.
PROTECTIVE ROD. A carbon rod of high resistance connected into the circuit as a safety measure.
PYROMETER. A meter for measuring excessive heat.
QUADRANT. A quarter of a circle; an angle of 90 degrees.
QUARTZ. A hard rock of native silica.
QUENCHED SPARK. A spark gap made of a series of metal plates insulated from each other.
QUICKSILVER. Mercury; a liquid metal.

RADIAL. Spreading from a centre.
RADIATION. The transmission of ether waves through space.
RADIATING CIRCUIT. The aerial circuit.
RADIO TELEPHONY. Transmission of speech by electro magnetic waves.
REACTANCE. The opposition offered to the flow of current by back electro motive force, etc.
REACTANCE COIL. An adjustable iron core around which is wound a coil of wire.
REACTION. Inverse action.
RECTIFIER. An apparatus for changing alternating current to direct current.
REFRACTION. The change in direction or bending of the electro magnetic waves.
REGENERATIVE CIRCUIT. A reactionary circuit.
RECEIVING DETECTOR. A device to change the characteristics of incoming oscillations so as to make them audible.
RECEIVING TUNER. An oscillation transformer which allows the operator to receive electro magnetic waves of different lengths.
RELAY. An instrument consisting of an electro-magnet which actuates upon receiving a current and in actuating opens and closes a circuit.
RELUCTANCE. The resistance offered to the flow of lines of magnetic force.
RESISTANCE. That property of an electrical conductor which tends to oppose the flow of current over it. Everything in a circuit offers resistance to the flow of current.
RESISTANCE BOX. A box filled with resistance coils connected in series with each other; a resistance frame.
RESISTANCE, OHMIC. True resistance.
RESISTANCE, SPURIOUS. Counter electric motive force.
RETARDATION. A retarding of the rate of transmission of signals.
RESONATOR. A sound box.
RETENTIVITY. Coercive force.
RHEOSTAT. An instrument used to offer resistance to the flow of current. Made of a number of metal coils (German silver or iron) connected together in series and mounted on a frame from which the coils are insulated.
RHUMKORFF COIL. An induction coil.
ROTARY. Turning on an axis—rotating.
RUBBER COVERED WIRE. A cable either solid or stranded

with a rubber covering and an outer protective covering of cotton braid.

SAL AMMONIAC. Ammonium chloride.

SECONDARY COIL. The coil of a transformer into which the current is induced.

SERIES. An electrical connection where lamps are connected so that they depend one on the other for supply, the current passing through each lamp successively. The opposite to multiple.

SET COLLAR. A ring used on a shaft or spindle to prevent end play.

SEXTANT. An instrument used on board ship to measure angles.

SHEET METAL GAUGE. A gauge to measure the thickness of metals.

SHELLAC. A gum gathered from trees in India used in radio and electrical work in the form of a varnish. An excellent insulator.

SHORT CIRCUIT. Two wires of opposite polarity coming in contact with one another without any controlling device.

SHUNT. A shunt for the receiving relay consisting of the coils of an electro magnet.

SHUNT WINDING. A system of winding where the armature winding is in parallel with the field winding.

SILICON. A mineral. Used as a detector.

SINGLE PHASE. Using only two wires and one electromotive force; sometimes called monophase.

SIXTY CYCLE A. C. This is when the current changes its flow of direction sixty times a second. This frequency is used a great deal for lighting and power purposes.

SLIDING FRICTION. The friction that exists between moving parts in sliding contact with each other.

SLIP RINGS. Two rings on an alternator that take the place of a commutator on a direct current dynamo.

SOLENOID. An electro magnet without the iron core.

SPARK COIL. An insulated wire wound around an iron core, used for producing a spark from a source of low pressure.

SPARK GAP. The space between the ends of an electric resonator across which the spark jumps.

SPECIFIC GRAVITY. The density of a solution against that of another, using water as a standard.

SPECIFIC RESISTANCE. Resistance of any material having a cube of one centimeter.

SPIRAL WINDING. The system of winding used on a ring armature.

STAGE CABLE. A cable containing twin conductors each insulated from the other and the whole covered with a composition covering.

STAND-BY. A position of tuning, allowing the reception of waves of various lengths. QRX.

STANDARD CELL. The Weston Cell is now used as the standard.

STARTING BOX. An adjustable resistance to regulate the flow of current when starting up the motor.

STATIC. Atmospheric disturbance.

STATIC CHARGE. An electric charge at rest.

STATIC LEAK. A coil of wire used in the aerial circuit of tuner to allow atmospherics to leak to earth.

STATIC TRANSFORMER. A transformer without moving parts.

STATOR. The stationary part of an induction motor or generator.

STEEL. Iron hardened by the addition of carbon and manganese.

STEP DOWN TRANSFORMER. A transformer that steps down the voltage and raises the amperage; has a greater number of turns of wire in primary than in secondary.

STEP UP TRANSFORMER. A transformer that steps up the voltage and lowers the amperage; has a greater number of turns of wire in the secondary than in the primary.

STORAGE BATTERY. An accumulator. A number of cells for the storage of electricity.

STORAGE CAPACITY. The number of ampere hours that can be got from a storage battery.

SULPHATING. The formation of a lead sulphate in storage batteries. May be overcome by prolonged charging.

SULPHURIC ACID. A compound of sulphur, hydrogen and oxygen.

SWITCH. A device for opening or closing a circuit.

SWITCH BOARD. A board to which the mains are led connecting with bus bars, fuses and switches.

SWITCH, DOUBLE POLE. A heavy switch that disconnects or connects two leads simultaneously.

SWITCH, KNIFE. A switch with knife like blades used on circuits carrying high amperage.

SWITCH, SNAP. A small switch made to give a sharp break used on house lighting circuits, etc.

SWITCH, THREE WAY. A switch so constructed that by turning its handle connection can be made from one lead to either of two other leads and also so that connection can be completely cut off.

SYNCHRONOUS. Simultaneous; to correspond in time.

SYNCHRONOUS MOTOR. A motor which runs in synchronism with the alternating current supply.

"T" AERIAL. An aerial where the horizontal span is tapped in the middle by the lead-in wire; thus forming a letter T.

TELEFUNKEN. German name for radio telegraphy.

TERMINAL LUGS. Metal terminals for ends of wire used so that good and quick connection can be made.

TESLA COIL. An oscillating transformer.

THERM. A unit of heat.

THERMAL DETECTOR. A detector which acts by heat energy.

TOGGLE JOINT. An elbow joint.

THREE WIRE SYSTEM. A system of distribution of electrical current where three wires instead of two sets of two wires are used. The middle or neutral wire acts as a positive for the one side and of the system and as the negative for the other side. The advantage of the system is the saving of copper.

TICKLER COIL. A coil in the circuit of a vacuum tube receiver to transfer a part of the oscillating plate current energy into the grid circuit to enable the vacuum tube to generate oscillations of high frequency. It is coupled to the secondary of the oscillation circuit. An inductance coil.

TONE FREQUENCY. Spark frequency.

TRANSFORMER. An apparatus used on an alternating current circuit to either raise or lower the voltage. Made of two coils of wire named the primary and the secondary coils and a laminated iron core. The coils are insulated from the core and from each other. The current enters the transformer through the primary coil and sets up a magnetic flux around the core; the secondary coil cuts the lines of magnetic force and thus a new current is induced in the secondary.

TRANSFORMER COILS. The two coils in a transformer; primary and secondary.

TRANSFORMER CORE. A core made up of thin iron plates laid one on top of the other.

TRANSMITTER. An instrument used to produce sounds to be transmitted.

TRANSVERTER. A trade name for a motor generator.

TUNING. The process of securing the maximum indication by adjusting the time period.

TWO PHASE. An alternating current system of electrical distribution making use of two currents of different phase. Can be arranged with either three or four wires.

UNIPOLAR DYNAMO. A dynamo where one part of the conductor slides around the magnet.

ULTRAUDION. An audion used in a circuit having a type of energy coupling so that a powerful relay action may be obtained. Its elements are connected in two circuits so arranged that the energy coupling may be obtained through a bridging condenser in its plate filament circuit.

VACUUM. A space destitute of all substance.

VACUUM TUBE. The name given to the highly exhausted glass tube containing three elements. Used for detector in radio work.

VALVE AMPLIFIER. Audion type vacuum tube containing three electrodes.

VALVE TUNER. A tuner used with a valve detector.

VARIABLE CONDENSER. A condenser which allows of easy and quick adjustment.

VARIO COUPLER. A device for varying the inductance in a circuit. The primary and secondary coils are connected magnetically but not electrically.

VARIOMETER. A device for varying the inductance in a circuit. Made by connecting two inductances in series.

VARLEYS CONDENSER. A static condenser.

VELOCITY. The rate of motion of a body.

VIBRATION PERIOD. In electrical resonance the period of a vibration in an electrical circuit.

VOLTAGE. Electric motive force or pressure.

VOLTMETER. An instrument used to measure the pressure of a circuit.

VULCANITE. Vulcanized India rubber.

WATT. The practical unit of electrical power. Amperes times voltage.

WATT HOUR. Watts times length in hours. One watt expended for one hour.

WATT MINUTE. One watt expended for one minute.

WATT SECOND. One watt expended for one second.

WAVE CHANGER. A transmitting switch to change from one wave length to another.

WAVES, ELECTRO-MAGNETIC. Ether waves due to electromagnetic disturbances.

WAVE LENGTH. The distance covered by a wave from the transmitting station before the next successive wave starts.

WAVE TRAIN FREQUENCY. The total number of waves being produced or received per second.

WAVE METER. An instrument to measure wave lengths.

WIRE GAUGE. A gauge for measuring the diameter of wires.

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