A POPULAR GUIDE TO RADIO

By

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FAMOUS ANNOUNCERS OF IMPORTANT EVENTS—GRAHAM MCNAMEE (SEATED) AND PHILLIPS CARLIN

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PREFACE

The purpose of this book is to furnish a complete radio guide or manual, in which the functions of the modern radio receiving and transmitting circuits, and associated fundamentals of electricity and magnetism, are explained in non-technical terms. Related subjects and other useful information are included, which makes the work not only a popular but practical presentation of the science of radio.

While a chapter has been devoted to each of the important phases of radio operation, there have also been incorporated other features of value to those interested in radio. One such feature is to be found in the text describing rather completely information on obtaining radio patents. The subject of correlation between radio communication and the effect of natural phenomena, such as weather, has been gone into rather extensively. While this subject has seldom been referred to, even briefly, in other works, the time has come when the meteorological aspects of the radio communication situation must be recognized by the radio student.

In certain parts of this text valuable assistance has been given by Mr. S. Jay Teller, Patent Attorney; the Burgess Battery Company; the Raytheon Company; the National Broadcasting Company; the Radio Corporation of America; the Hammarlund Mfg. Co.; and the Kodel Radio Corporation, to whom due credit is hereby given.

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CHAPTER I

THE DEVELOPMENT OF RADIO

Radio is a comparatively new science. Many developments are based upon one or two fundamental laws of nature. Radio involves a wide variety of scientific studies. Magnetism, electricity, sound, light, mechanics, meteorology, terrestrial and atmospheric phenomena, are all interwoven to make possible this great form of communication. That every radio set owner and operator may be able to grasp the fundamentals of radio transmission and reception, it is necessary to understand at least the rudiments of the basic sciences. Every one interested in radio should have this fundamental knowledge of the art.

Wire communication, such as the telegraph or the telephone, is a visible means of conducting electric current from place to place. Transmission is direct, no great amount of energy is thrown away in transmitting signals to unnecessary places, and it is private. Radio is quite different. Space, sometimes called the ether, is the medium through which the signals are transmitted. Energy must be sent through space without an actual conductor. This energy is sent forth as a wave that travels with the speed of light. Such a wave, radiating in all directions from the point of emission, is called an electromagnetic, or radio wave.

Because of its widespread applications to commercial and home life, radio plays a highly important part in the world of today, and no one should be without a general conception of its development and fundamentals of operation. It is based primarily on electricity and, while nearly all of us are familiar with electricity in its general applications, we know much less of its functions in our radio receivers. It is the desire to present here, in terms easily understood, the latest accepted knowledge of radio transmission and reception, and related phenomena. Underlying principles, with the help of drawings, diagrams and photographs, have been set forth for ready grasp by those who may not be acquainted with technical and scientific terminology. The definite phenomena influencing and connected with radio have been explained in individual paragraphs, as far as practicable. However, no arbitrary attempt entirely to segregate each subject has been made, since the various subjects are all more or less related.

Attempts were made, more than a score of years ago, to signal at a distance by electromagnetic waves, or induction, without the medium of wires. It is well known that when an electric current changes its direction of flow through one wire, a current will be induced in another wire parallel to the first. And now this simple principle of electromagnetic induction is so enlarged in its scope, that radio waves may be propagated around the earth at the rate of seven times in one second.

The growth of the present day system of radio transmission and reception has been such that it is unfair to credit its complete development to one person or group of persons. As is the case with all gradual developments covering so many branches of science, one mind provides the rough idea, another improves it, while others, as soon as the general possibilities of the idea are unfolded, assimilate and bring it to a high state of efficiency. So it has been with radio. We see in it an art of still greater possibilities, to be studied and improved upon by countless investigators. Our present knowledge of radio is imperfect. There are many strange things that even the keenest mind cannot explain with satisfaction.

Nobody actually invented radio. The theory has been known for a long time. Many inventors have been, and still are, working on the theories of radio. In the early days of wireless several different systems came into existence at about the same time. However, *Guglielmo Marconi*, an Italian scientist, is known as the inventor of wireless, and much credit is justly due Marconi.

Prior to 1867 some scientists believed in the electromagnetic theory of light, but it was not until then that the theory was seriously advanced by *Maxwell*. He later predicted the existence of electromagnetic waves such as are now used in radio work. The discovery by *Hughes* in 1879 that metal dust could be made to cohere by the action of an induced electromagnetic current, was perhaps one of the first steps in wireless development. Still later, in 1887, the honor fell upon *Hertz* actually to demonstrate that electromagnetic waves could pass through space. He was able to show this by using an electric oscillator for setting up the waves, and a resonator for detecting them. While this detection distance was but a few feet, it was sufficient to demonstrate the possibility of transmission, provided a sensitive enough detector could be found.

Several other investigators worked for nearly a decade longer until, in 1896, Marconi, whose investigations led him to the conclusion that the waves discovered by Hertz could be utilized for telegraphing without wires, filed his application in England for the first patent for wireless telegraphy. He successfully conducted experiments in communicating a distance of two miles. In the following year Marconi established communication over a distance of four miles, and still later over a distance of ten miles between ship and shore stations. The iron dust cohering principle discovered by Hughes was first used by Marconi for the detection of signals, but later he developed a magnetic detector. In 1898 and 1899 the first practical applications of wireless telegraphy were put into effect, and, during maneuvers of British warships, messages were exchanged up to a distance of about 85 miles. These applications continued in several countries with increasing success until 1902 when spark stations of considerable power were built in America and England. On December 17, 1902, the first message was transmitted across the Atlantic, and on January 19, of the following year, President Roosevelt and King Edward exchanged felicitations.

The United States Weather Bureau early saw that wireless transmission could benefit navigation, as storm warnings and ocean weather forecasts could be furnished ships at sea. Accordingly, experiments began under the direction of *R. A. Fessenden,* and the Weather Bureau became the pioneer Government agency in the investigation of wireless telegraphy. In 1904, President Roosevelt put this governmental wireless work under the control of the Navy Department where it has remained. Since that time important advances in the art were made, and such men as *John Stone, Lee De Forest, Ambrose Fleming, F. A. Kolster, Poulsen, Shoemaker, E. H. Armstrong, L. A. Hazeltine,* etc., were granted patents on wireless apparatus and communication methods.

When *Dunwoody* and *Pickard* discovered the rectifying properties of carborundum and silicon crystals in 1906, great advances in receiving distances were made, as these types of detectors proved to be much more sensitive than any other kind developed. In 1908 Fessenden began experiments with high frequency transmissions and succeeded in establishing telephonic communication over a distance of about 600 miles. This was the beginning of radiophone transmission, but the systems were crude as compared to present day radiophone stations.

The first great practical demonstration of wireless came in 1909 when the *S. S. Republic* collided with the *S. S. Florida* off the coast of New England. Assistance was successfully called by wireless and all of the passengers and crew were saved. The following year saw an act passed by the Congress of the United States compelling American vessels to carry wireless apparatus and operators. Since then radio has saved many lives and much property at sea.

Experiments in radio telephony were carried on with success during 1914 and clear communication was established between distant points. The experiments were repeated over land and excellent results were obtained. Later, radiophone communication was established between Washington, Paris and Hawaii.

A patent was issued to E. H. Armstrong covering his feed-back or regenerative circuit. This circuit revolutionized radio telegraph and telephone reception. But in a recent patent case it was held that Lee De Forest also was an inventor of the oscillating tube receiving circuit, and thus has been brought about some interesting radio patent litigation. Suits and counter-suits relative to radio have been in progress for years, and for that reason the radio experimenter has been given a short résumé of patent procedure in this volume.

In 1904 Dr. Fleming was awarded a patent on thermionic valves, the forerunner of the modern electron tube. In 1918 particular impetus was given radio by the continued development of the electron tube as an efficient rectifier and generator of undamped or continuous wave oscillations.

As far back as 1877, *Emile Berliner* was working on his voice and sound transmitter now known as the microphone, which is one of the most important parts of the broadcasting station. The inventor of television and phototelegraphy in America, *C. Francis Jenkins*, has now adapted his invention for use with radio, and pictures are sent instantly over great distances. The transmission of motion pictures, or even photographs of events as they happen is but a step further. Actual experiments are being conducted, and it will not be long before such transmissions will be possible.

The World War rapidly expanded and developed radio. Governments were forced to develop experiments which would aid their activities and, with the close of the war, much talent and equipment were available for further experimentation. The development of the regenerative circuit, and the subsequent presentation of the neutralized tuned radio frequency or neutrodyne nonradiating receiver, by *L. A. Hazeltine*, hastened the use of radio receiving sets by the public for entertainment purposes. Broadcasting stations rapidly sprang into existence until the entire country was covered. Since that time the broadcasting of programs by radio has been a matter of widespread interest. Today the estimated number of families owning radio receiving sets runs into millions, while approximately 750 broadcasting stations are now operating.

The duplication of broadcasting stations has, indeed, threatened the development of the art; so, since 1912, the Government has imposed necessary regulations. Operating wave lengths have been assigned and the number of stations in congested regions limited. Some of the restrictions were lifted in 1926 with the result that congestion and interference became quite serious. Such a condition was not long tolerated, and the 69th Congress, early in 1927, passed legislation to correct the difficulty.

The President of the United States then appointed a Radio Commission of five members to take charge of the radio situation and to regulate it. As long as the Government exercises its control over American broadcasting the public will be assured of the development of radio, and better broadcasting and receiving conditions. There need be no alarm that radio as a form of entertainment will be short-lived or that confusion will exist for more than short periods at a time. Radio broadcasting is a fixed form of American social and commercial life.

The technical developments of radio are much more stable and the preferences of the public for radio programs and radio apparatus are better understood. Greater distances are now consistently covered, and programs are furnished to homes that hitherto have been isolated and out of reliable radio reception range. Many stations now broadcast some feature simultaneously by interconnection methods using long distance telephone wires, and millions of people may hear what is going on at some place thousands of miles away. Radio instruments have recently undergone a vast improvement, but there must continue to be a great period of development, the length of which we cannot predict.

CHAPTER II

A STUDY OF ELECTRICITY AND MAGNETISM

ELECTRICITY. What do we mean by *electricity?* How often this question has been asked as we wonder at its marvelous powers! It is quite impossible to give electricity other than a general definition. Electricity is a material *agent* having a form of *energy* which, when in motion, manifests itself by magnetic, chemical and thermal effects. When at rest, it is accompanied by an effect of potential energy. Whether in motion or at rest, it is of such a nature that, when present in two localities within the limits of association, there is a mutual interaction of its forces between the two localities. These effects are the only manifestations of the presence of electricity.

MANIFESTATIONS OF ELECTRICITY. Electricity manifests itself either as an *electric charge* or an *electric current.* When we have a charge of electricity we have electricity at rest and it is then termed *static electricity,* and it has certain properties. When we have an electric current we have electricity in motion, with certain additional properties. While the sources of static electricity differ essentially from those used in producing electricity of motion, one should not conceive that they are different things. The effects of either have great similarity and they should be regarded as substantially identical.

ELECTRICITY IN RADIO. Radio exhibits electricity in all its characteristics, and the study of radio includes nearly every branch and action of electricity. In order that one may understand, even in a general way, the actions of the electric current in the radio apparatus, a fairly complete survey of the subject must be presented, to which the layman should give more than casual attention. Most of the radio applications of electricity depend upon the flow of the electric current. This also applies to commercial uses, the electric railway, telephone, lighting and all forms of mechanical motion in which electricity is involved. In radio, however, the effects of stationary or static electricity are apparent and of great importance, especially in the study of electric charges.

EFFECTS OF ELECTRICITY. A wire carrying an electric current looks the same as a wire which does not carry a current. We cannot refer to the current as a fluid for if that were the case it would be forced to flow through a solid wire. We look upon this flow as an electron motion by which minute portions of electricity fly with the speed of light from atom to atom of the wire. In order to determine whether a current is flowing in a wire we must depend upon the effects which are produced.

THE ELECTRIC CHARGE. What then are the manifestations of an electric charge and an electric current? Everyone is familiar with the elementary experiments which produce electric charges. For instance, fur when rubbed on a dry day, sputters and gives off minute *sparks*. A rubber comb or fountain pen, if rubbed with fur or silk, becomes charged, and gives off sparks and attracts other light uncharged particles. During clear cold weather the friction of one's shoes on the carpet will charge the body so that sparks can be drawn from the finger tips. From the early days of civilization it has been known that dissimilar bodies will charge each other by *friction*, that the charged body will attract some other light body, as shown in Figure 1, and that the attracted body, when it assumes the charge through contact, will be immediately repelled from the attracting body. Thus came the adaption of the theory that unlike charges attract and like charges repell.

ATTRACTION AND REPULSION. These phenomena are observed in various electrical studies. If a glass rod is rubbed with a cloth it becomes charged and this charge may be transferred, either by contact or induction, to some other body. If we suspend two separate light pith balls, so that they can just touch one another when in a normal position, and touch these two balls with a charged glass rod, both assume the same charge from the same source, and immediately repell each other, as shown at *B* in Figure 2. But if one ball is charged by contact with the charged body (the glass rod) and the other ball charged by the rubbing body (the piece of fur) the two balls then assume the opposite charges of the two charging objects and are attracted (*A*) to each other. So the conclusion is reached that there are two charges of electricity, and they are called *positive* and *negative*. The term *charge* may mean either positive or negative, but whenever possible, the kind of charge should be specified. Two positive charges will repell each other; two negative charges will repell each other; a positive or negative charge will attract an uncharged body, but that body, as soon as it assumes sufficient of the charge of the attracting body, will be repelled; and a negative and a positive charge will continue to attract each other until the two different charges have become *neutralized*.

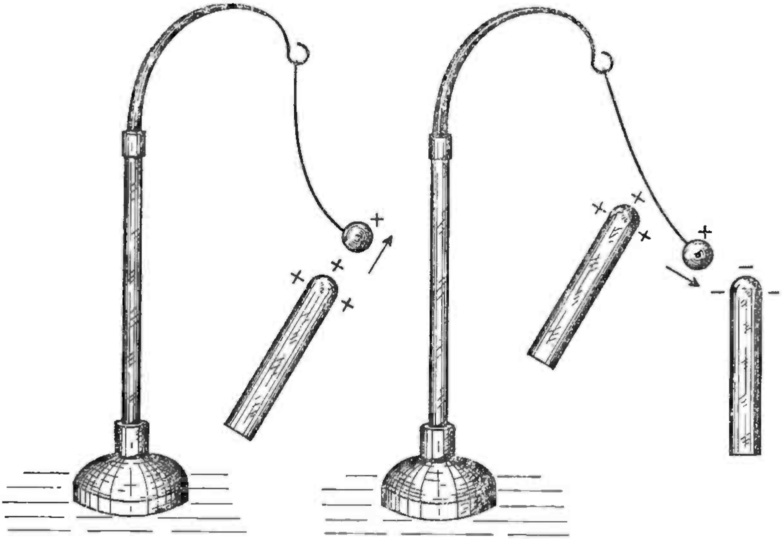


FIG. 1. ATTRACTION BY A CHARGED BODY

ELECTRIC INDUCTION. Consider two metallic conductors, as shown in Figure 3, placed upon insulating supports. One conductor, indicated at *A*, is charged so as to be electrically positive. If the uncharged body, indicated at *B*, is brought close to *A* it will be found that its normal neutral condition has become divided into its two electrical components; the negative portion being attracted to the end nearest the charged conductor *A*, and the positive portion being left at the farther end. This is called charging by *induction*, and demonstrates the principles of the attraction of unlike charges and the repulsion of like charges. As long as *A* is kept near *B*, the two charges on *B* will remain separated. If the far end of the conductor *B* is touched, the positive or repelled electricity will be removed. The conductor *B* will then contain nothing but negative electricity which is held at the end nearest *A*. If the conductor *A*, containing the original charge, is removed, the negative electricity on the second conductor *B* will be free to spread evenly over it as shown in *C*. In all cases of induced charges an unlike or dissimilar charge will be found on the side next to the charged body, and a like charge on the farther side. This same effect is noticed on wires carrying high frequency currents and is a form known as *skin-effect*, which will be explained later.

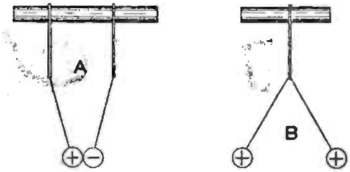


FIG. 2. REPULSION AND ATTRACTION OF CHARGES

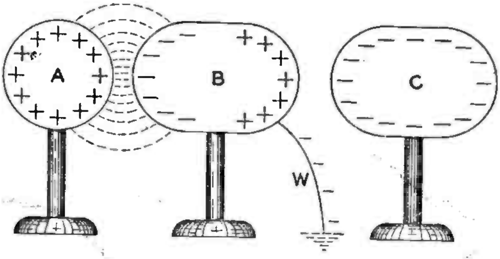


FIG. 3. ELECTRIC INDUCTION

Electric Capacity. The area of the surfaces of the charged and uncharged bodies, their distance apart and the kind of insulating material which separates them, determines their *capacity* for holding a charge of electricity. A larger charge can be held on a large surface than on a small one. This effect, known as the *condenser* effect, will be explained in the chapter on condensers.

Positive and Negative Electricity. There is no real reason for calling electrical charges by the terms, *positive* and *negative*. If a glass rod is rubbed with silk, the rod assumes a positive charge, but if a stick of sealing wax is rubbed with a piece of flannel the wax will assume a negative charge. It is not altogether correct, therefore, to say that *all* bodies that are charged by friction assume positive charges of electricity. One kind of static electricity is never developed alone. When two substances are rubbed together both always become oppositely electrified to an *equal* amount. In general, whenever any electricity of either kind is developed, an equal quantity of the other is found. When two bodies containing equal amounts of opposite charges are brought together, both become discharged or neutralized. During this process of discharge the electricity, previously in a condition of static rest, assumes a condition of motion or a dynamic state, shown by the spark which jumps between the two charged bodies.

Insulation of the Electric Charge. The passage of electricity from point to point sometimes causes a spark, but before this can be produced we must have charges of great strength and there must be considerable difference of strength between the two charged bodies. This difference is called *potential difference*, but it is held in place by *insulation*. When you touch a charged object with your finger the charge is immediately neutralized through the body by the negative earth charge, but when the body is suspended by a silk thread, as shown in Figure 1, the charge is not neutralized. It is evident that the electricity cannot traverse the silk thread; otherwise it would have been impossible to impart the original charge to it. Substances which do not permit the passage of electricity are called *non-conductors* or *insulators*, while those that allow an electric current to flow are called *conductors*.

In order, therefore, to charge an object, it must be well insulated, so that the charge will not be neutralized by the earth charge. The best insulating substances, named in the order of their effectiveness are: air, glass, hard rubber, silk, procelain, synthetic and phenolic compositions, marble, etc. Theoretically speaking, there is no such thing as a perfect insulator as all substances will break down when the potential difference becomes too great. Dry air is the best insulator known.

THE ELECTRIC CURRENT. An electric current is a flow of electricity, the manifestations of which differ from static electricity. In static electricity we do not have a flow, but a sudden attraction and neutralization, through contact or the breaking down of the insulation. In dynamic electricity we must have a conductor capable of sustaining the flow. A conductor is some metal or alloy and may be used in an electric circuit for two purposes; to obtain a high degree of *conductivity*, or to obtain a high *resistance* to the flow of the electric current. Such expressions as flow and current are the survivors of former days when it was believed that electricity was a fluid of some kind. These terms serve well, however, to express the meaning.

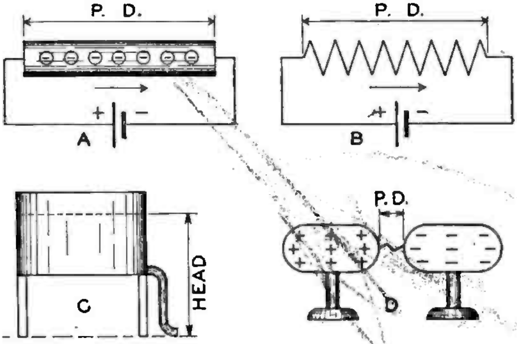


FIG. 4. POTENTIAL DIFFERENCE

POTENTIAL DIFFERENCE. Electricity in motion is not produced in the same manner as static electricity. In order to obtain an electric flow from one terminal to another, there must be a *circuit* which must be completed or closed. See *A* and *B* in Figure 4. If the circuit is open, even if the gap is minute, the current cannot flow. To obtain this flow, even if the circuit is closed, there must be a pressure difference between the positive and negative terminals, so that they will tend to seek each other. This difference is called the *potential difference*, and the greater the difference, the more difficult the current will be to control. When the difference is extremely high careful insulation of the conductors must be made. Suppose a reservoir (*C*), placed at a high elevation, connected with a lower elevation by a water pipe; the difference in height will control the pounds pressure of the water at the outlet end of the pipe. This difference in height between the two ends of the pipe or head as it is called, corresponds to the potential difference between the positive and negative current sources.

ELECTROMOTIVE-FORCE AND THE VOLT. The factor causing the flow of an electric current is termed the *electromotive-force.* The flow of electricity in a wire depends upon the electromotive-force just as the flow of water through a pipe depends upon pressure. The water analogy is perhaps the best method of visualizing the phenomenon of the electric current flow. But water may be directly handled, it has weight, volume, motion and it occupies space. Suppose we have a pump which is forcing water through a pipe at a certain rate of speed. The force of the pump will regulate the pressure necessary to overcome the natural resistance of the pipe and to deliver the required amount of water at the discharge end. The size of the pipe will determine the amount of water that is transmitted. A larger pipe will be needed to transmit a certain amount of water at low pressure than will be required to transmit the same amount at high pressure. The higher the pressure the smaller the pipe required to pass a certain amount of water per unit of time. If we now imagine the water replaced by electricity and the pump by a battery or electric generator, the pressure or electromotive-force is the *voltage,* measured in *volts.*

ELECTRICAL UNITS. The effect or work performed by electricity may be measured, and the greater this effect the greater is the quantity of electricity involved. The unit of quantity of electricity is called a *coulomb*. The unit employed in the measurement of the electromotive force is the *volt*. The volt is the force which will cause a current of one ampere (the unit of current) to flow through an electric circuit having a resistance of one unit (the ohm). The electromotive force is often spoken of as the voltage of the electric circuit and also as the potential difference between the two conductors of the circuit.

THE AMPERE. The unit of electric current, which corresponds to the unit measurement of water passed through a pipe, is called the *ampere*. It expresses the rate of flow of current through a circuit having unit resistance (one ohm) when the potential difference is one volt. This is comparable to one gallon of water flowing through a pipe of a standard resistance of one unit under a pressure of one pound. The ampere is also the *rate* when one coulomb flows through the circuit for one second. The amount of an electric current is always expressed in amperes as it shows very definitely the *quantity* of electricity flowing per second. The *milliampere* is one thousandth of an ampere and the *microampere* is one millionth of an ampere or one thousandth of a milliampere.

THE OHM. The unit of resistance to the flow of an electric current is called the *ohm*. It corresponds to the friction effect produced by the walls of a pipe when water is forced through. The ampere, the volt and the ohm are directly related and connected by the formula known as *Ohm's Law* which, in effect, states that the strength of the current is equal to the electromotive force divided by the resistance of the circuit. The ohm is the measurement of resistance in a circuit when a current of one ampere will flow with an electromotive force of one volt. For very small resistances the unit is called the *microhm* or the millionth part of an ohm, while for very high resistances the unit is called the *megohm* or a total of one million ohms. The resistance of a circuit depends upon the material used in the conductors, the length and size of the parts and, to a lesser degree, the temperature of the parts.

OHM'S LAW. The formulae expressed by Ohm's Law are often applicable to radio circuits and, expressed briefly, are as follows: The number of amperes flowing in the circuit is equal to the number of volts of pressure *divided* by the resistance of the circuit in ohms. The number of volts or electromotive force of the circuit is equal to the *product* of the amperes flowing in the circuit and its resistance in ohms. The resistance of a circuit, expressed in ohms, is equal to the number of volts *divided* by the amperes flowing through the circuit.

THE COULOMB. The unit of electricity is called a *coulomb.* It is the *quantity* of electricity passed through the circuit by a current of one ampere for one second regardless of the resistance or the potential difference.

THE JOULE. The unit of electrical energy is called the *joule.* It is the amount of energy expended when one ampere passes through a resistance of one ohm for one second.

THE WATT. The unit of power is the *watt.* This represents the rate at which work is accomplished when a current of one ampere flows against a resistance of one ohm. It is also equal to one joule per second. Watts are obtained by taking the *product* of the number of amperes that flow in the circuit and the potential difference in volts. When large powers are expressed, the term *kilowatt* is used, meaning 1,000 watts. One electrical horsepower is equal to 746 watts or 0.746 kilowatt.

RADIO UNITS. The ampere, volt, ohm, watt, farad and henry, are the fundamental units referred to in radio work. Watts and kilowatts are used chiefly in referring to the power of broadcasting stations, while amperes, volts, ohms, megohms, mhos, microfarads and microhenrys, are used in connection with receiving sets. The farad, henry and mho are explained elsewhere.

THE MAGNET. One of the most familiar pieces of physical apparatus is the *magnet.* We are all acquainted with its antics; how it will pick up bits of iron or steel and induce similar magnetism in pieces of iron and steel. All magnets, regardless of shape, have two *poles.* For the sake of convenience these poles have been named *north* and *south* poles. Like electricity, we cannot see, feel, taste, smell nor hear magnetism. Magnetism and electricity have been well named twins because wherever one is found, so is the other. In fact, in electrical work of all kinds, magnetism must be present. Without it the great generators would cease to produce, power from electric motors could not be obtained, and radio waves could not be propagated. Furthermore, like electricity, we have in magnetism two opposite conditions; not charges, but poles. Magnetic poles of similar magnetism will repell each other, and dissimilar poles will attract each other. The power of magnetism can also be induced in non-magnetized pieces of iron or steel.

Magnetic Induction. If a bar of soft iron is brought near the pole of a magnet (A) it becomes magnetized, as shown at B in Figure 5. Upon removing the magnet (A) the bar is found to be free of any magnetism. This method of producing magnetism in another piece of iron is called *magnetic induction*. We have seen that an insulated conductor can be charged with electricity by induction or by the proximity of a charged object. As is the case with electric induction, a dissimilar magnetic pole is induced in the end of the bar next to the permanent magnet. For instance, if a north pole end of a permanent magnet is brought near the end of a non-magnetized iron bar, a south pole will be induced in the adjacent end of the latter while a north pole will be repelled to the far end.

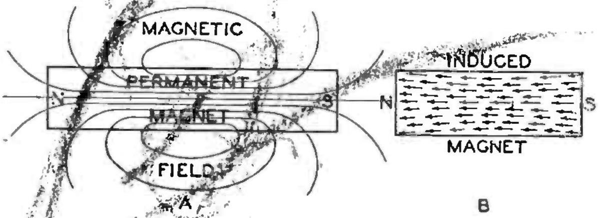


Fig. 5. Magnetic Induction

Magnetic Properties. Iron and steel possess great magnetic properties. In fact, practically no other metals possess any magnetic abilities whatever. Steel has the quality of holding magnetism and magnets made of this metal are termed *permanent* magnets. Iron, especially soft and annealed iron, loses its magnetic properties immediately it loses contact with a permanent magnet. Sometimes a small portion of magnetism will remain and this is called *residual magnetism.*

THE MAGNETIC FIELD. The region about a magnet in which a magnetic substance will be repelled or attracted is called its *magnetic field.* Invisible lines pass out from one pole of the magnet and extend to the opposite pole. These lines are called magnetic curves or *lines of force* and embrace the magnetic field; they never cross but are always concentric and semi-parallel, and they are closer together or more dense near the magnet, and gradually diminish at some distance away. See Figure 6. If a permanent magnet is placed beneath a sheet of paper or a piece of window glass and the paper or glass then sprinkled over with fine iron filings, this dust will assume positions along the lines of force, showing very clearly the character and position of the lines. If a small magnet be suspended on a thread, as shown by *M* in Figure 6, so as to be near a pole of similar polarity, it will be immediately repelled and, following the curvature of the lines of force, it will

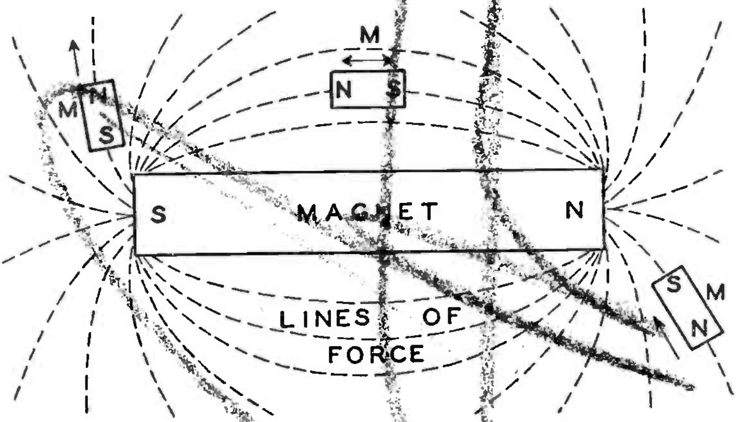


FIG. 6. MAGNETIC FIELD OF FORCE

move toward the pole of opposite polarity. If *M* is held near the large magnet, but not permitted to swing toward the attracting pole, it will arrange itself parallel to the lines of force.

The Earth a Great Magnet. The earth is a great magnet with lines of force running approximately from the two geographical poles, although the magnetic poles are not exactly coincident with the geographical poles. If a bar magnet is suspended on a thread it will gradually turn until it lies in the plane of the earth's north and south magnetic lines of force, and the magnet's poles will point north and south. The south pole of the magnet will point toward the north pole of the earth and it cannot be made to assume any other position when freely suspended. The compass, with which every one is so familiar, operates on this principle, the

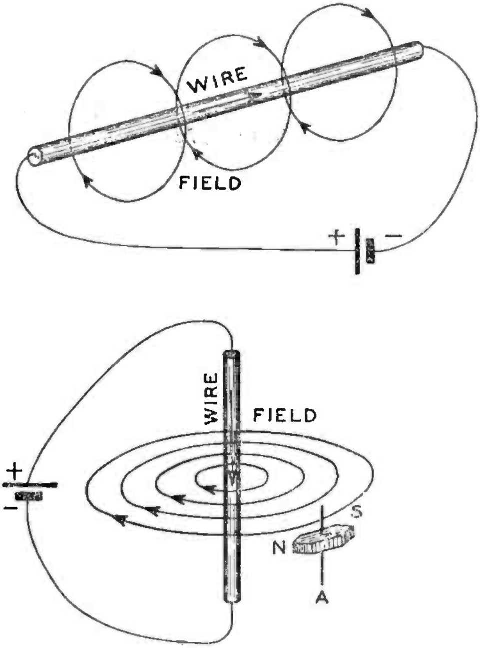


Fig. 7. Magnetic Field About a Wire

little needle always pointing north and south and remaining parallel to the earth's magnetic lines of force.

ELECTROMAGNETIC EFFECTS. We have previously considered electricity and magnetism separately. Now it must be shown how they always work together. The flow of electricity through a wire produces certain magnetic effects. If a straight wire, through which an electric current is passing, be placed vertically beside a horizontal compass so that it is parallel to the axis of the needle, the needle will then be *deflected* a certain amount and become tangent to an imaginary circle about the wire as shown in Figure 7. The needle *A* will remain in this new deflected position as long as the current flows through the wire. If the flow of current in the wire is reversed the compass needle will be immediately deflected to the opposite position, making a swing through 180° but again becoming tangent to the imaginary circle. This readily proves that an electric current has direction.

THE ELECTRIC CURRENT HAS DIRECTION. A simple rule enables one to determine the *direction* of the flow of current through a wire. When the wire is grasped with the *right* hand so that the thumb is extended along the wire, and the curved finger tips point in the direction taken by the deflected compass needle, the thumb points the direction of the current. Or, if the direction of the flow is known, place the hand so that the thumb points in the direction of flow; the finger tips then indicates the direction taken by the lines of force about a wire. This method is sometimes known as the rule of thumb.

THE ELECTROMAGNETIC FIELD. If a wire carrying an electric current is wound into a coil or solenoid a much stronger magnetic field can be produced. In this way the lines of force about *each* of the individual turns combine to form a larger magnetic field about the coil. These lines of force are nearly parallel to the center line of the coil or the core upon which it is wound. The two ends of the coil produce magnetic poles, north and south, extending from which are magnetic lines of force similar to those observed about a permanent bar magnet. See Figure 8. If the coil is grasped by the *right* hand so that the fingers point in the direction of the flow of current through the turns of wire, the thumb then points toward the north pole of the coil. We have now combined the two familiar terms into what is known as an *electromagnetic field.* An *electromagnet* is therefore an arrangement for producing magnetic effects by means of an electric current flowing in a coil of wire.

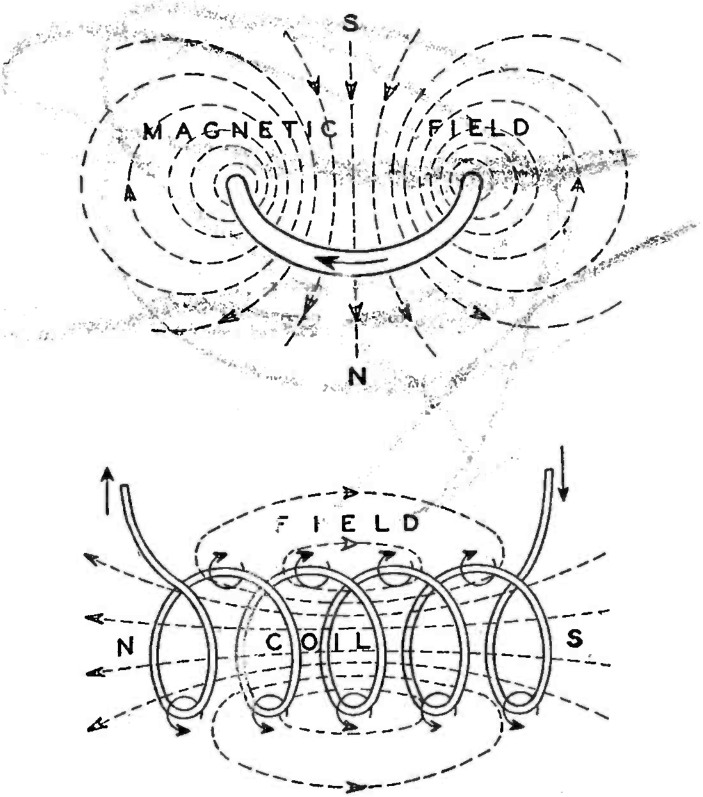


FIG. 8. MAGNETIC FIELD ABOUT A COIL OF WIRE

MAGNETIC LINES OF FORCE IN A COIL. The air space in the center of the coil can carry but relatively few magnetic lines of force. If a bar of soft iron is inserted in the space the number of magnetic lines greatly increases. This is due to the *permeability* of the iron which permits it to carry a much greater number of magnetic lines of force than air and, consequently, the degree of magnetism is much greater. The bar of iron becomes a magnet and has all the properties of a permanent magnet, as shown in Figure 9. If the bar is of steel it will retain most of its induced magnetism after the current is turned off and becomes a permanent magnet. If the current flowing in the coil is reversed the magnetic poles will also be reversed.

Properties of Electromagnets. Two electromagnets suspended freely in the air will attract or repel each other in the same manner as two permanent magnets. The action displayed by the two electromagnets in attracting or repelling each other is dependent upon their relative size and the strength of the current flowing through them. This controls the strength of their electromagnetic fields. The powerful turning effect of the electric motor is the result of the application of this principle of electromagnetic attraction and repulsion.

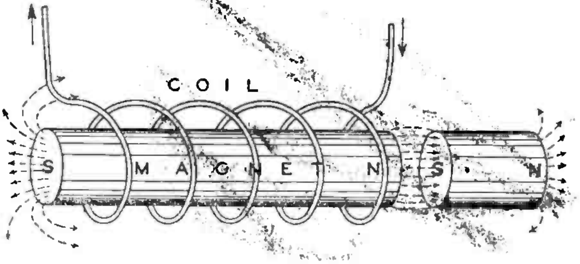


Fig. 9. Iron Core Magnetized by an Electric Current in a Coil

Currents Produced by Magnetic Fields. A current of electricity flowing through a coil will produce magnetic effects in a bar of iron placed within the magnetic field of the coil; conversely, a magnetized bar of iron will produce current effects within a coil of wire because of the influence of the magnetic field. If a coil of wire, made into a solenoid with an open center, has its two ends connected to a sensitive instrument for the detection of electric currents, it will show a momentary surge of current if a permanent magnet is passed through the coil. See Figure 10. The current surge takes place only during the insertion or withdrawing of the magnet.

INDUCED ELECTROMOTIVE FORCE. Now if the magnet is thrust within and withdrawn from the coil in rapid succession the flow of current will be practically continuous, except that its direction will be reversed each time the direction of the moving magnet is changed. The current which is induced in the coil is called the *induced electromotive-force*, commonly referred to as simply *e.m.f.* and which also causes the potential difference.

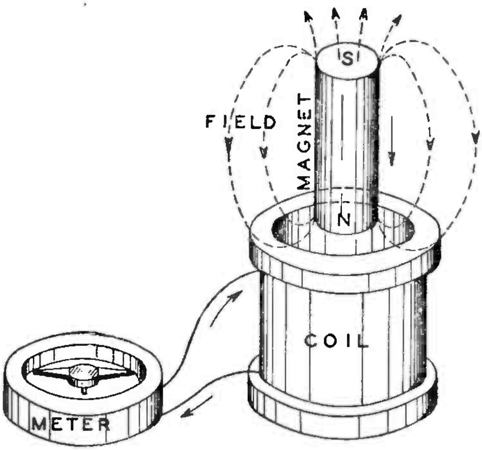


FIG. 10. CURRENT INDUCED IN A COIL BY A MAGNET

ONE CURRENT WILL INDUCE ANOTHER CURRENT. The same effect may be produced if the bar magnet is replaced by another coil of wire, as shown in Figure 11. If an iron bar should be inserted within the smaller coil the number of magnetic lines of force becomes increased, and a more powerful current will be induced in the outer coil. To eliminate inserting and withdrawing the inner coil, the effect can be produced if the current passing through it is turned off and on at *S*. Each time this circuit is made and broken there will be a registration on the recording instrument. If the number of turns of wire on the two coils have been properly proportioned the induced current can be regulated and can be made so high that it will break down the air gap and produce sparks many inches in length. This principle of electromagnetic *induction* is used in *transformers, spark coils,* and other electrical apparatus.

ELECTROMAGNETIC APPLICATIONS. We have seen that electric currents and magnetic fields are directly related. Practical application of these principles is based on the three following experimental facts: If a conductor is passed through a magnetic field a current of electricity will be induced in the conductor. When a current flows through a conductor placed in an external magnetic field and the polarity of the conductor's magnetic field becomes first similar and then opposite to the polarity of the external field, a push and pull effect is exerted on the conductor. These three principles may be utilized to produce power by means of machines. Such *machines* are for the conversion of electric power into mechanical power or vice versa. When driven by mechanical

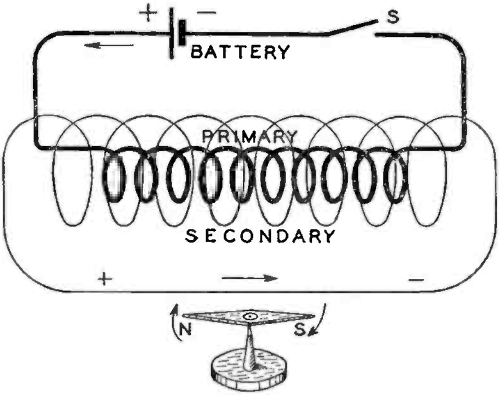


FIG. 11. CURRENT INDUCED IN ONE COIL BY ANOTHER

power to produce an electric current they are termed *dynamos, generators* and *magnetos;* when the machine uses an electric current to do mechanical work, it is called a *motor*.

GENERATED ELECTRICITY. There are two kinds of generated electricity; *direct current* and *alternating current.* All generators produce alternating currents, but the current may be so regulated by a *commutator* that it will flow in but one direction. This is direct current. Batteries give a direct current which has a much smoother flow than that obtained from a generator. The alternating current generator is a machine which has a number of revolving magnets passing very close to an equal number of stationary coils of wire, each mounted on an iron core piece. As these magnets pass the coils momentary currents are set up in the latter, and due to the changing positions of the magnets, two pulsations, moving in opposite directions, are set up in each coil.

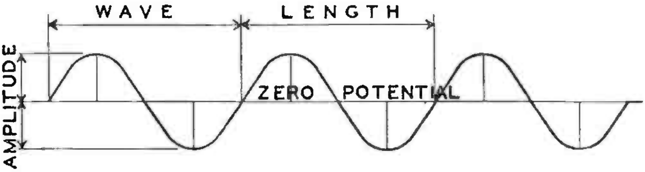


FIG. 12. FORM OF ALTERNATING CURRENT

ALTERNATING CURRENTS. It has been shown how the inserting of a bar magnet in a coil of wire will produce a current flowing in one direction, while the removal of the magnet will cause a current to flow in the opposite direction. This is an alternating current, the maximum value of the current in one direction being equal to the maximum value in the other. All of the changes of current occur over and over at regular intervals in a properly designed alternator, and are called *cycles.* See Figure 12. The alternator has no permanent positive and negative terminals as the polarity changes with each half-cycle or *alternation,* while the current assumes in turn, all values between zero and the maximum value of the machine.

THE ALTERNATING CURRENT GENERATOR. The *alternator* is used to produce an alternating current by means of some other source of energy. If a conductor moves from *right* to *left* across a magnetic field a current will be induced in it having the same direction as if the magnetic field were moved past the conductor from *left* to *right*. Suppose the conductor formed into a *loop* and, revolving within it, a magnetic field produced by a north and south pole of a magnet. As the north pole passes the upper part of the loop it induces a current flowing in one direction and, as it continues to revolve and the south pole passes the same part of the loop, a current is induced flowing in the opposite direction. The same takes place in the lower part of the loop and, thus, two *pulses* of current and induced electromotive force take place, flowing in opposite directions for each revolution of the magnet. This device may be called an elementary type of alternator. To obtain a current direction change of 60 cycles per second, which is the electrical standard in this country for commercial uses, a single magnet of two poles would require a speed of 60 revolutions per second. Large machines cannot be operated at such excessive speeds so the number of poles on the *rotor* or revolving magnet, or coils on the *stator* or stationary field piece, is increased and the alternator operated at a much lower speed. Some alternators have stationary magnets and rotating coils wound on an *armature* core. The magnetic field, whether stationary or revolving, is produced by a number of electromagnets separately excited by a small direct current generator. The current is collected by sliding contacts known as *brushes* which slip on collector rings of the armature, or the current is fed to the rotating field magnets by the same means from a small direct current generator.

THE DIRECT CURRENT GENERATOR. A direct current generator is simply an alternator which has been fitted with a current-reversing commutator so that the pulsations of current are always in the same direction. The collecting brushes are so placed about the revolving commutator that the reversal of the armature winding connections occurs when the current in that particular coil is zero and about to flow in the opposite direction.

ALTERNATIONS, CYCLES AND FREQUENCY. The potential of an alternating current rises and falls with exact regularity. During the change of direction the potential begins with zero volts and gradually rises to the maximum voltage of one electrical sign and then drops to zero again. See Figure 12. The current then reverses and starts to flow in the opposite direction reaching the maximum voltage of the opposite electrical sign and then it returns to zero volts. Each rise from zero to the maximum potential is called an *alternation*, and the two opposite alternations make one cycle or completion of the positive and negative potential swings. The number of cycles which occur in a unit of time (a second) is the *frequency*. Each time the cycle is repeated the same potential values are passed through; for example, each maximum of the positive sign occurs just one-fourth of a cycle after the preceding zero potential and each maximum of the negative sign also occurs at the same place in the cycle, or during the middle of the alternation. An alternating current having 1,000 cycles per second will have 1,000 periods of maximum positive potential and 1,000 periods of maximum negative potential, or 2,000 alternations in potential. During the time of the 1,000 cycles there will also be 2,000 periods when the potential is at zero voltage.

ALTERNATING CURRENT PHASE. When a circuit has resistance but no induction or capacity the potential and current will always flow in *phase*. In other words, the same values of potential and current will occur over and over at the same definite parts of successive cycles. But there are certain lags and leads which take place in an alternating current circuit having reactance and, in such cases, there will be a difference in phase. This is a difference in time and is best expressed in a fraction of the length of the cycle as an *angle*. A difference in phase of one cycle is equivalent to the angles of a whole revolution or 360°. One-eighth cycle is, therefore 45°; and two points in a cycle, when the current and potential differ in phase, have a *phase angle* of 45 degrees. For example; if the maximum value of potential occurs one-fourth of an alternation in advance of the maximum value of current, the two are *out* of phase one-eighth of a cycle, or 45 degrees. A single alternating current, such as we have been discussing, is termed a *single-phase current,* whereas several currents differing in phase are termed *polyphase* or *multiphase currents.* In any alternating current circuit where there is some reactance the voltage and current will have some difference of phase.

Alternating Current Reactance in a Coil. If an alternating electromotive-force is impressed on a circuit having large inductance and low electrical resistance, the changes of current will induce a still greater potential in the coil due to *self induction.* But the original applied voltage must pass through the point of greatest change or when it has zero volts in the cycle, so that the induced potential will be at its maximum. As the applied and induced potentials are at an opposite phase the resistance of the circuit is greatly increased. This is known as the *reactance* of an inductance coil to an alternating current. A small inductance coil passing a low frequency alternating current has a low *inductive reactance.* When the frequency of the current increases the reactance of the coil also increases. The higher the frequency the greater is the reactive resistance to the flow of an alternating current in a coil having inductive properties.

The Condenser. A *condenser* consists essentially of two insulated conductors. If they are connected in a direct current circuit, a steady current cannot pass. If a current flows into a condenser it stops as soon as the conductors assume the potential of the charging current. If this latter voltage is removed and the circuit completed, a current will flow in the opposite direction from the condenser until its plates no longer have any potential difference. But if an alternating current is applied to the condenser circuit an alternating potential is constantly flowing in and out of the condenser to keep the potential between the plates equal.

Alternating Current Reactance in a Condenser. The condenser has a reactance in a circuit similar to an inductance coil but of an *opposite* nature. The smaller the capacity of the condenser and the lower the frequency of the alternating current the greater is the *capacitive reactance.* When the frequency of an alternating current is very high the reactance of a condenser is very low. An increase in frequency lowers the reactance of a condenser while it increases the reactance of a coil.

IMPEDANCE IN AN ALTERNATING CURRENT CIRCUIT. A circuit may have inductance and capacity in addition to its natural electrical resistance when an alternating current is flowing. When this combined reactance and natural resistance operates to obstruct the flow of an alternating current it is known as the *impedance.* However, as inductive and capacitive reactances are the reverse of each other, the *total* reactance of a circuit is the difference between the two reactances measured in ohms and giving the impedance designation to the predominating reactance. The electrical resistance in ohms cannot be added to this total reactance in order to obtain the impedance. Graphically, they should be combined as straight lines at right angles in proportionate lengths. Assuming them as two forces acting together at right angles, their *resultant* is the impedance.

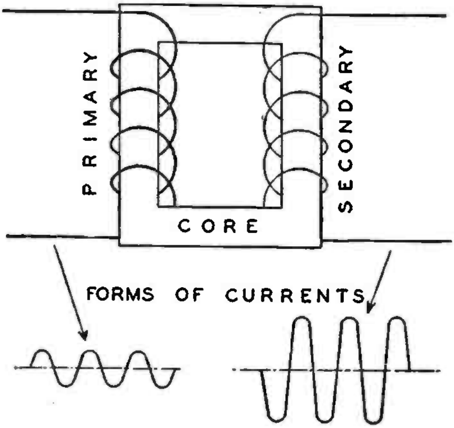


FIG. 13. ALTERNATING CURRENT TRANSFORMER

RESONANCE IN AN ALTERNATING CURRENT CIRCUIT. When two reactances, inductive and capacitive, are equal, a state of *resonance* is said to exist. The alternating current then has a flow similar to a direct current, and the impedance of the circuit equals the natural resistance to a direct current.

THE ALTERNATING CURRENT TRANSFORMER. If we have a uniform ring or closed iron circuit, the metal may be magnetized by means of an electric current so that the lines of force are continuous within the substance of the ring or core. The magnet has no external poles and there is no place for the magnetic lines of force to enter or leave. Such a magnet is used as the *core* of the *alternating current transformer.* A transformer consists of two coils of wire so placed as to have a mutual inductance with respect to the same magnetic field. See Figure 13. The coil connected to the supply current is called the *primary,* while the coil in which the current is *induced* is called the *secondary.* Each time the current in the primary reverses its direction a new magnetic field is built up and another current surge takes place through the secondary in an opposite direction. The current induced in the secondary is always alternating regardless of whether the primary current is alternating, intermittent or a pulsating direct current. Let us suppose a transformer wound with 1,000 turns of wire on the primary and 5,000 turns on the secondary, and with a current of 5 amperes at 110 volts passing through the primary. The winding *ratio* of the transformer is 1 to 5. The voltage induced in the secondary will be five times that of the primary, or 550 volts, while the amperage will be reduced one-fifth of the original, or to one ampere. The number of watts original current in the primary is 550 and the number of watts induced in the secondary also 550. In practice the number of induced watts will be slightly less as the transformer is not 100 per cent efficient. When the induced voltage is higher than that of the original, the transformer is said to be a *step-up* transformer, such as has just been described.

TRANSFORMER EFFECTS. If the winding is reduced, so that the secondary has but 200 turns, the ratio is then 5 to 1 or *step-down,* as the output voltage will be only 22, but the amperage may be 5 times that of the original, or 25 amperes. The number of watts in the two windings remains the same, or 550. It must be remembered that the voltages and amperes given by the secondary can be regulated to any amounts by varying the windings of the coils. A greater number of turns of fine wire on the secondary may increase the original voltage to many thousands, but the amperage will be correspondingly reduced. It is impossible to take more watts out of a transformer than are put in. The current delivered by a transformer is called the *output* and is *always* an alternating current. The current used in the primary is called the *input* and may be an alternating current, an interrupted direct current or a pulsating direct current (varying voltage current) as in the case of radio audio frequency transformers.

THE ALTERNATING CURRENT IN RADIO CIRCUITS. The principles of alternating currents are widely applied to radio circuits. The currents used are very high frequency alternating currents. While ordinary commercial alternating currents have a frequency of only about 60 per second, in radio work the lowest of these frequencies lies well above 10,000 per second and may even be higher than 300,000,000 cycles per second. This vast difference in frequency changes entirely the behavior of radio circuits and they cannot be treated in the same manner as ordinary low frequency alternating current circuits. When low frequency current flows through a wire its main opposition is the natural resistance of the wire, but in radio circuits impedance is of extreme importance. Furthermore, these high frequencies are entirely too rapid to operate any reproducing devices, since the human ear will not respond to vibrations as high as 10,000 per second. The very rapid alternations are called *radio frequency currents* and the slower alternations, which are within the range of the human ear, are called *audio frequency currents.* In order to make currents at radio frequencies audible it is necessary to reduce their rates to audio frequency. This phase of radio reception will be discussed further.

THE ELECTRON THEORY. The most interesting subject in the study of electricity is the story of the *electron.* We have seen how electric charges can be produced and that electric currents are in motion, but we have failed to find out what these charges consisted of and how the current moved about its circuit. Only within recent years has science attempted an explanation to account for the phenomena observed. We speak of this explanation as the *electron theory.*

CATHODE RAYS. Some years ago investigators working with high frequency electricity discovered that a current could be made to pass through a highly exhausted glass tube, in the form of rays. As these rays proceeded in a straight line from the cathode (the electrode by which a current leaves) they were called *cathode rays.* But the investigator Crooks believed them to consist of negatively charged particles projected with great velocity from the cathode. It was found that the straight line in which the rays proceeded could be deflected from its course by the presence of a positively charged plate, toward the plate, and away from the plate when it was negatively charged. The fact that these cathode rays passed through thin metal foil indicated that the charged particles were much smaller than the molecules and atoms of the foil. They were then given the name—*electrons.*

MATTER AND MOLECULES. First consider *matter.* Any substance that has weight, volume and other physical characteristics is matter. It may be broken and rebroken into minute parts, but the time comes when it is no longer divisible. The smallest possible portion of a substance retaining all its individual characteristics is called a *molecule.* The molecule is not visible under the most powerful microscopes known to man. Scientists believe that the smallest visible portion of matter contains at least several hundred molecules.

ELEMENTS AND ATOMS. There are less than one hundred known *elements* on the earth and each has been given a general term. An element contains nothing other than the material itself. But a *substance* or *compound* is made up of two or more elements in certain proportions and combinations. The smallest portion of a compound or substance is a molecule, and the smallest particle of an element is an *atom.* But an atom of an element may also be a molecule of the element, being the smallest particle in either case. However, molecule is generally used in the sense of being a particle of a substance, while the atom is associated with an element. As a molecule is a particle of a compound and a compound is made up of two or more elements, we can say that a molecule is made up of two or more atoms of the elements entering into the composition of the substance or matter. The chemist uses a special method to express the elementary composition of matter. For instance, a molecule of *water* contains one atom of oxygen and two of hydrogen, and is expressed by the chemical formula—H_2O.

ELECTRONS. For years the atom was considered the smallest possible particle of matter, but as we attempt to bring about the ultimate subdivision of the atom, we obtain electricity in what may be called its original state. The particles of negative electricity shooting out at high speed from the cathode as cathode rays are called *electrons*. They are much smaller than atoms; in fact, some atoms contain a great number of electrons. Although an atom of an element contains a number of electrons of pure negative electricity, the atom is, normally, electrically neutral. Each atom must, therefore, contain a quantity of positive electricity equal to the negative electricity indicated by its electrons. See *A* in Figure 14. This positive charge is contained in the *nucleus* of the atom, as the atom is conceived to consist of this nucleus or sphere, uniformly charged throughout with positive electricity, and containing the negative electrons arranged in rings or layers so as to circulate rapidly in orbits about the nucleus. Taking this view, the atom is supposed to have a somewhat open miniature solar system, with lighter atoms having few, and heavier ones having many electrons. The nucleus accounts for practically all of the mass of the atom.

THE PROTON. Consider the simplest known atom; the atom of hydrogen. It is made up of the single positive nucleus, which is practically the complete atom, as there is only one electron of negligible mass revolving about it. The mass of the atom contains a very small positive charge to balance the single electron negative charge, and the atom is electrically neutral. As this nucleus has an elementary positive charge equal in value to that of an electron, we call the nucleus a *proton*. The hydrogen atom, therefore, consists of one negative electron and one positive proton. Many atoms, however, contain a nucleus of several protons.

THE ION. If, by some means an electron (*D*) is removed from an atom the balance between the strength of the positive nucleus or protons and the negative electrons becomes upset, and the positive charge of the excess proton predominates. This is illustrated by *C* in Figure 14. This electrical state of an atom of gas due to the removal of an electron changes the atom to an *ion*. Because of the excess of positive charge the ion is known as a *positive ion*. The electron, when removed from an atom, becomes a *free* electron. As such it will go wherever it is attracted. If it becomes attached to some neutral atom, the amount of negative electricity in that atom (*B*) then becomes excessive, due to the presence of the electron with no balancing proton, and the atom becomes a *negative ion*. The substance of an ion practically remains the same, as the protons—which contain the mass of the atom—cannot be moved nor combined. Only the electrons are free to move about. The more electrons removed from or added to the atom, the greater becomes its electrical charge. Because of this, ions may vary greatly in their electrical strength.

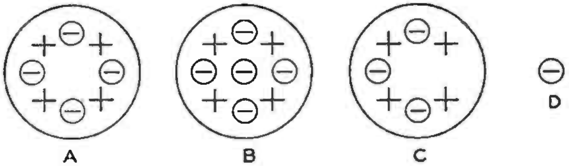


FIG. 14. STRUCTURE OF THE ATOM, ION AND ELECTRON

FREE ELECTRONS. The conduction of electricity in a metal is due to the *free electrons* which move through it, carrying with them their true negative charges. As the atoms are of open structure the electrons readily pass between the interstices of the molecules composing the metal. The phenomenon of induction indicates that there are many free electrons, or that electrons are free to move about. We remember that a glass rod takes on a positive charge when rubbed, and the material used for rubbing assumes a negative charge. When we rubbed the rod we removed many electrons which then combined with the atoms of the material and produced a negative charge, while the deficient atoms of the glass became positive. We have also seen (Figure 3) that when the positively charged body *A* was brought near an end of the uncharged body *B* it induced a negative charge in that end because it had acquired an excess of electrons. The other end of *B*, having lost an equal number of electrons, exhibits a corresponding positive charge. When we touched this positive end the surplus of positive electricity did not run off, but on the contrary, free electrons from the earth passed up (*W*) to replace the missing electrons which were held at the opposite end. When this influencing positive charge (*A*) was removed, the bound electrons at the far end of the body (*B*) were free to move. But as the deficient atoms had already received the necessary electrons from the earth, there could be no recombination and the electrons spread over the body (*C*) as an excess of negative electricity.

ELECTRONS IN MOTION. The electric current which is simply electrons in *motion* has been discussed. See *A* in Figure 4. Since the electrons are negative and are free to move we must believe that the flow of current or electrons must be from negative toward positive. Each electron also has a minute magnetic field about it. As they move the magnetic fields also move, so whenever we have a stream of electrons or an electric current, there is a magnetic field present. When a conductor is heated the electrons move much faster, and it is impossible to prevent the electrons from gaining so much energy that they freely leave the substance and enter some nearby cooler one, especially if it contains an attracting positive charge. When a metal is heated nearly to the melting point electrons are thrown off at a high rate, very much in the same manner that molecules of boiling water escape as steam. Some metals will give off a greater flow of electrons than others. In this respect, *thorium*, a comparatively rare metallic element which is radioactive, is outstanding. The use of thorium or some *thoriated* metal for the emission of electrons when heated, will be discussed further in the chapter on electron tubes.

Ionization of Gas. If we have two metallic conductors, each insulated and slightly separated, and apply a current having a high potential to them, there will be a great potential difference and tension across the space. Negative electrons begin to pass over to the positive conductor, moving with great speed and increasing in number. As this number grows the resistance in the air gap may be overcome and the current will flow across as long as the potential is applied to the electrodes. During the passage of the electrons they collide with many of the atoms of the gas which is between the electrodes. Because of these collisions the atoms lose electrons. This is known as *disassociation*. Ions are produced and the gas has been *ionized*. Positive ions are attracted to the negative electrode, and the negative ions are attracted to the positive electrode. These ions collide with additional atoms and still more electrons are set free. Thus, the addition of negative and positive ions and free electrons tends to increase the current flow between the two electrodes. See *D* in Figure 4. The greater the potential difference between the electrodes the greater and faster the electron stream will flow and the heavier the ionization of the air or gas between. This phenomenon takes place in a gas between all bodies having potential difference. Soft electron tubes, spark transmitters, lightning, alternating current rectifiers and other radio apparatus, will be referred to further in appropriate chapters.

Resistance to Electrons. The slightest external electric force causes electrons to pass continuously between the atoms of a metal conductor, thus creating a flow of electricity. The electrons are constantly checked by their impacts against atoms and other electrons, and in this way they are retarded by *resistance*. The degree of atomic compactness within the conductor determines the rate of flow of electricity through it. Very dense atomic structures hinder the flow of electrons and, if the conductor is small and the current flow large, the electron resistance will become so great that the conductor will heat or even melt.

CHAPTER III

THE SOURCES OF THE ELECTRIC CURRENT

CURRENT SOURCES. There are two primary sources of an electric current; a *battery*, and an electric *generator*. The battery is best known in radio work and for that reason it will be more fully discussed, while the generator current will be referred to in connection with the use of the battery *eliminator* in radio reception.

THE ELECTRIC CELL. A primary or galvanic *cell*, is a combination for converting chemical energy into a electric current. A cell consists of two elements called *electrodes* which are placed in a liquid or semi-liquid, called the *electrolyte*. A cell is a single unit of the combination capable of producing electricity, while a battery is made up of a number of cells and the term battery, when applied to a single cell, is quite misleading. The two essential elements of a cell are usually *zinc* and *copper* or *zinc* and *carbon*. The electrolyte solution in which these electrodes are suspended is usually made of salt or acidulated water. The combinations depend upon the type of cell and the nature of the required output.

SIMPLE PRIMARY CELL. A simple type of *primary cell* can be made by taking a piece of zinc and a piece of copper, and placing them in a glass container, vertically parallel, but not touching. A weak solution of water and sulphuric acid is poured into the glass. See Figure 15. Bubbles of hydrogen gas arise immediately from the zinc strip, but if a wire connects the two metals the bubbles at the zinc will diminish and a heavy flow will commence from the copper strip. The strip of zinc will slowly waste away, dissolved in the solution of acid, while the copper strip is unharmed. As long as the wire connects the two metals they will be at different potentials with respect to each other.

THE BATTERY CIRCUIT. The two dissimilar metal electrodes have names. The copper, from which the current flows to the external circuit, and which draws the electrons through the electrolyte, is the positive electrode, and is called the *cathode*. The zinc, from which the stream of electrons flow, into the electrolyte, and which receives the return from the circuits, is the negative electrode or *anode*. The current traverses both the electrolyte between the anode and cathode and the connecting wire so that it makes a complete circuit. The term *circuit* is applied to the entire path along which the electricity flows, and the wire along which it passes is the *conductor*. Bringing the ends of the two conductors connecting the battery electrodes together or into contact, and then separating them, is called making and breaking, or closing and opening, the circuit. The arrangement of acidulated water and pieces of copper and zinc is called a *voltaic cell* after Volta, the Italian, who devised the combination. A series of such cells, properly connected, is a *voltaic battery*.

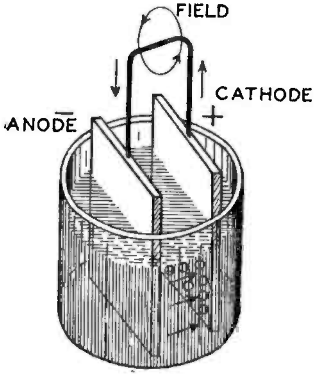


FIG. 15. SIMPLE PRIMARY CELL

CHEMICAL ACTION IN THE CELLS. When the cell is exhausted and the zinc has been consumed we find that the electrolyte contains the zinc in the form of zinc sulphate due to the chemical action between the zinc and the acid solution. The electrical energy was derived by this chemical action. If the cell is made of plates of the same material we have similar chemical actions on each plate which tends to neutralize the electrical effect. In the primary cell only one plate is acted on by the electrolyte. The greater the *disparity* between the two plates the greater will be the difference in potential between them, and the greater the amount of current. The degree of rapidity with which the negative substance is consumed will also tend to regulate the amount of current flow. As platinum is least affected by acids and zinc is the most readily consumed, this combination makes an ideal voltaic cell. However, it is obvious that platinum cannot be used; carbon or copper is substituted. Carbon, being the least expensive, is more generally used.

USE OF ZINC IN BATTERIES. The zinc used in cells must be very pure. If it has impurities, a *local action* will take place on the surface of the zinc due to the differing rate of consumption between pure zinc and the impurities. This will produce useless consumption of material as well as a lowering in efficiency. In radio work this is of the utmost importance, as each of the local actions will give rise to small electric currents which may produce additional noises in the telephones. The use of cheap or poorly built batteries may be the cause of much internal noise within the radio receiving set. When a cell is indicated in a radio diagram or any electrical circuit the negative or zinc electrode is represented by a short thick line and the positive electrode by a long thin line.

THE DRY CELL. The foregoing describes the best known type of galvanic wet cell, but for practical purposes a cell of this kind is difficult to use. To avoid the inconvenience of the wet cell, as well as the gas and corrosive danger of the electrolytic salts and acids, the same principles have been incorporated in the *dry cell.* Everyone is familiar with the dry cell. It is used for every purpose where a steady electric current of small proportions for short periods of time is required. It may be used in any position and will withstand much rough treatment. Millions of them are made and used annually, especially since the development of the low voltage radio electron tubes. Such cells are called dry because they carry their electrolyte in some absorbent material so that the cell may be placed in any position without spilling its contents. The cell is only apparently dry. The container is a zinc cup which

PLATE 1

Top: Radio A, B, and C dry batteries—courtesy Burgess Battery Company. *Center:* Storage A battery and charging unit—courtesy Gould Storage Battery Company. *Lower, Left and right:* Raytheon charging units—courtesy Raytheon Company. *Lower, center:* Metallic rectifier—courtesy Kodel Radio Corporation.

serves as the negative electrode and the electrolyte is water in which *ammonium chloride* (*sal ammoniac*) and *zinc chloride* have been dissolved. It is absorbed by a pulp lining placed around the inside of the cup, which is filled with a dampened mixture of *powdered carbon* and *manganese dioxide*, in the center of which is imbedded the positive carbon electrode. The cell is then sealed with a top covering of sealing wax or a tar compound. Dry cells deteriorate when not in use, the smaller sizes giving out first. Batteries should not be permitted to freeze, but should be kept as cool as possible. A dry cell becomes exhausted as soon as the electrolyte has been consumed and the inner surface of the zinc container has been changed into *zinc sulphate*.

USE OF DRY CELLS. The potential of a standard dry cell is about 1.5 volts. On short circuit it will generally show a current flow of about 25 to 30 amperes. But in order to secure the best service from such a cell it should be used only in a circuit which does not require much amperage and not for very long periods at a time. In no case should these cells be used where excessive currents are needed. It should be remembered that a dry cell will give its best service with greatest economy under the following arrangement: If one ampere is required the cell may be used only about 2 hours at a time; if $\frac{1}{4}$ of an ampere is needed per hour the cell may be used from 4 to 7 hours each day; and for continuous service, not more than 0.10 ampere per hour should be consumed.

CONNECTING DRY CELLS. If a circuit requires higher voltage the cells should be connected to allow 1.5 volts to each cell. For instance, if six volts are required, take 4 dry cells and connect them in *series*. See *A* in Figure 16. The outer negative post of one cell should be connected to the middle or carbon positive post of the *next* cell, and so on, until the two remaining posts are positive and negative, one on each of the two end cells. In this case the total voltage of the battery equals the sum of the separate voltages of the individual cells. If a higher amperage flow is needed it may be safely taken from dry cells if they are connected to give this greater amperage. This is a *parallel* connection and all of the negative or outer posts of all of the cells are connected, and all of the inner or positive posts are also connected. See *B* in Figure 16. In this case the total amperage is equal to the sums of the separate amperages, but the potential remains the same as that of a single cell. If higher potentials and amperages are needed the connection is called *parallel series*, in which the required number of sets of cells (*B*) is connected in series (*A*) to get the proper voltage. See *C* in Figure 16. As an example, 16 cells are shown connected in this way to give an output of 6 volts and 120 amperes.

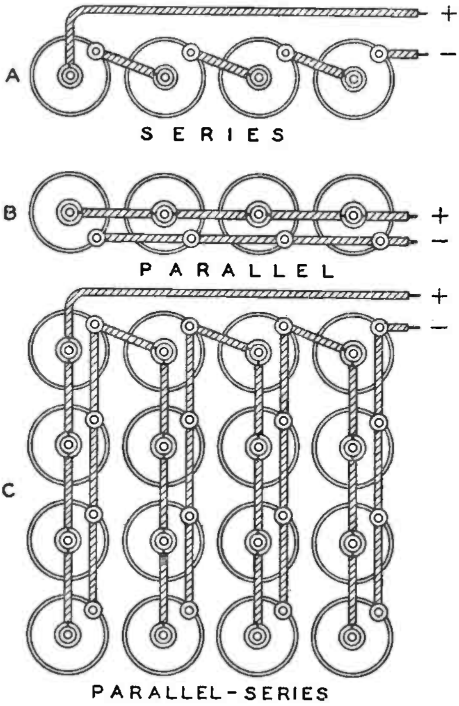


FIG. 16. CONNECTING DRY CELLS

(*A*) Series Connection; (*B*) Parallel Connection; (*C*) Parallel Series Connection.

THE STORAGE CELL. *Storage cells* differ from dry cells in all respects. Dry cells and galvanic batteries are known as primary cells as they create an electric current which keeps up as long as the elements and electrolyte are active. The storage cell is a *secondary* cell. It may be charged and discharged over and over without any renewals of the electrolyte and electrodes. There are two kinds of practical storage cells in use; the *lead-plate* cell and the *nickel-iron* cell. The former is the most universal and best known, and was developed many years ago by *Planté*. The nickel-iron cell, a comparatively recent invention of Thomas A. Edison, is reliable and, because of its lighter weight, has several advantages over the older type of lead cell. As the lead type of battery is more widely used at present we shall first consider its actions and uses.

THE LEAD STORAGE BATTERY. Generally speaking, a lead battery consists of a number of lead sheets or *plates* which are immersed in a solution of sulphuric acid electrolyte. The cell may consist of but two plates separated a small distance, or a number of plates, according to the desired capacity in amperes. They are connected alternately so as to present the greatest possible surface for chemical action. The electric current which is sent through a storage battery for charging purposes causes certain chemical changes to take place and electrical energy is thus changed into chemical energy. After the charging current is removed a *reverse* action takes place and the chemical state of the cell produces electrical energy. Storage cells do not store up electricity; they merely hold the chemical energy which produces an electric current until still further chemical actions reduce the elements and electrolyte to their original state. When a lead cell is formed and then charged, *hydrogen* gas is set free at the negative plates, and *oxygen* gas at the positive plates. The composition of the plates is changed and the *specific gravity* of the electrolyte is raised. When the cell is discharging the electrodes change to *lead sulphate*, and the hydrogen and oxygen recombine to form additional water which accounts for the lowering of the specific gravity of the electrolyte when the cell is discharged. If the cell discharges too much or too rapidly, a great amount of lead sulphate may be formed and cause *buckling* and damage to the plates.

STORAGE CELL PLATES. In the original Planté cell the plates consisted of sheets of pure lead, but in the modern cell each plate is merely a lead *grid* having hundreds of small openings. These holes are *pasted* with an active material or paste made from the necessary lead oxides. The grid, therefore, serves the purpose of holding the active materials after they have been pressed into place. All cells require negative and positive plates. The positive plates are filled with a paste of *red-lead*, and the negative plates with a paste of *litharge*. After the plates have set and the cell is built up, a current is sent through the battery and the positive plates are chemically changed into *lead-peroxide* and the litharge in the negative plates is changed into *sponge-lead*. If solid lead plates were used it would take many months before they would assume the spongy consistency necessary for maximum operation, and the high capacity reached by the modern pasted cell. The negative plates of a storage cell become a dull gray color, and the positive plates a reddish brown. The *separators* in a storage cell, which are placed between the plates, are made of thin wood or perforated hard rubber sheets. All similar plates of the cell are connected with a lead strap which is welded to the upper or projecting lugs of the individual plates. These connectors are put on opposite sides of the cell, and each set terminates in a common positive and negative connection. The cells are then connected in series to form the battery, allowing two volts to each cell.

STORAGE BATTERY ELECTROLYTE. A single cell of a lead-plate battery, when fully charged, will register a little higher than 2 volts, regardless of the size and number of the plates. The size and number controls the capacity in amperes the battery will furnish for a given time. When the cell is in a working condition it is filled with the electrolyte so that the plates are just covered. This electrolyte consists of a small quantity of pure sulphuric acid in solution with distilled water. When tested for *specific gravity* it should present a hydrometer reading of not less than 1.210. The *hydrometer test* is one of the most accurate methods of determining the condition of a cell, and may replace voltmeter readings. During the course of charging the specific gravity of the electrolyte increases and, when it reaches the proper reading, the cell is fully charged.

STORAGE BATTERY CHARGING. Direct current must be used for charging storage cells as it flows steadily in one direction, and it is easy to obtain constant negative and positive connections. The positive wire is connected to the positive post of the cell, and the negative wire to the negative post. Each cell of the storage battery is rated to deliver approximately 2 volts and the number of cells determines its total voltage. This is important to remember when charging batteries. The amount of current that flows through the battery is dependent upon the difference between the voltage of the battery and the charging voltage. As about 2.5 volts is the maximum required for the charging of one cell, the necessary voltage may be easily calculated. If the voltage of the charging current is excessive, a suitable resistance must be placed in the circuit. A cell that has been fully charged shows a specific gravity test of about 1.280 and, when discharged, the reading may fall as low as 1.140.

THE HYDROMETER TEST. For battery testing a syringe hydrometer should be used. It consists of a glass tube and rubber bulb, and contains, within the bulging portion of the glass, a weighted glass *float* that sinks to various depths according to the density of the supporting liquid. The end of the syringe is placed within the cell and sufficient electrolyte is drawn up into the tube to raise the float. The floating gauge has graduations marked on it, and the specific gravity may be instantly read. The electrolyte is then returned to the cell. In no case should the condition of the storage battery be tested by connecting a piece of wire across the terminals to note the resulting spark. This practice is to be strongly condemned as no battery should ever be short circuited.

STORAGE BATTERY CAPACITY. The *capacity* of a storage battery is rated in *ampere hours.* An ampere hour is a current of one ampere flowing steadily for one hour. The capacity of a battery is determined by the number of amperes flowing, and the number of hours they will continue to flow. For instance, if two amperes per hour flow for thirty hours, the capacity of the battery is sixty ampere hours. The number of amperes that the battery will give without injury to itself is called the *normal rate* of discharge. The size of the battery, that is the area of surface and number of plates in each cell, determines largely its ampere hour capacity and rate of discharge, as well as the length of time it will operate between charges. In many cases a large capacity battery will be more economical than a smaller one as the latter may require recharging every few days. When a radio set requires from 3 to 4 amperes the capacity of the battery should be not less than 60 ampere hours. A ten tube set, each tube drawing a quarter of an ampere an hour, requires 2½ amperes each hour which means that a 60 ampere hour battery will operate the tubes for about 24 hours before recharging. However, it is not good practice to allow a battery completely to run down. As soon as the specific gravity falls to 1.160 and the individual cell voltage to 1.7, the cell must be recharged. The time consumed in recharging is from 8 to 14 hours.

DETERMINING POLARITY. Before a battery is connected to the charging current the polarity of the supply wires should be ascertained. As both wires look the same it will be necessary to conduct a test for polarity, if the positive and negative terminals are not known. The easiest method of doing this is to take a glass of water in which a spoonful of salt has been dissolved, and dip the ends of the wires into the water while holding them about an inch apart. Tiny bubbles will form about the negative wire. This wire is then attached to the negative terminal of the battery and the other is attached to the positive terminal.

THE EDISON STORAGE BATTERY. The *Edison,* or nickel-iron battery, has for its positive plate a number of hollow tubes held in a perforated frame made of nickel plated steel. They are tightly filled with *nickel peroxide* and *flake nickel,* the latter greatly increasing the conductivity of the peroxide. The negative plate consists of pockets of perforated nickel plated steel supported in a frame of similar material, and these pockets are filled with *iron* *oxide.* The assembly of this battery is similar to the lead battery, the positive and negative plates being alternated, all of each kind being connected. In this case the electrolyte, instead of being an acid, is an *alkaline* dilute solution of *caustic potash* mixed with distilled water to a specific gravity of approximately 1.220. A small portion of *lithia* is added to the solution mixture.

EDISON BATTERY CAPACITY. The rated capacity of this type of battery is not based on any special ampere hour discharge, for, unlike the lead battery, the discharge may be at any rate without material injury to the cells. Overcharge does not harm. A fully charged cell registers about 1.5 volts, which is about 0.5 volt less than the charge of a lead battery. When discharged, the cell voltage reaches about 1.2. The state of the Edison cell cannot be satisfactorily determined with the hydrometer, and the voltmeter should be used to take readings of internal conditions.

STORAGE BATTERY CARE. All storage batteries must be given the best of care, never be handled roughly nor permitted to fall. Since lead batteries contain acid which will destroy almost anything it touches, the batteries should be kept in acid proof trays. The top of the battery must be kept clean and dry, as the metal portions are subject to *corrosion* by the acid and the fumes.

CHARGING CURRENT. Before a storage battery will give a current of electricity it must be charged with a separate electric current so as to bring the active materials into the proper chemical state. Only direct current can be used for charging. Alternating current which, for commercial purposes, changes its direction about 120 times a second (60 cycles), is unfit for direct battery charging, as it would attempt to charge and discharge the cells with each reversal of current direction. Unfortunately, alternating current is the one kind that is almost universally available. This is because its transforming qualities makes possible its transmission over great distances.

CHARGING WITH ALTERNATING CURRENT. The radio owner who has direct current available is indeed fortunate, for charging operations are greatly simplified. Alternating current, however, may be changed into a *pulsating* direct current by means of the rectifying principle. There are several methods of rectifying alternating current; the chemical system, the electron tube, the mechanical polarity changing vibrator, and the newly discovered metallic rectifier which permits electrons to pass in but one direction. Instead of 120 complete alternations in direction there will be 60 pulsations in one direction per second. An *intermittent* current flowing in one direction is the result, and we can obtain a negative and positive terminal for connection to the storage battery.

CHARGING WITH DIRECT CURRENT. If direct house lighting current is available it may be used in charging a storage battery. However, it is higher in voltage than is desirable, and, if a storage battery should be directly connected to it the low resistance of the battery would permit so high a current to pass through that the soft paste elements of the cells would be disintegrated, and the battery would be ruined. Regulation of the current is accomplished by placing some external resistance in the circuit. A simple arrangement is to connect the battery to the 110 volt direct current supply circuit through a number of electric lights. The charging current then passes from the negative terminal of the circuit through a bank of lamps, and into the battery by way of the negative post; thence, out through the positive battery post into the positive wire of the circuit. The number and size of the lamps in the resistance will depend upon the number of amperes required for charging the battery. For every ampere of charging current desired to pass the battery approximately 110 watts of lamps will be needed. For a normal charging current of 4 amperes it will be necessary to use 440 watts of lamps (the product of 110 volts and 4 amperes) connected in parallel into a *bank* which is then connected in series in the circuit, as shown by *A* in Figure 17. As the battery is also in series with the lamps, the 4 amperes needed to light them passes through the battery and provides the charging current.

THE CHEMICAL RECTIFIER. The chemical type operates on the principle that electricity will not flow in both directions between two dissimilar metals that are immersed in certain conducting solutions. An example is an *aluminum rod* immersed in a *borax* solution held in a *lead cup.* Electricity will flow only from the rod to the container. When the supply current alternates and the aluminum rod becomes positive for 60 of the 120 alternations per second, bubbles will form about the rod and act as insulators, preventing the flow of electricity. But when the lead cup is positive during the next half of the cycle, these bubbles are not formed, and there is no interference to the flow from the negative aluminum rod to the lead cup. The current obtained, therefore, is simply the pulses of current of one potential which pass the rectifier. The solution used in the chemical rectifier should be slightly less than a saturated solution of borax and distilled water. The rectifier is connected in series with the supply current and the storage battery, and the lead plate terminal to the positive plate of the storage battery, as only the positive pulsations are permitted to pass through. See *B*, Figure 17.

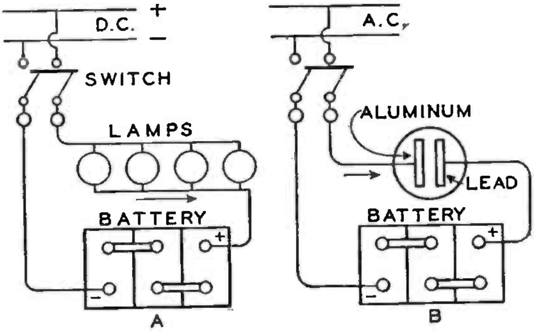


FIG. 17. STORAGE BATTERY CHARGING

(*A*) Charging with Direct Current; (*B*) Charging with Alternating Current.

THE TRICKLE CHARGER. There is another type of charger known as the *trickle charger*, which permits a very small amount of current to pass through during long intervals. This method of keeping the storage "A" battery in a state of constant charge is highly convenient. It may run day and night whenever the set is not in use, and the battery is always kept fully charged. The charging rate of a trickle charger should be so determined that the battery will have returned to it an amount of charge equal to that withdrawn by the operation of the set, plus a small additional amount to compensate for losses and inefficiency. As a rule, this charging rate should not exceed one half an ampere per hour.

THE ELECTRON TUBE RECTIFIER. The *tube rectifier* consists of a gas filled tube containing two or three electrodes. One electrode is a filament which is heated or lighted by the supply alternating current, and the other is simply a cold plate of some kind. When the tube is lighted the gas is rendered conductive in but one direction so that the flow of electricity passes only when the filament is negative, or 60 times out of every 120 alternations per second. When the filament becomes positive during the remainder of the alternations the gas is a non-conductor, and current cannot pass. When the storage battery is connected with the tube rectifier the current can pass from the supply wire through the positive terminal of the battery, and out through the negative terminal to the plate of the tube, thence across the gas to the heated filament and back into the supply line of the power circuit. This type of charger will work with all sizes of storage batteries, and will charge a number at one time. There can be no leakage back from the battery as it is impossible for the current to pass through the gas when the tube filament is not lighted. It is not necessary that the device be removed from the circuit when not in use. Some resistance may be necessary, however, to reduce the original voltage of the supply.

METALLIC RECTIFIERS. Two new methods of rectifying alternating currents for battery charging have been devised. One is the use of a colloidal alloy tube, while another is a copper alloy disc. The latter operates on the principle that this particular alloy will permit electrons to pass between the atoms in but one general direction. The *Raytheon* metallic tube rectifier consists of a cathode of colloidal alloy about which is packed fine silver containing sulphuric acid. Rectification takes place between the cathode and the silver, as the current can pass in only one direction. It is a half-cycle rectifier passing $2\frac{1}{2}$ amperes at 8 volts for charging a 6 volt battery. The *Kuprox* copper disc rectifier employs a unit composed of about 12 special alloy discs connected in series-parallel. Such a unit will operate as a half-wave and full-wave rectifier, but will not pass more than $1\frac{1}{2}$ amperes. Both types of rectifier must be used in the secondary circuit of a step-down transformer delivering a potential of not over 8 volts.

CURRENTS FOR THE RADIO RECEIVER. Radio receiving sets require a certain amount of electric current for their operation. Some sets, however, such as those operated by a rectifying crystal, need no battery. In these cases the sensitivity of the receiver is very low. Batteries are required with all electron tube sets, and if the current is not derived from a battery, it must be obtained from some other source. The electron tube, as explained in the chapter dealing with that essential piece of radio apparatus, requires two, and sometimes three, sources of electric current. One source of low voltage is used to light the filament, and is universally known as the *"A" current*; another source of higher potential, used to charge the plate, is known as the *"B" current*, while still another source, used to give a negative bias to the grid, is known as the *"C" current.*

THE "A" CURRENT. The "A" current is usually derived from storage batteries for the standard 6 volt tubes, and from dry cells for low voltage tubes. It may also be derived from rectified and filtered alternating current. The "A" current is comparatively heavy and its strength depends upon the number of tubes in the receiver and their current consuming capacity. A heavy drain on the "A" battery will require frequent recharging of the storage battery or renewal of the dry cells.

THE "B" CURRENT. The "B" current, used on the plates of the tubes, and for operating the telephones or loud speakers, is of much higher potential than that from the "A" battery, but the current consumption is considerably less, being measured in *milliamperes*. The number of tubes, and the type of speaker, will determine the rate of consumption. The cells used in construction of the "B" battery need have but small capacity in ampere hours. It is a common practice to make these batteries up from a large number of cells similar to those used in flash light batteries, as the capacity is quite sufficient. The potential of "B" batteries usually runs in multiples of 22½ volts, the smallest standard unit being of that voltage but having intermediate connections for several lower voltages. The size of the "B" battery used in the radio receiver will depend upon the number and style of the tubes. The "B" current may also be obtained from small storage cells, each cell being rated at 2 volts. A sufficient number of cells are connected in series in a rack. The charging of the "B" storage battery is similar to the charging of the "A" storage battery, except that the charging voltage must be higher, and the rate considerably less. Large radio sets are more economically operated on storage "A" and "B" batteries.

THE "C" CURRENT. The "C" battery is familiar, at least in name, to most users of radio receivers, although the exact purpose of it does not seem to be well understood by the layman. If a high potential "B" current is used on the plate of a tube we must consider the flow of electrons from the filament to the plate. The grid acts as a valve or trigger control for the flow of electrons and, in an amplifier tube, very slight variations of the potential of the grid cause relatively high variations in the electron flow of the plate. When the "B" potential is high, the current flow is also high, but if the grid is given a steady negative charge, less current will flow, and it may be stopped entirely, thus reducing the drain on the "B" battery when no signals are being passed by the tube. The use of the "C" battery not only saves the "B" battery, but it tends to prevent distortion in the tube. The plate current should be an exact reproduction of the *changes* in grid variation. The "C" battery consists of a number of small cells connected in series. Its negative terminal is connected in the grid side of the circuit and its positive terminal to the negative "A" filament lead. The current consumption is negligible, and the battery will last for many months. The use of the "C" battery will be referred to further.

BATTERY ELIMINATORS. As already explained, an alternating current cannot be used for charging storage batteries, nor can it be used for the direct operation of the tubes, unless rectified. The use of generated current on the plate or filament of a tube would result in a powerful hum which renders all radio reception impossible, by changing the polarity 120 times each second. However, the use of suitable rectifying and filtering apparatus will so change the characteristics of the alternating current that it can be used on the plate of the tube or for lighting the filament. Such a device is known as a *battery eliminator.* The chief method of operation is the rectifying principle, with modifications and the addition of suitable filtering devices. This may be accomplished either by electrolytic or chemical rectifiers, or by electron tubes. There are a number of manufactured eliminators that employ both principles. The results are the same; the current is rectified and made to flow smoothly and steadily. A suitable filter system makes unnoticeable any irregularities and fluctuations in the rectified current. The filter system consists of a suitable arrangement of condensers and choke coils. "B" battery eliminators cannot deliver a voltage in excess of that taken from the supply line (110 volts) unless step-up transformers are first used to increase this potential.

SIMPLE TYPE OF CHEMICAL ELIMINATOR. A simple chemical rectifier unit is easy to build. Four heavy glasses of about one-half pint capacity each and a few strips of aluminum and of lead are used. The strips of metal are bent to hang over the edges of the glasses at points opposite each other, one sheet of lead and one of aluminum to each glass. The elements in each glass are then connected as shown at *A* in Figure 18. A solution of about one ounce of ordinary borax to one pint of water is poured in the glasses to within three-quarters of an inch of the top. Besides the rectifying units, several fixed condensers and a choke coil of several thousand turns of fine wire are required. A variable resistance of at least 25,000 ohms is used so that proper "B" voltage can be taken off. This system of condensers and the choke coil will satisfactorily filter out the characteristic intermittent hum.

The Raytheon Tube Battery Eliminator. Certain electron tubes are used to convert an alternating current of high potential into a direct current for use in the plate circuits of radio receivers. The *Raytheon tube*, indicated by *R* in Figure 18 *B*, gives a full wave rectification instead of but single alternations or half-cycles. Both halves of the cycle are permitted to pass as a direct current. It will provide a reliable, continuous and steady source of plate current, and assures a distortionless flow through the reproducing units. The tube has two anodes by which the current enters, and one cathode by which it leaves. The former are small, while the

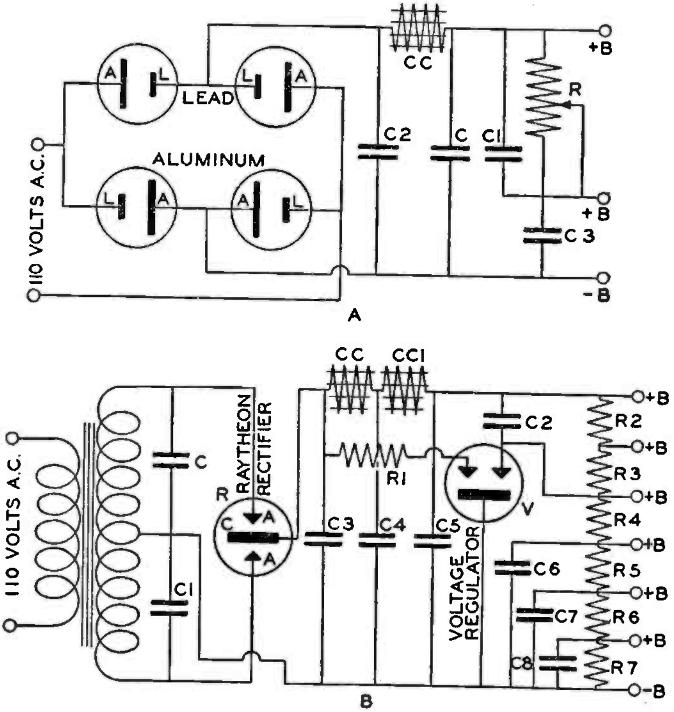


Fig. 18. Alternating Current Battery Eliminators
(*A*) The Chemical "B" Eliminator; (*B*) The Raytheon Tube "B" Eliminator.

latter is large. Rectification occurs by virtue of the fact that on the reverse alternation clouds of electrons attempt to bombard the small anodes and build up a space charge which effectively blocks the flow of current in that direction. On the forward alternation, the cathode being large, the electrons have a large surface to strike and, consequently, low resistance is offered the current flow. *Helium gas* is used within the tube because of its low density and the comparatively light mass of its atoms and ions. The battery eliminator circuit that the radio experimenter has been advised to follow is shown in Figure 18 *B*. In this connection a voltage regular tube is used to keep the high potential output constant. Voltage regular tubes are more fully described elsewhere. A step-up transformer which will increase the 110 volt current to about 400 volts must be used. The secondary of this transformer is wound so the potential is delivered in two blocks of about 200 volts each.

THE RAYTHEON TUBE ELIMINATOR FILTERING SYSTEM. The two choke coils, *CC* and *CC1*, shown in Figure 18 *B*, should have inductances of between 20 to 30 henries at the maximum direct current drain. These coils together with the high potential filter fixed condensers, will filter the intermittent hum of the rectified alternating current from the final output. Variable resistances are used to give finer regulation of the actual "B" current. The locations of the condensers and resistances are indicated in Figure 18 *B*.

CAUTION. It should be remembered that all battery eliminator circuits using 110 volts and delivering much higher potentials at the secondary and elsewhere for rectification are potential sources of *danger*. A short circuit may cause fire or damage to the receiver, and a serious *shock* may be given. The rectified current should be handled carefully and all wires thoroughly insulated and protected by fuses and switches. In such circuits the iron cores of the transformers should be grounded. It will be well to place a large capacity fixed condenser in the ground wire of the receiving set to prevent grounding of the apparatus in case of a short circuit in some portion of the built-in battery eliminator. The use of such a condenser will not affect the operation of the receiver.

CHAPTER IV

THE FUNDAMENTAL PRINCIPLES OF RADIO

TRANSMISSION OF ENERGY. Radio transmission of energy is brought about by sending out through space electromagnetic waves which have some of the general transmitting characteristics of heat, light, sound or water waves. For instance; if an iron bar is heated, it will send out heat waves; if a piano key is struck, the related wire will send out sound waves; if a lamp is lighted, it will throw off light waves; and if a stone is let fall into still water, it will send out water waves. In all cases, the *wave motion* is a form of energy which is transmitted through some medium having conductivity for the type of wave in question. Wave motion is always caused by a *vibration* of some sort at its source.

VIBRATION A SOURCE OF WAVE ENERGY. The heated iron bar, is a source of vigorous vibration because of the movement of its molecules. As the bar becomes hotter, the molecular agitation increases until the metal melts. Striking the piano key vibrates a wire and due to the sounding board, the vibrations are transmitted to the air in the form of sound waves. The sounding board, in order to propagate waves within audible limits, must have no vibratory period of its own. This condition is called *aperiodic.* A radio circuit which has no natural frequency, but which responds to any vibration, is known as an *aperiodic circuit.*

THE ETHER. Sound and heat vibrations are conducted through some tangible medium. Light waves which have extremely high frequencies or rates of vibration, are conducted by a hypothetical medium that exists everywhere in space, and is known as the *ether.* Electromagnetic waves are believed to be transmitted by the same medium to some extent, although these electric frequencies vary greatly and the wave lengths are very high as compared to those of light waves.

WAVE MOTION. To obtain an electromagnetic (radio) wave we must set up an electrical vibration in a *radio circuit* so that it will *radiate* a wave. Before we can understand vibrating radio circuits a study of wave motion is of particular importance and, water is often selected for illustrative purposes. Imagine a ball dropped into a pool of still water. At the point where the ball strikes the water, an up and down motion is set up and is transmitted over the surface of the pool, but without any forward movement of the water itself. See Figure 19. These waves spread out in circular form, concentric with the point at which the ball strikes the water. Within a few seconds the water at this point will again be calm, but a block of wood floating upon the surface some distance away, is given a bobbing motion as the wave passes beneath it. Energy has, therefore, been transmitted over this distance by means of a wave motion. The number of "bobs" imparted to the block in a given unit of time represents the frequency of the wave.

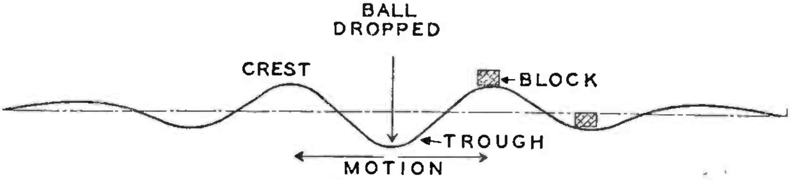


FIG. 19. WATER WAVE MOTION

WAVE LENGTH. Each wave has two opposite motions. One is the depression or *trough*, and the other is the rise or *crest*. Every wave has length. In our water wave analogy the *wave length* is taken as the distance from one wave to another or between the crests of two successive waves. All wave lengths are similarly measured.

WAVE VELOCITY. The distance that one crest travels in a unit of time (one second) will be its *velocity*. Waves of various kinds have different velocities, depending upon the conducting medium and the generating sources. Water waves may vary greatly, however, as large ocean waves may pass at the rate of a mile a minute while the small ripple produced by the ball will travel only a few feet per second. Sound waves in air travel a little less than

1,100 feet per second, while the velocity of radio waves is about 186,300 miles per second.

WAVE FREQUENCY. The velocity, frequency and wave length have definite relationships. It is possible, if the velocity is definitely established, to vary the frequency and wave length accordingly. If, in our small water wave in the pool, the block is permitted to rise and fall a great many times each second, the frequency of the waves is high and the wave length or distance between crests must be short. But if the block is raised only a few times, the frequency must be low and the wave length greater. Therefore, if the velocity remains the same, waves of long length have low frequencies, and waves of short length have high frequencies. The motion of a wave, from the beginning of the rise of a crest, then through the crest down to the lowest part of the depression or trough and back to the beginning of the next crest, is called a *cycle.* The frequency is expressed in cycles; to say that a wave motion has a frequency of one thousand, means that its motion passes through 1,000 complete cycles per second. The velocity per second must be always equal to the *product* of the frequency and the wave length. For instance, if the water wave has a velocity of 10 feet per second, and the distance between wave crests is two feet, the frequency will be five wave crests per second, or, if there is a frequency of two waves per second, the wave length between crests must be 5 feet. When referring to many cycles or high frequencies, the cycles are grouped into units of a thousand each, and are known as *kilocycles.*

DAMPED AND CONTINUOUS WAVES. Dropping the ball into the pool set up a *train* of waves, but the train soon died out, leaving the surface calm. The train of waves is then said to be *damped.* See Figure 20 *A*. But if another ball is dropped just as the first wave train is fully developed, another wave train is started in harmony with the first. If this is kept up the wave trains will not die out but be kept in motion by successive balls or sources of power and vibration. Such waves are then said to be *continuous waves.* See Figure 20 *C*. For instance, if we have a freely swinging pendulum and hold it to one side and then let go, it will swing back and forth or *oscillate* until it comes to rest. The first oscillation moves through the greatest distance and has greatest amplitude, but this strength gradually dies away and each swing is less until the pendulum comes to rest. This entire series of oscillations makes up the cycles that the pendulum passes through as the result of one original impulse. These oscillations may be said to be damped, and the whole series resulting from one push given to the pendulum is but one *train*. However, if at the completion of one swing of the pendulum or at the end of the cycle, we give it a fresh impulse of the same strength as the original, the swings are then *undamped* or continuous, as the amplitude does not decrease after each complete swing. The number of complete wave trains in damped radio transmissions may have a frequency considerably over 1,000 per second. Each train is made up of a large number of wave oscillations. The continuous wave has constant amplitude as long as the steady electric oscillations keep up in the circuit.

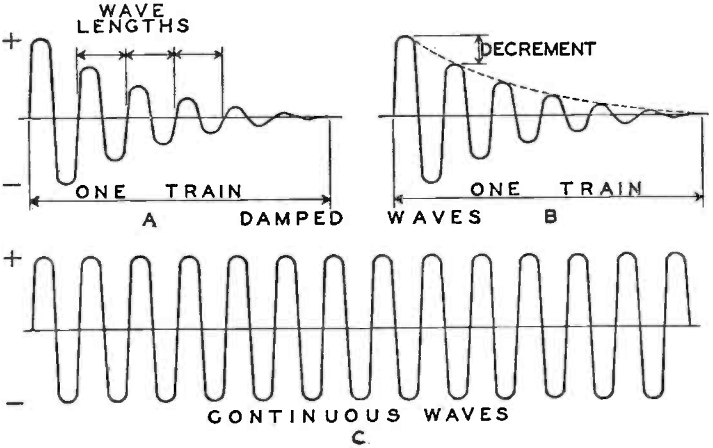


FIG. 20. WAVE MOTIONS
(*A* and *B*) Damped Waves; (*C*) Continuous Wave.

WAVE AMPLITUDE. Referring again to the water wave, the greater the surface of the water displaced the greater is the amount of energy transmitted. Ocean waves have more power than waves on a small body of water. The difference in height between the crests and troughs of the waves is called *amplitude.* In general, it may be said that the energy depends upon the degree of amplitude.

RADIO WAVES. We now have in wave motion: The velocity, the frequency, the wave length, and the amplitude; and the whole may be in the form of damped waves or continuous waves. Radio waves are due to electromagnetic disturbances of such a nature that they will produce about the center of occurrence, an oscillating magnetic and electric field. If we have a wire through which flows an alternating current, an alternating magnetic and electric field will be set up all about it. These fields will travel away from the wire by wave motion. Radio waves have the velocity of light, which is about 300,000,000 meters, or 186,300 miles, per second. Since this velocity is constant, the frequency and wave length have a direct relationship. The waves are also alternating, having the characteristics of the radiated current at the place of origin.

FREQUENCIES USED IN RADIO. The frequency used in radio transmission for continuous and damped waves is very high, due to the fact that more power is radiated at high frequencies than at low. The amplitude of waves of high frequencies is much greater than that of low frequencies. These high frequency currents are beyond the range of human hearing. If they were sent through a telephone receiver no sound could be heard as the diaphragm could not vibrate at such a high rate, due to its mechanical inertia and, even if it could, the ear would not detect the vibrations. The human ear can detect only those sound waves sent up from vibrations having a frequency varying from about 50 to less than 10,000 per second. The audible waves vibrate at *audio-frequencies,* while those used for radio broadcasting at 10,000 to 300,000,000 cycles per second, or *radio-frequencies.* In speaking of radio waves, it has been the common practice to refer mostly to the wave length, giving that in meters; but there is now a growing tendency to state the facts more clearly, and to speak of the frequency of the wave motion in cycles per second.

OSCILLATING CIRCUITS. We have seen that the action of some vibrating apparatus is necessary to produce a train of waves. The source of vibration of electromagnetic waves is an oscillating electric current passing through a circuit. The circuit from which the oscillations are sent forth is called the *antenna sending circuit* and consists of certain apparatus which will produce the required frequency in the outside system of wires or *antenna*, from which the electrical energy is *radiated*. To oscillate freely, an electric circuit must have a certain inductance and capacitance. Wire coils form the inductance and condensers provide the capacity.

RADIO WAVE PROPAGATION. It is safe to say that more study, without arriving at some really definite conclusions, has been given to the propagation of radio waves than to any other art. It is now believed that lines of force, which are set up between the antenna and the earth beneath become separated from the antenna with each cycle of the charging and oscillating current, and become radio waves. Thus energy is said to be radiated, and the action is known as *electromagnetic radiation*. Ordinary electric and magnetic fields of force, do not exist far from a conductor, and do not become detached. Since the electric fields about an antenna build up and die down with each oscillation of the antenna charging current, it follows that the energy present in the field must be drawn back into the antenna when the field collapses, as the maximum potential begins to diminish. However, not all of the energy which had at first moved out from the antenna will be withdrawn into the conductor before the potential difference (between the antenna and ground as two plates of a condenser) begins to build up in the *opposite* direction. Thus, energy is again sent out in the form of an electric field, but in the opposite direction. There is then left a certain amount of energy in the form of an electric field. Because the antenna is already sending out more energy, this field is pushed off by each following field. Each successive movement is a wave or cycle of opposite direction. The moving electric field will produce a magnetic field and, so, we find that the advancing electric field has a magnetic field swinging back and forth, but at *right angles* to the electric field. Antenna currents having very high frequencies will prevent the return of but little of the collapsing electric field, and this accounts for the radiation of more energy at such frequencies than at lower frequencies.

RADIO WAVE INDUCTION. A radio wave from a broadcasting station spreads out symmetrically from the antenna with uniform intensity and, as it passes a given point, the magnetic field varies from moment to moment from the maximum in one direction to the maximum in the opposite direction. The cycle from one maximum through zero back to maximum in the same direction is performed in a very small portion of a second. If the wave length is 300 meters, this cycle is performed in one-millionth of a second or repeated one million times each second. In a previous chapter we have seen that when a wire is passed through a magnetic field, a current is set up in it. In radio reception there is a receiving antenna or wire, and as the advancing electromagnetic waves *sweep* across it, an electric current is set up in the antenna. It is alternating in value and of the same frequency as the electromagnetic wave. In this case the wire is not passed through the advancing field but the field sweeps past the wire. The induction results are the same. This *induced current*, being of such a high frequency, is a radio frequency current, and is the kind always found in the antenna while the broadcast wave is passing.

RADIO WAVE ATTENUATION. The broadcasting station sends out a radio frequency electromagnetic wave and, if the station is properly tuned, it will not vary in amplitude or frequency. However these waves spread out, due to the increase in distance from the transmitter, and their amplitude decreases. This decrease, expressed in terms relative to the full strength at the source, is called the *attenuation* of the wave.

MODULATED CARRIER WAVES. The continuous series of wave trains sent out from the transmitting station constitute the *carrier wave*. See *B* in Figure 21. This wave would serve no purpose and would not be audible, if it were not for the fact that it is possible to alter it by *modulation*. This consists of the impression of sound waves (*A*) from the microphone. The wave then assumes the form shown at *C*. The amplitude of the high frequency current in the antenna is varied with the strength of the voice into groups or trains of an audible frequency. If we had a picture of the continuous carrier wave, shown at *B*, we would see that it has been *moulded* to conform with the shape of the sound waves shown at *A*, to the form shown at *C*, because of the sound waves from the microphone which are impressed upon it. The resulting trains having audio frequency characteristics may be detected in the receiving set.

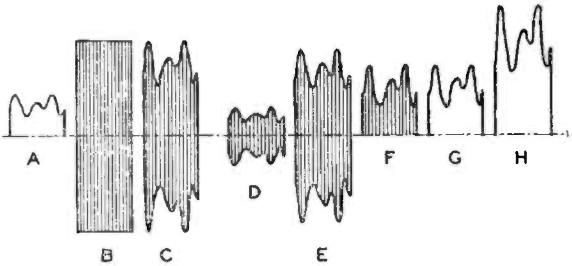


FIG. 21. RADIO WAVE FORMS

(*A*) Microphone Current; (*B*) Continuous Carrier Wave; (*C*) Modulated Carrier Wave; (*D*) Received Radio Frequency Current; (*E*) Amplified Radio Frequency Current; (*F*) Rectified Current in Detector; (*G*) Average Audio Frequency Current; (*H*) Amplified Audio Frequency Current.

THE ANTENNA CIRCUIT. The current induced in the receiving antenna (*D*) is of the form shown at *C* in Figure 21, and consists of a modulated radio frequency current. Coupled to the antenna is a circuit consisting of inductances in the form of coils, and capacities in the form of condensers. This is the *antenna tuning circuit* and it is capable of being *tuned* or adjusted so that it will respond to only one frequency, that of the desired incoming wave. The ideal radio receiving set is one that can be tuned to one frequency, barring all others. Unfortunately, this is impracticable as yet, and other frequencies close to the one desired may also be received, causing some degree of *interference*.

AMPLIFYING CIRCUITS. Coupled to the antenna circuit may be one or more other circuits which *amplify* the incoming radio frequency waves and also aid in the tuning of the set. See *E* in Figure 21. But there need be nothing complicated about radio reception as the apparatus may be of the simplest sort. If it is the desire to cover great distances or produce sound on a loud scale, a more elaborate receiving circuit is required. The various instruments and apparatus required for radio reception will be described in later chapters.

TUNING CIRCUITS. The coils in the tuning circuit are for the purpose of introducing inductance and reactance in the circuit. The more inductance placed in a circuit the longer will be the wave lengths that the receiver will respond to. If the inductance is cut down to zero the set will respond only to waves of the same length as that obtained naturally by the length of the antenna, unless certain corrections are made which will cut down its natural period. The condenser is another device for varying the wave length or frequency. For the sake of simplicity and ease of tuning the condenser is made *variable*. A gradual turn of the dial will increase or decrease the amount of capacity and reactance and change the resonance to various frequencies. Now if we tune the antenna circuit, and any secondary circuits with which the set may be provided, to the frequency of the transmitted wave, using the inductance and capacity, the maximum power of the received oscillations will be transferred to the different circuits and a *maximum voltage* will exist *across* the terminals of the tuning circuit. These terminals are the *inputs* of the detector circuit.

THE DETECTOR CIRCUIT. As we have seen, radio frequency currents are beyond the range of audibility. To make them audible, they must be changed in frequency, but not in characteristics. The *detector circuit*, which really is not a detector but a rectifier, consists of a rectifying unit and a pair of telephones connected across the terminals of the radio frequency tuning circuit. The rectifier may be a certain kind of crystal or an electron tube. The maximum flow of current passes through it as the antenna circuit must be tuned to resonance and maximum potential induction. Because of this maximum flow of current at one frequency other waves of nearby frequencies are drowned out to a great extent. The rectifier or detector permits the alternating current coming from the tuning circuit to flow through in but one direction. See *F* in Figure 21. This changes the alternating current into a pulsating direct current but the frequency is still too high to be audible. But as the incoming wave has been modulated into groups or trains at the broadcasting station, there is, for each one of these groups of waves, a unidirectional or direct pulse of current through the telephones. The pulses follow one another with the rapidity with which the sound waves have been impressed on the carrier wave during its modulation, and the diaphragm of the telephone is therefore actuated at the passing of each wave train. See *G* in Figure 21.

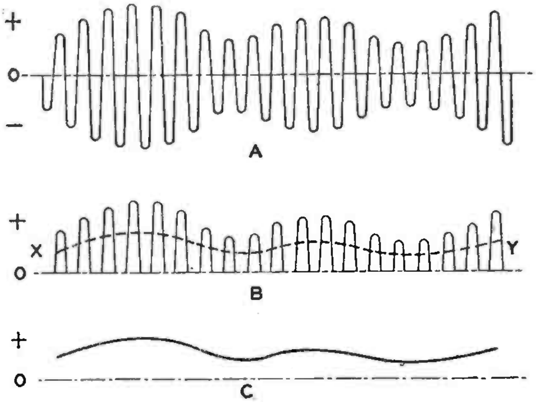


FIG. 22. FORMS OF RECEIVED CURRENT

(*A*) Antenna Induced Current; (*B*) Rectified Detector Current; (*C*) Average Current and Telephone Displacement.

SOUND REPRODUCTION. A coil of fine wire, such as the windings of a telephone receiver, presents a high impedance not only to the radio frequency wave, but to the rectified and unidirectional pulsations of current, as the pulses occur at the same rate. See *A* and *B* in Figure 22. The telephone windings are shunted by a small fixed condenser which has practically no reactance to the rapid pulsations and permits this current to pass. But variations in amplitude of the rectified current (B), due to the impressed modulation, pass through the telephone windings as potential variations only. That is to say, generally speaking, it is an *average* current. See xy in Figure 22. The amplitude of the vibrations (C in Figure 22) of the telephone diaphragm will depend, of course, upon the strength and amplitude of the electromagnetic field passing the antenna. The average current flowing in the telephone windings is the audio frequency current and may have an extreme displacement frequency of up to 10,000 cycles per second.

THE CARRIER WAVE. It has been shown that a carrier wave of high frequency is necessary for the transmission of telephone and telegraph signals if the continuous wave method is to be followed. It might be thought that the carrier wave could be eliminated and the vibrations of the microphone at the transmitting station be carried directly into the antenna, thus doing away with the intermingling of frequencies, and the necessity of rectification. This scheme will not work in practice. It would require an enormous antenna and great power to cause the low frequency voice currents to radiate sufficient energy to travel even a short distance. The necessity for the high frequency carrier wave is obvious, especially when we realize that the amount of energy sent out is proportional to the frequency of the wave.

DECREMENT OF WAVE TRAINS. The circuit is *resonant* when its reactance to the radio frequency current is zero and its tuning at this point is the *resonant frequency*. Now as long as the alternating current resistance of the circuit remains at zero and we have an *absolute* resonant frequency, the sustained electrical oscillations will apparently go on and on without diminishing in amplitude. This is the case in the continuous wave transmitting station emitting a carrier wave. But if the current that is established in the circuit gradually dies down, it is said to be damped, and this decrease, when expressed in the logarithmic relation between successive maximum values of the cycles, is called the *logarithmic decrement*. This decrement may be considered as a number which bears a relation to the rate of decrease of a wave train. The lower the decrement, the better the set is adjusted, and the closer the absolute resonant frequency is approached. In a circuit having reactance the wave trains die away, and the greater the reactance or the lower the resonant frequency the more rapidly the trains die away, and the greater will be the decrement between complete oscillations. It may be defined as the *ratio* of the dissipation of energy per cycle to the energy transmitted during the same period of time. As shown in Figure 20, the decrease in amplitude does not die out in a straight line, but is a gradually flattening curve, and the difference in the height of two successive cycles is the logarithmic decrement.

DECREMENT AND INTERFERENCE. The smaller the decrement the sharper the possible tuning and the less the chance of *interference* with stations on other wave lengths. When a transmitter has a high decrement, the difference in amplitude between the first and last waves of a train will be very great and, because of the larger electric impulse of the first wave, a larger response will be obtained from receivers within range. This first impulse will force a current into receiving sets which are not tuned to it, which acts to *broaden* the tuning and produces interference. Spark transmitters have a very high damping and correspondingly large decrement. They are therefore one of the principal causes of radio interference. When a circuit has a very feeble damping or the decrement is low, each impulse is small and of nearly the same value, so that the waves die out very slowly. In this case the circuit is quite sharply tuned.

APPARENT DECREMENT OF CONTINUOUS WAVE TRAINS. An unmodulated continuous wave, as produced from an electron tube acting as an oscillation generator, has no decrement. There are no wave trains or falling off in amplitude as long as the power remains constant. But as soon as the carrier wave is modulated (*C* in Figure 21) there are constantly changing amplitudes or groups of wave trains. A modulated undamped wave may affect radio receivers which are slightly *de-tuned,* in the same manner as a damped wave which has decrement. The effect of this modulation is most noticeable when the broadcasting station is nearby, and often interference over a wide range of tuning is observed. When the transmission is on long wave lengths the interference is *greater* than when on short wave lengths. This explains the limitations to the use of long wave lengths for radiotelephony. The radio frequencies approach the audio frequencies when long waves are used and, because of the strong pulsation of the speech currents and great variations in amplitude, the interference is over a band of many meters on either side of the established transmitting wave length.

THE SPARK TRANSMITTER. *Spark transmitters* are the oldest type of radio wave oscillators; they are simple and of rugged construction and, while their decrement is considerable and tuning is broad, they are well adapted to some methods of communication. The spark is obtained from a *spark coil* or high tension transformer. The former usually operates on batteries, and the latter on alternating current.

THE SPARK COIL. The induction or *spark coil* consists of a *primary coil* of a few turns of heavy wire over a soft iron *core.* This primary is connected in series with a *vibrator* that works at one end of the core. The contacts and tension of the vibrator control the rate at which the current passing through the primary coil is broken. A large capacity condenser is shunted across the vibrator points to absorb the sparking when the current is broken. Over the primary coil and the iron core is wound the *secondary coil* which consists of many thousands of turns of fine wire, wound in carefully insulated layers and sections. The making and breaking of the primary current by the vibrator sets up an electric current of very high potential in the secondary. When the two terminals of the secondary are connected to a *spark gap* a continuous stream of sparks will pass across the gap as long as the sending key (which is in the primary and battery circuit) is pressed. Each break in the primary circuit caused by the vibrator interruption produces a spark in the spark gap. These sparks occur at an audible frequency and each one completes a single train of oscillations. Each train has a number of oscillations consisting of many alternations of current which grow less and less in amplitude as the train is damped out. See *A* and *B* in Figure 20. For instance, a spark discharge having a frequency of 1,000 audible trains per second produced by 1,000 interruptions of the vibrator per second, may have hundreds of oscillations to each train, thus making the total oscillations per second far beyond the audible limit. When alternating current is used, the spark coil or transformer does not need a vibrator as the current alternations provide the necessary changes in primary strength, with a result of one wave train per alternation.

THE SPARK GAP. A *spark gap* consists of two insulated metal electrodes or rods arranged so that the distance between ends can be adjusted. The length of the gap is limited by the potential at the terminals of the secondary of the spark coil or transformer. The spark gap may be built either as a simple stationary gap, as explained above, or as a *quenched gap* or as a *rotary gap;* the two latter types produce a better spark with steady tone and the damping is not so pronounced.

OSCILLATING SPARK TRANSMITTING CIRCUIT. A condenser is used in series with an inductance and across the spark gap, and as the condenser discharges across the gap, it sets up the necessary radio frequency oscillations bunched together into groups or trains. A rapidly changing electromagnetic field is produced about the coil inductance. This is called the *oscillation transformer*, and is connected in series with the antenna. The high potential of the spark coil is therefore used to charge the condenser so that it can discharge across the spark gap. Oscillations pass freely until the energy is spent or the train is damped, when another discharge takes place producing a second train of waves. The cycle takes place as many times per second as the vibrator of the spark coil works, or the primary current of the transformer alternates. The antenna is charged with the radio frequency oscillations with audible groups of wave trains impressed upon them, and radiates just as any antenna will when charged with a rapidly alternating current.

STRENGTH OF SPARK SIGNALS. If a spark station sends out a wave train frequency of 1,000 or more per second, the amount of power sent out will be much greater than on a frequency of only 500 per second. The waves are more nearly continuous as the separate trains have little time to die out. These wave trains strike the receiving antenna more frequently, and their amplitude does not need to produce so great an effect of strength as when the waves are far apart. The higher frequency also gives off a higher pitched tone, more easily heard and distinguished through interference.

CONTINUOUS WAVE PRODUCTION. It is impossible to increase the spark frequency toward the continuous state beyond certain limits by the use of spark coils and rotary gaps, so it becomes necessary to use some source of undamped wave production, such as the high frequency *alternator*, the *arc convertor*, or the *electron tube*. As this latter source is the one of most importance in radio, it is explained quite fully in other chapters. Here we shall consider only the alternator and the arc. The higher the frequency of the transmitted wave and the nearer it approaches a pure wave, the less is the power required for radiation. The tuning becomes very sharp and on the shorter wave lengths it is often quite difficult to attain. However, it is possible to obtain these very high frequencies only by the use of the electron tube as an oscillator, while the alternator and the arc produce lower frequencies and higher wave lengths.

THE ALTERNATOR. As we have seen in a previous chapter, the frequency of a generated alternating current is directly proportional to the speed of the generator. The *Alexanderson alternator* generates a high frequency current which easily forces oscillations direct into the antenna circuit. The natural frequency of the circuit must be tuned to equal that of the alternator when driven at a constant speed, so that both are at the same resonant frequency. The alternator must, of course, be driven at great speeds, often 20,000 r.p.m. The flow of antenna current is controlled by a *key* which short circuits some of the antenna circuit, thus detuning the antenna and increasing its impedance, and quickly changing the resistance to the flow of the antenna current. This is often called the *magnetic amplifier*, for pressure on the key increases the antenna current to its maximum flow.

THE ELECTRIC ARC. The arc convertor, as well as the alternator and spark transmitter, is rapidly being replaced by the electron tube as an oscillator of radio frequency currents. However, the arc is widely used and will not be totally replaced for a long time, if at all. The arc is a reliable source of undamped wave oscillations and it is not so sensitive to variations as the alternator and spark transmitter. The arc is mostly used in high power long-wave and long distance communication. If we have two *carbon rods* which are connected to the two terminals of a direct current source, and touch these rods together at their ends and then separate them a short distance, an electric *arc* will occur between the two across the gap. This flow of electricity, which gives off a brilliant light, will continue as long as the potential is maintained. The behavior of the arc is, however, opposite to what we might suppose; if the current feeding the arc is *increased*, the current flowing through the arc is *decreased*. This phenomenon makes it possible to use the arc as a generator of continuous radio waves.

THE POULSEN ARC CONVERTOR. When the arc is used as an oscillator, such as in the *Poulsen arc convertor*, it is shunted by a tuned radio oscillating circuit. This circuit consists, as a rule, of an inductance coil and condenser, and is shunted directly across the arc and its direct current supply. The shunt condenser becomes charged because it draws some current away from the arc. As this current through the arc *decreases*, the direct current potential to the arc *increases*, as explained above, and continues to aid the charging of the condenser. When the condenser charge nears its maximum it draws less on the arc current and permits more current to pass through the arc. This in turn causes the arc potential to fall off in proportion and leaves the condenser charged with a *higher* potential than now exists in the power supply to the arc. The condenser must, however, discharge this current, and the effect of the inductance coil in series with the condenser is to permit the current to surge so that the condenser plates assume potentials opposite to those which first existed. This opposite charge will not remain, and it immediately begins to return to the proper side of the condenser, as controlled by the polarity of the supply operating the arc. This causes a rise in voltage and the condenser is recharged, but in a direction opposite to the original charge. Thus, we have a condition in which the direct current arc supply flows in a direction opposite to that in the oscillating circuit. The condenser discharges; the surge from the coil changes the polarity of the plates, and the action begins over again. In this way, continuous oscillations or cycles of changes of charges and discharges take place and an alternating radio frequency current flows through the circuit. The frequency of this circuit is controlled by the inductance of the coil and the capacity of the condenser.

Arc Extinction and Ignition. The current which decreases the flow across the arc is called the *extinction voltage*, and that which increases the flow is the *ignition voltage*. In order that the arc may be quickly extinguished and reignited, it is acted upon by a transverse magnetic field. Such a field is made by two powerful electromagnets which cause a greater de-ionization of the arc which brings about a marked difference between the extinction and ignition voltages.

Cooling the Arc. The positive terminal of the arc is of copper and made so that a stream of water can be circulated through it to keep it cool. The negative terminal is not water cooled, but is slowly rotated. Burning the arc in hydrogen gas tends to aid the magnetic field in producing de-ionization.

Working and Compensating Waves. The wave emitted by the arc station has a peculiar and fascinating flute-like sound. When the key of the transmitter is closed the circuit may be tuned so that the arc emits a wave several meters longer than when the key is opened. The wave emitted when the key is closed is called the *working wave*, and the wave given when the key is open is called the *compensating wave*. The former can be read in code while the latter gives only the *intervals* between the dots and dashes. If the tuning between the two waves is very close, it will be difficult to read the signals. Arc stations tend to interfere over a wide band, as they emit two separate waves.

CHAPTER V

THE USE OF RADIO ANTENNAS AND GROUNDS

THE ANTENNA. The *antenna,* often called the *aerial,* consists of one or more wires, by means of which the electromagnetic waves are either radiated or received at radio frequencies. In the case of a transmitting station the antenna is alternately charged positive and negative at a very high rate from one terminal of the oscillation generating apparatus, while the other terminal is connected to the ground. The antenna above, the ground beneath, and the air space between, form a huge condenser which stores up considerable electrical energy. About the antenna and this condenser great fields of force reach out, always alternating in unison with the antenna charging current, and moving farther and farther out with each cycle in the form of waves. With each alternation new electrostatic fields of force occur, repelling a portion of the old field, and causing a disturbance of an electrical character for a considerable distance about.

RADIATION FROM THE ANTENNA. To understand how the antenna radiates energy we must consider that the electric field is a region in which various electric forces may be found. There is a tendency to represent electromagnetic fields by means of lines, but it should be remembered that the electric force exists *throughout* the influenced region, and not only at the particular places where the lines have been drawn. The force pervades space in the same manner that light does, but to a greater extent. When the magnetic field is produced it is accompanied with certain stresses and strains in the transmitting medium—the ether—and it moves off into space as a wave. The action of this moving field is such that electric currents are produced in all conductors of electricity within range.

ANTENNA HARMONICS. Practically every object capable of being vibrated has a fundamental vibration period. In the case of the radio antenna this point is the period at which the radio frequency current oscillates freely, due to the state of resonance brought about by the proper balancing of the capacity and inductance of the circuit. While the greatest current flow occurs at the fundamental frequency there will also be slight oscillations at a few additional frequencies, which are known as *harmonics*. These harmonics or overtones, have definite mathematical relationships to the fundamental frequencies and, in radio, the vibration of the circuit is limited to the odd harmonics only; three, five, seven, etc., times the fundamental frequency. If a nearby commercial station is transmitting on 2,000 meters, it may cause interference in the radiophone broadcast band by transmitting a fifth harmonic on 400 meters. Many stations are now adjusted to suppress harmonics.

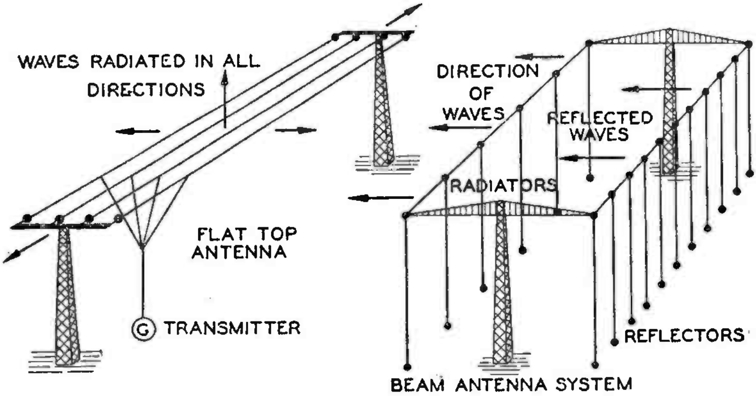


FIG. 23. TRANSMITTING ANTENNAS

ATMOSPHERIC ELECTRICITY. At the transmitting station it is always necessary to use a high, large antenna (see Figure 23), but for reception purposes it is not advantageous to use a large antenna. The audibility of the signal does not depend so much upon the signal strength, as upon its *ratio* to other disturbing noises. These noises are usually caused by *atmospheric electricity* and man-made electrical devices, commonly called *static* and *strays*. They will be discussed in another chapter. The smaller the antenna, the less static will be picked up, but the intensity of the induced current will be correspondingly less. Static, however, will be even less and, with suitable amplification, the signal strength can be made partially to overcome the *noise level.*

Vertical Antenna. There are various types of antennas. The *vertical* wire antenna has certain advantages over other kinds. It will send or receive waves in all directions as it has no directional effect. This antenna (Figure 24) is not in common use because a tall support from which to suspend it is required and it does not provide the full condenser effect that many radio experts desire.

Fig. 24. Vertical Wire Antenna

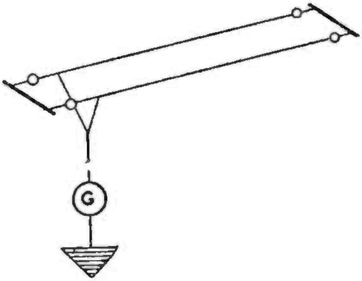


Fig. 25. L Type Antenna

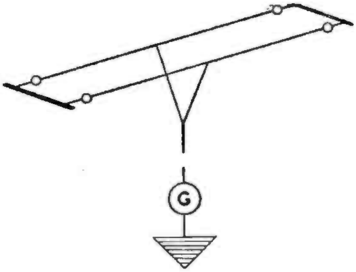


Fig. 26. T Type Antenna

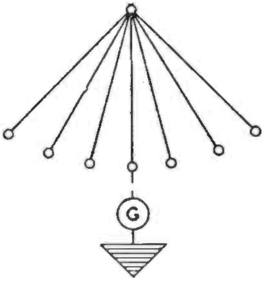


Fig. 27. Umbrella Type Antenna

L Antenna. The *L* type antenna (Figure 25) is one in which one or more horizontal wires are suspended between two supports, and vertical wires are brought down from one end to connect with the instruments. It is a good general purpose antenna, and for reception purposes should be at least 50 feet high and 75 feet long.

It is not a good directional antenna, but it will receive somewhat better along the direction in which it points.

T Antenna. The *T* type of antenna (Figure 26) is much the same as the L, except that the lead-in wires are connected to the middle of the horizontal wires. This type is commonly used on ships as the horizontal wires are supported by the masts. It is slightly directional in a plane along the direction in which the wires point.

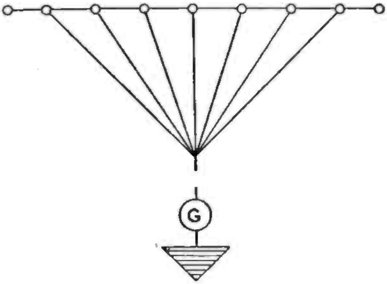


Fig. 28. Fan Type Antenna

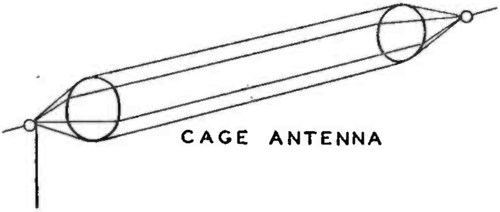


Fig. 29. Cage Type Antenna

Umbrella Antenna. The *umbrella* type of antenna (Figure 27) consists of a number of wires radiating outward and downward from a central vertical support, each end being brought to an insulating support near the ground. It makes an excellent transmitting and receiving antenna as there is no directional effect. The antenna wires also serve as braces for the central mast.

Fan Antenna. The *fan* type of antenna (Figure 28) consists of a high horizontal wire from which a number of wires are brought down to a common point near the ground, to make a large vertical fan. The wires, while in one plane, have little directional effect. It is therefore a good type of transmitting antenna. While there is a large wire surface, only three points of insulation are provided.

CAGE ANTENNA. The *cage* type of antenna (Figure 29) serves no real purpose except in some short wave work. Such an antenna is rather short, and consists of 4 or more parallel wires separated and supported on light wooden rings or hoops not less than 12 inches in diameter. The ends of these wires should be brought together and attached to the insulators and supports.

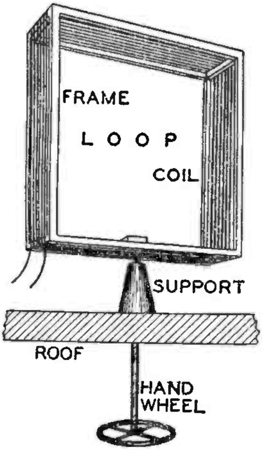


FIG. 30. LOOP ANTENNA

LOOP ANTENNA. With multitube radio receiving sets, the *loop* antenna (Figure 30) is especially useful. It is a type of antenna that is merely an inductance, and may be used with satisfactory results within a building. It eliminates the necessity for a ground connection, and possesses marked directional effects. Satisfactory results cannot be expected with a loop antenna unless there are very good electron tube amplifying arrangements, both for radio and audio frequency currents, so that the intensity of the feeble currents generated in the coil may be greatly increased. The fact that any coil of wire, no matter how small, will pick up these currents is clearly demonstrated by the common experience, which most radio operators have had, of hearing signals on sensitive sets without any antenna or ground connection whatever. This is entirely due to the loop antenna effects of the coils and wiring of the set. The more radio frequency amplification in the set, the greater the distance which may be covered in signal reception without an antenna.

A SIMPLE LOOP ANTENNA. It is due only to the development of the electron tube as an efficient radio frequency amplifier that the loop antenna has made advances. Its use within an ordinary building is satisfactory in connection with a sensitive receiver. A common type of loop antenna, shown in Figure 30, consists of a number of turns of copper wire wound on a frame about 4 feet square, which revolves on a base through 360 degrees. The turns of wire on the coil have, of course, a certain amount of distributed capacity and therefore there is a fundamental wave length to the coil. If short waves are to be received the coil must have a very few turns. For longer waves, more turns may be employed.

DIRECTIONAL RECEPTION WITH A LOOP. The loop antenna should receive as much energy as possible. To accomplish this the coil is turned to *intercept* as many of the magnetic lines of force as possible without producing opposing currents in the turns of wire. When a coil antenna is turned against the direction of the electromagnetic waves the inductance property of the coil is greater. The magnetic force is horizontal and at right angles to the direction in which the electric wave is traveling. See Figure 31. Therefore when the coil is pointed in the direction from which the waves are coming, it is threaded by the magnetic lines of force which are at right angles to the advancing wave, and the maximum electrical energy (radio frequency current) is induced in the coil. When it is turned at right angles to the direction of travel of the wave, no lines of magnetic force pass through the center of the coil and, therefore, little or no voltage is induced in it. Consequently no signal can be heard.

SIGNAL STRENGTH IN LOOP ANTENNAS. The direction of the broadcasting station may be quite accurately determined by observing the position of the coil when the received signal is at its *minimum* strength, since this degree of volume is more easily determined. This directional principle is the one used in *radio compass* work, of which more will be said. The loop antenna does not give a real zero signal in any position; the signal goes down to a minimum, but is seldom entirely eliminated. The effect is produced because the coil acts as an antenna; the lead-in wires aid in detection to a slight degree, and this electrical unbalancing of the coil is sufficient to prevent an absolutely silent position except in exceptional cases.

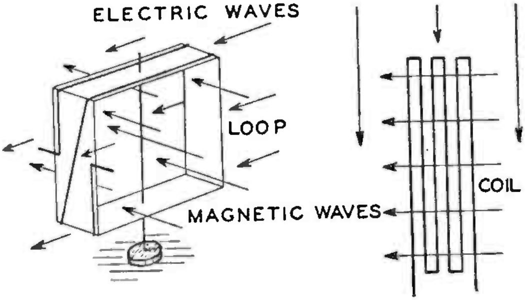


Fig. 31. Directional Effect of Loop

Single Wire Antenna. The *single-wire* type of antenna (Figure 32) is the one most commonly used for out of doors. It is usually connected between trees, buildings, or poles set up in the earth or on the roof of the house. The wire can be used in any position and has but little directive effect. A wire fence may be used if not too long. Insulated wire may be laid along on the surface of the earth, buried beneath it, or placed in pipes underground. When the antenna is very close to the earth or underground reception is possible over short distances and static interferences may be nearly eliminated.

Telephone and Electric Circuits as Antennas. Electric light wires coming into the house may be used for radio reception. They pick up considerable energy, and high frequency currents are induced in them by the passing radio waves. However, the wires should never be connected directly to the radio set as they might become grounded or short circuited. A small condenser should be connected in series with one of the wires, as it forms a barrier to the low frequency lighting current, but permits the passage of the radio frequency currents. A special plug may be purchased which is simply screwed into the light socket, and the antenna connection made to a binding post provided for the purpose. Telephone wires are often used in much the same manner, except that instead of connecting directly to the wires of the telephone through a condenser, a connection may be attached to some part of the metal bell box. A common method is to cover a tin plate with a piece of waxed paper and then place the telephone on the plate, connecting the plate to the radio set. In both cases ground connections should be made as usual.

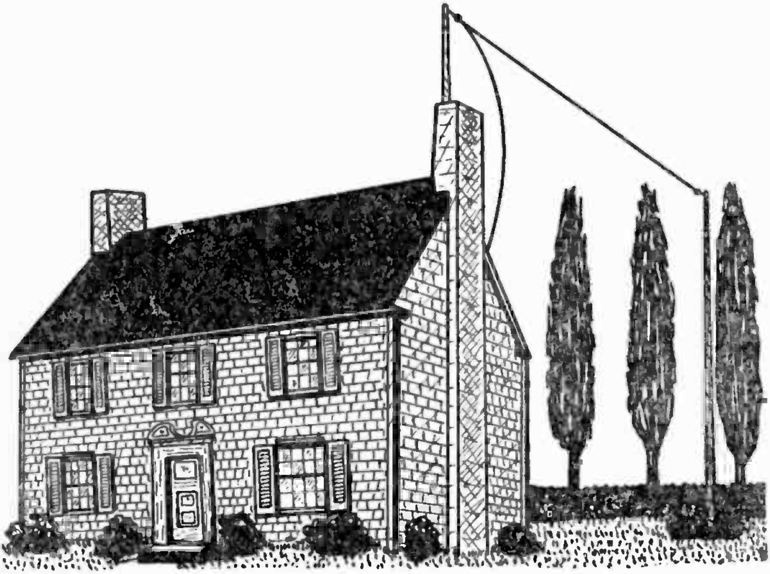


FIG. 32. SINGLE WIRE ANTENNA

INDOOR ANTENNAS. Any inside wiring in the house may be satisfactorily used for radio reception—the door bell system, a wire placed around a room over the picture moulding or in a loop beneath the carpet. When the receiving set is in the same city with the broadcasting station almost any small metal surface may be used as an antenna. Bed springs, metallic clothes lines, or a bit of wire temporarily laid out on the floor or suspended across the room, will work quite satisfactorily. In these latter cases it is difficult to obtain sufficient capacity in the antenna circuit, and it will be found somewhat difficult to tune the set easily. *Body capacity* will often be present and when the set is touched, the natural capacity of the body will be added to the natural resonance of the antenna. When the hand is removed the set is, consequently, detuned. For long distance work the best outdoor antenna should be used, or a well-balanced loop of the proper capacity.

SHORT WAVE ANTENNAS. Now that *short waves* for radio work are used so extensively, it is necessary to give close attention to the matter of antennas. As has been shown, the fundamental wave length of the antenna must be somewhat *less* than the wave length on which the radio set works. The set must be designed so that its capacity and inductance is very low, in order that as large an antenna as possible may be used. Use is made of a vertical antenna which often consists of a copper pipe or tube extending vertically into the air for a distance of between 25 to 50 feet. A counterpoise ground may be used with this kind of antenna.

GROUNDS. A *ground* connection is always necessary in radio reception, except in the case of the loop. See Figure 33. Even when using a loop additional energy may be picked up if the regular ground post of the receiving set is grounded, as well as connected to the proper loop terminal. The ground connection is highly important and, indeed, upon it often depends the success or failure of the radio set. The most practical ground connection is that made to a water pipe, as shown in Figure 33, or to the steel frame of a building. The water pipe is part of a system which runs for many miles underground, and provides the best contact with the earth. Pipes connected to the hot water, steam or gas systems may be used, in the order mentioned, as optional earth contacts. Some gas pipes are not grounded, being insulated at the meter, and this fact should be ascertained before attempting their use. At some places where the earth has poor conductivity and water pipes or other means of connection are not available, it becomes quite difficult to obtain satisfactory earth connections.

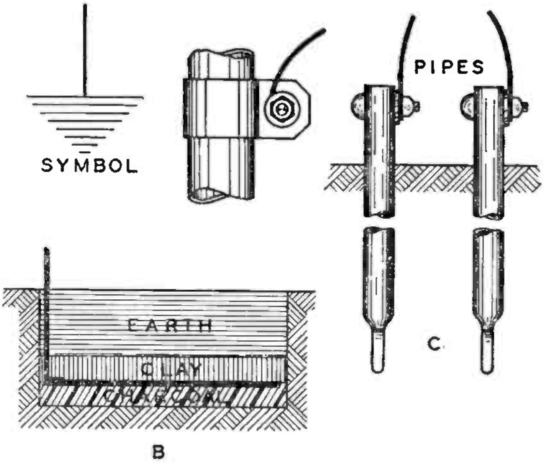


FIG. 33. GROUND CONNECTIONS

(*A*) Water Pipe Connection; (*B*) Buried Plate Ground; (*C*) Driven Pipe Connection.

In this case a hole should be dug down to permanently moist earth and a large copper plate buried in a mixture of charcoal, salt, earth and water. See *B* in Figure 33. A heavy wire is soldered to the plate and brought up through the filled-in hole. Another method is to drive one or more galvanized iron water pipes, not less than 6 feet in length, into the ground. Each pipe should be connected to the ground wire by means of a bolt passing through the pipe at the top. This method is indicated at *C*. If a satisfactory ground cannot be obtained in this manner, it will be necessary to construct an artificial ground.

THE COUNTERPOISE. An artificial earth capacity is termed a *counterpoise.* It is not to be recommended unless other attempts to secure a good ground fail. The counterpoise is simply *another* antenna supported a few feet above the ground and connected to the radio set in the same manner as a ground wire ordinarily is. The area covered by the counterpoise should be somewhat larger than that covered by the antenna. A counterpoise must, of necessity, be used on aircraft, being generally furnished by the metal portion of the ship, while the antenna is a trailing wire of sufficient length.

WATER PIPE GROUNDS. When the ground connection is made to the water system, the pipe should be carefully scraped and cleaned, and the wire or copper band securely soldered to it. Copper bands, which clamp about the scraped portion of the pipe may be purchased, and will make very good connections if carefully installed. A wire of any size may be used, for the ground connection but it should not be smaller than number 14. In most cases city or state regulations call for wire as large as number 10.

ANTENNA WIRE. Hard drawn copper wire is used for the construction of the antenna. It should be a *stranded* cable made up of a number of small copper wires, to gain in strength and conducting surface. As high frequency currents travel on the surface of the conductor, it is desirable to have as much surface as possible. A stranded conductor has more area for carrying the current than a solid wire. One made of about seven number 22 enameled wires will provide the best outdoor antenna material. It is not at all necessary to use bare wire as the insulating material does not prevent the waves from inducing currents in the protected wire. Antenna wire comes in several styles, such as a woven wire of seven strands of number 22 or 24 copper wire, bare, tinned or enameled, and number 14 hard drawn copper wire, either plain, tinned or enameled. Antenna wire made of aluminum has been used but has not proved popular because it is brittle and difficulty is experienced in soldering the joints. Loop antenna wire is generally called Litz or Litzendraht. It is made from a number of high quality fine enameled wires stranded so as to form a cable which is bound with a fine silk covering. The wire, when completed, is not much larger than an ordinary number 20 or 22 magnet wire. Litz wire is made of about 50 strands of number 38 enameled copper wire. There is also a copper braided ribbon which is about one-half an inch wide, and composed of about 25 strands of copper wire. It is quite flexible and has considerable flat surface. Some stranded wires are loosely braided in circular form. Flat copper ribbon, with snap hooks at each end, is also used. It is often put up in a holder, similar to a surveyor's steel tape measure, so that it can be wound up or pulled out as necessary. Still another antenna material is similar to flexible hollow electric conduit. Antennas have been put out in the form of tightly coiled springs so that they may be stretched out between supports, such as opposite sides of a room. These latter forms of antenna materials are principally for temporary use.

Antenna Insulation. The insulation of an antenna is a matter of great importance. If the *insulators* are defective or dirty, a considerable portion of the energy received by the antenna will be permitted to leak off to the ground without passing through the receiving set. Insulators are placed between the ends of the wires of the antenna and its supports. Porcelain is one of the most satisfactory materials for use in constructing insulators, and glass is now being extensively used. Moulded insulators which have eyebolts built into them are used and withstand considerable strain. See Figure 34. Others with skirts and ribs are used, as this ribbed surface provides more area over which the current must leak to escape into the ground.

Antenna Supports. The antenna should be carefully supported and be drawn taut. Swinging or sagging will constantly change its relation with the surface of the earth or the roof of the building beneath, which will tend to vary its natural capacity to a slight degree. This variation will give rise to a form of signal irregularity, known as *fading* or *swinging*, of which more will be said in another chapter. The antenna may be set up between a tree and a house, and when the wind blows the wire is slack and taut at intervals. To obviate this, one end of the wire is fastened to a spring which keeps a certain tension on the wire at all times. Still another, and more practical method, is to attach the wire to a rope which passes over a pulley. The lower end of the rope carries a weight heavy enough to balance the pull of the wire. As the tree moves in the wind, the weight rises and falls. Such devices prevent some signal fading as well as the snapping of the antenna wires when too much strain is thrown upon them.

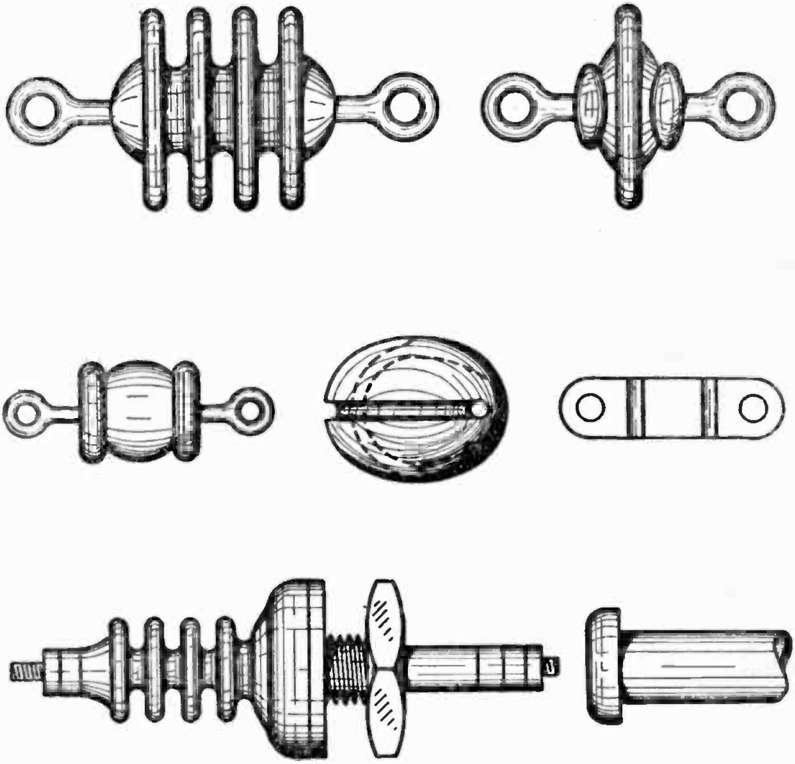


FIG. 34. ANTENNA INSULATORS

ANTENNA SWITCHES. An antenna *switch* is a necessity in all antenna installations. It disconnects the receiving apparatus from the antenna, or the antenna may be grounded when not in use. The switch is a large single-blade double-throw knife switch, and is often mounted on the outside wall just where the lead-in wire from the antenna comes to the building. It is best mounted on supports several inches away from the wall and should have a porcelain base. When the set is not in use the blade or knife is thrown over to the ground contact, from which a heavy copper wire leads directly to the ground. In addition to the ground switch the antenna lead-in should be attached to a suitable lightning arrester. In stations that transmit and receive, an antenna switch consists of several blades with a double throw. When set on one side the antenna is connected to the receiving set with the battery connections turned on, and when thrown to the opposite side, to the transmitter with its power connections set up.

THE DANGER OF LIGHTNING. The danger from *lightning* during the summer season is a question that has been frequently raised. When an outdoor antenna is used, there is some danger of induction in the antenna, and on rare occasions it may be the target for a direct discharge of lightning. Direct hits to radio antennas are very rare, due no doubt to the grounding and protection given by careful radio operators. The grounding of the antenna by a switch is entirely satisfactory, but the switch may be forgotten, or there may be no one to attend to it if a storm arises. The use of a good *lightning arrester* to assure protection is to be recommended.

THE ANTENNA LIGHTNING ARRESTER. A well grounded antenna served as a lightning rod and due to the grounding of the induced charges, the immediate region may never be visited by a stroke of lightning. The protective lightning arrester should be connected between the antenna lead-in and the ground. It consists of two metallic points placed very close together. The radio frequency currents induced in the antenna by the passing waves are too weak to jump across the intervening air gap, even when it is placed in a vacuum. The area of these points is made so small that their capacity will be negligible, in so far as its effect on the reception of waves is concerned. If a high potential atmospheric charge is induced in the antenna it will attempt to run off into the ground. But, due to the choking effect of the coils in the radio set, it is blocked to a certain extent. The major portion of the charge will jump across the intervening gap of the arrester, and seek its outlet into the ground by this path without causing any effect on the receiver other than a loud static crash; something which *cannot* be avoided. If the points of the gap are placed in a vacuum, the dielectric resistance to the discharge between them is lessened, and smaller atmospheric discharges which are induced in the antenna will be permitted to pass off into the earth without attempting to pass through the radio set. If it were not for this means of passing the high potential discharges off into the earth, they would force their way through the radio set, and possibly do considerable damage. If a severe charge passes into the antenna, it may cause some damage as well as injury to the person listening and, if there be a direct stroke of lightning, serious injury and damage may result.

LOCATING THE LIGHTNING ARRESTER. It is preferable to locate the arrester on the outside of the building and near the window where the antenna lead-in is brought through. Run this lead-in directly to the top connection of the arrester, and then into the building. A ground wire is next taken from the bottom connection of the arrester to a good ground immediately below. This wire should be heavily insulated, and soldered or clamped to the ground connection, which, in most cases, may be a 6-foot length of pipe driven full length into the earth. If it is impossible to obtain this type of ground the next best thing is to procure a water pipe connection with as short an inside lead as possible. The attachment of lightning arresters or switches to interior ground connections is not recommended in any case, and should be carefully avoided whenever possible.

TYPES OF LIGHTNING ARRESTERS. The best lightning arrester for radio protection is the *vacuum* type; it is much more sensitive than other kinds, and it will act on weak atmospheric discharges before the set can be damaged. This kind is more effective and reliable than the open air-gap and resistance types. As an electric spark will actually travel through a vacuum 72 times farther than it will through air, it is easily seen that a spark which will jump in a vacuum cannot jump when in the open air. If it does not jump to the ground contact, the induced charge must pass through the radio receiving set. Air gap arresters are not so efficient; they are subject to moisture, dirt, insects, and other causes of short circuiting. A good way to test an arrester is to connect a spark coil across its terminals and, if good, a steady spark will flash between the two points.

ANTENNA LEAD-IN WIRES. The *lead-in* wire connects the antenna to the radio set. It usually consists of a continuation of the antenna, and is passed through a window after contact with the outside switch or lightning arrester. But, if the antenna consists of two or more wires, the surface of the lead-in wire must have the same area as the combined surfaces of the wires in the antenna. We have seen that radio frequency currents travel on the surface, and therefore we must provide enough surface on the lead-in wire to take care of *all* the current flowing on the wires of the antenna. The lead-in wire should be carefully insulated where it passes through the building. Special types of lead-in insulators are in use; a standard type is indicated in Figure 34. When the wire is to be passed beneath a window sash, a strip of copper, well wrapped with insulating tape, may be used. Such a strip can be shaped to fit over the sill, and is so thin that it will not interfere with the closing of the sash. Inside the building the lead-in should be a good grade of large flexible cord wire, and should be taken to the receiver in as direct a line as may be without running close to any grounded objects or other wires.

CHAPTER VI

THE ELECTRON TUBE AND CRYSTAL RECTIFIERS

ELECTRON TUBE DEVELOPMENT. The development of the *electron tube* has taken place over a number of years though it is comparatively new to the radio world in its practical applications. It has made possible the reception of radiophone broadcasts over long distances and has developed world-wide radiotelegraphy for practical commercial purposes. Long distance telephone communication would not have been entirely possible without it. Commercial radiophone service between New York and London, means communication between any point in the United States and England, since cities may be linked with the radio centrals in those two cities. All this is due to the electron tube. The electron theory is now put to practical use, and operates under a principle that upholds the theory.

THE ELECTRON TUBE. The name given to this essential piece of radio apparatus—electron tube—is taken from the flow of electrons between electrodes within it. It has been shown that there is a decided electron flow (negative electricity) from a body when it is rubbed or heated and that if there is a positive attracting body near by, the electrons will pass to the positive body. While electron tubes have been given a great variety of trade names, the fundamental principles are the same in each case. Many years ago, Edison discovered that he could obtain a flow of current from a lighted electric lamp filament to a cold plate near the filament. Unfortunately for that distinguished inventor, he found no way to utilize the discovery, but the action has always been known to science as the *Edison effect.* A convenient method of heating a piece of metal so that an electron flow may be obtained, is to form it into a fine wire which is made incandescent by passing an electric current through it. A wire cannot become incandescent in open air without being consumed. Therefore, as in the case of the electric lamp, it must be placed within a glass bulb from which oxygen has been excluded.

THE ELECTRON TUBE FILAMENT. The *filament* is the most important part of the vacuum tube. It is generally made of tungsten, a rare metal, with an extremely high melting point. In the course of construction it is mixed with parts of *thorium oxide* and carbon, formed into a wire and processed so that the surface of the wire is covered with pure thorium metal, an effect brought about by the consumption of the carbon. When this filament is heated to a high temperature while placed in a perfect vacuum or in some *inert* gas, the metallic thorium crust gives an increase in the plate current which would not be otherwise obtainable. A filament of this type gives off a much heavier electron discharge and provides a more effective tube. Filaments are seldom burned brightly and, in many cases, only with a dull red glow.

THE ELECTRON TUBE PLATE. It is necessary that, in the electron tube, there be a piece of cold metal having an excessive charge of positive electricity to attract the electrons which are emitted by the heated filament. This piece of metal is known as the *plate*, and may be a circular tube or flattened cylinder. It is made of thin sheet nickel welded to supporting wires of the same material. The plate entirely surrounds the filament, but should be close enough so that the filament electrons have a very short distance to travel.

THE ELECTRON FLOW. If the filament is connected across an "A" battery having sufficient voltage to heat it, the plate connected to the positive terminal of a "B" battery, and the positive post of the filament "A" batttery connected to the negative post of the larger "B" battery, the plate becomes positive, and the entire filament negative. When the filament is heated or lighted, it becomes hot and commences to throw off electrons. These are attracted to the positively charged plate, which they bombard in great clouds. As each electron is a small portion of negative electricity and countless millions of them pass to the plate, there will be a flow of current through the vacuum between the plate and the filament, thus completing the circuit of the "B" battery. See Figure 35. As soon as the battery that excites the filament is disconnected, the emission of electrons ceases, and there is no

PLATE 2

First, second and third rows: Radio electron tubes—courtesy E. T. Cunningham, Inc. *Bottom row, center:* Electron tube sockets—courtesy Benjamin Electric Company. *Bottom, left and right:* Rectifying electron tubes—courtesy Raytheon Company.

further consumption of electricity from the "B" battery. When the electrons pass with great rapidity across the intervening space, they meet with no opposition. If gas remains in the tube the electrons collide with the atoms of the gas, and free additional electrons. It is not practicable to permit air to remain within the tube but if some gas, such as *argon, neon* or *helium* is introduced into the tube, the emitted electrons will free additional electrons, and the gas within the tube becomes *ionized* and is a good conductor of the "B" current.

Soft and Hard Electron Tubes. A tube with a poor vacuum or filled with a rare gas, is called a *soft* tube, and it is a good detector. A highly evacuated tube which depends upon its electron emission ability alone, is known as a *hard* tube. Such a tube is not a good detector, but makes a good amplifier. Soft electron tubes which may be ionized are more suitable for certain radio uses.

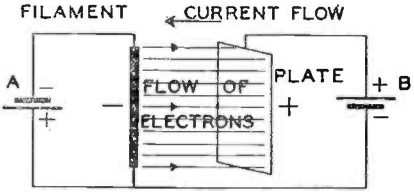


Fig. 35. Flow of Current in Electron Tube

Filament Lighting Voltage. We have seen that when a filament is lighted, a stream of electrons passes to the plate. This continues as long as the filament is lighted. The electricity consumed in the lighting of the filament varies from 1½ to 6 volts. The operation of small dry battery tubes requires but a single dry cell. Another type of tube requires about 4 volts, and is satisfactorily operated on 3 dry cells connected in series. All types of larger tubes require 6 volts, and are best operated by storage batteries. In all cases the battery used to light the filament of an electron tube is called the "A" battery. The current consumption of filaments varies, some tubes taking as little as 0.06 of an ampere an hour, while others may take over 0.5 of an ampere.

PLATE POTENTIAL. The plate of the electron tube is charged positively with respect to the negative filament. As a considerable gap must be bridged by the clouds of electrons bombarding the plate, the voltage of the battery used for this purpose must be relatively high. This battery is known as the "B" battery. A soft detector tube may require from 16 to 45 volts for the plate charge, while amplifier tubes in different circuits may require from 45 to 300 volts. The 'B" current can be supplied by dry cells or a number of small flashlight cells arranged in a single container, by small storge batteries or direct from the electric house current through a *"B" battery eliminator*. No variable resistance is used in the "B" circuit to vary the current, the full voltage of the battery being applied directly to the plate.

THE ELECTRON TUBE GRID. In addition to the plate and filament of the electron tube, there is a third electrode which is essential to operation in a radio circuit. This third element is known as the *grid* because of its appearance. It acts as a regulating valve or trigger. This grid is placed *between* the filament and the plate. It is generally made of very fine tungsten wire wound about two nickel wire supports in the form of a flat spiral with all of the points of contact welded to prevent any danger of becoming loose. The grid is interposed in the normal stream of electrons which fly out in all directions from the filament toward the enclosing plate surface. The flow of electrons, and consequent ionization, between the filament and the plate may be increased or decreased through the action of the grid. Electrons are forced to pass between the interstices of the grid and, if the grid is also given a negative or positive potential with respect to the filament and the plate, it will either repel or attract the electrons. If the grid is given sufficient negative potential it will even stop the electron flow from the filament. See *A* in Figure 36. This is the function of the "C" battery, and just sufficient of the negative bias should be applied to the grid to stop the flow of the "B" current when no signals are being received. When the grid is given a positive charge, see *B* in Figure 36, it aids the plate in attracting electrons, and seems to neutralize, in part, the effect of the space between the plate and the filament, so that a more powerful electron flow from the filament will result.

Electron Tube Vacuum. After the elements have all been put into place within the tube, the air must be pumped out. Not only is air in the tube taken out, but bits of gases in the elements which are liberated by heating. Some tubes having high vacuums are cleared of all remaining gases by vaporizing *magnesium* within the tube. This forces out all the gas, and as the magnesium condenses on the inner surface of the glass bulb, the bulb takes on a silvered appearance. Detector tubes containing certain gas combinations are now used. They are made by allowing a certain gas to be drawn into the tube after the air is expelled.

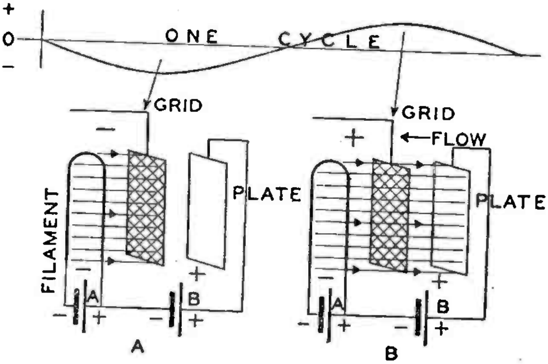


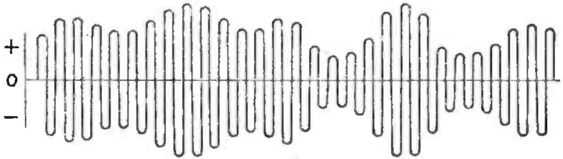
Fig. 36. Effect of Grid on Electron Flow

(*A*) Current Stopped by Negative Grid Potential; (*B*) Current Increased by Positive Grid Potential.

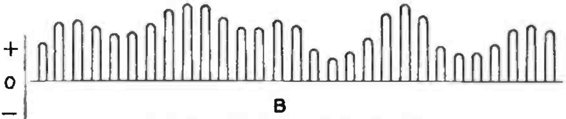
Uses of the Electron Tube. The tube is now ready to be used for a number of purposes. As a *detector* it will rectify weak radio frequency signals or currents which come in from the antenna. It will aid in the *amplification* of the rectified currents. It is used as an *oscillator* in radio transmission work, and certain classes of receivers where heterodyne methods are used. As a *modulator* the electron tube will modify the radio frequency current being sent into the antenna of a broadcasting station. This kind of modulation is the impressing of the voice fluctuations upon the carrier wave. Discussion of the electron tube in this chapter is limited to its *rectifying* properties as applied to the detection of radio frequency currents. The rectifying properties of the tube as an amplifier will be discussed in a subsequent chapter.

FILAMENT CURRENT CONTROL. To use an electron tube as a rectifier of radio frequency currents it should be connected as follows: The filament is connected to an "A" battery of the proper voltage, one terminal to the negative electrode of the battery, and the other to the positive electrode. The latter first passes through a *variable* resistance having a sufficient number of ohms. This is known as a *rheostat.* It consists of a small coil of special high resistance wire arranged in a circular shape so that when a sliding contact passes over it more turns of wire are cut in, or out, as the case may be, thereby changing the resistance it offers to a current flowing through. Another form of rheostat is the resistance offered to the flow of a current by a pile of loose graphite discs, which, when compressed, provide good contact and allow the full current to flow. This latter plan provides a very uniform graduation in current flow without noise, and for detector operation, is much to be preferred. Fixed resistances are often used on multi-tube sets and are types of self adjusting rheostats. They permit the use of a number of tubes of various filament voltages on a single set of batteries. Such resistances eliminate the hand rheostat and simplify the set wiring. As there are no moving parts, rheostat noises are not noticeable, and the tube is given longer life as the filament is held at an even temperature. On amplifying tubes the use of fixed resistances will generally assure a very steady tube current control.

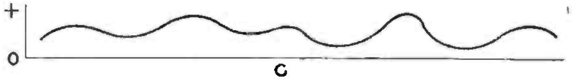
ACTION OF THE ELECTRON TUBE. Suppose the antenna circuit to be tuned to its maximum resonance so that the radio frequency output as sent into the tube grid circuit is at its greatest amplitude for some particular wave length. The filament of the tube is lighted by turning the rheostat until a satisfactory electron emission is obtained. A current now flows in the "B" circuit being carried across from the plate to the filament *against* the electron flow. This current is steady, and it produces an even pull on the diaphrams of the telephone receivers. But, if the antenna is connected and a signal is coming over it at radio frequencies, this alternating current will flow through the grid circuit of the set. See *A* in Figure 37. It is *impressed* upon the grid of the tube, thus



A
GRID CURRENT



B
RECTIFIED CURRENT



C
TELEPHONE CURRENT

FIG. 37. ACTION OF ELECTRON RECTIFIER
(*A*) Current Impressed on Grid; (*B*) Rectified Half of Grid Current; (*C*) Displacement of Receiver Diaphragm.

changing the grid polarity rapidly from positive to negative. These rapid changes cause corresponding changes in the flow of the "B" current between the filament and the plate, as the grid either attracts or repels the electrons flowing to the plate from the filament. The grid is a sort of valve or trigger which causes an increase or diminution of the plate current in accordance with its rapidly changing polarity. The variations in strength of these *triggerings* produce the modulated effect on the plate current which eventually is filtered out as an audio frequency current.

RECTIFICATION. If a wave of 300,000 cycles (300 kilocycles) per second is flowing through the circuit to the grid, the grid alternates between negative and positive 600,000 times each second and 300,000 breaks per second occur in the flow of the normally steady "B" current. These breaks occur when the current on the grid is *negative*; when it has that potential, the electron flow from the filament is temporarily repelled and there is a break in the flow. As the cycle on the grid changes, it takes on a zero potential and the "B" current again begins to flow. But the grid soon becomes positive and the "B" current flow increases, reaching its maximum at the time of maximum positive potential on the grid. An alternating current has two alternations to a cycle—positive and negative—but, when passing through the tube, one alternation is wiped away, as the flow of "B" current must be in but one direction. The result is a undirectional current pulsating according to the modulation. See *B* in Figure 37. The number of pulsations per second are the same as the number of positive alternations impressed upon the grid. If the wave has a frequency of 300,000 cycles per second, there are 300,000 negative, and 300,000 positive potentials occurring in the total number of 300,000 cycles. Hence, in the rectified current there will be 300,000 times when the pulsations of current reach the maximum value, but never go below zero potential to an opposite potential. This break or zero potential occurs while the *unrectified* half of the cycle is reaching its maximum potential on the grid.

RECTIFIED PULSATIONS AT HIGH FREQUENCIES. This current, after being passed through the plate into the "B" circuit, still has the radio frequency characteristics; that is, while it is unidirectional instead of alternating, it is broken up into the *same* number of pulsations as cycles. It is now known as a *rectified* direct current. As such, it still cannot flow through any circuit which has a high reactance, such as the telephones or loud speaker in the "B" circuit. Before the antenna current was permitted to flow to the grid and produce the impressed alternations, the "B" current flowed steadily and passed through the natural resistance of the "B" circuit (telephones, loud speaker or audio transformer primary), without encountering inductive reactance. But after the set is tuned and a station signal picked up, the resistance to the alternating and rectified pulsating current at radio frequencies in the "B" circuit becomes a serious reactance.

Plate Current through Telephones. As the pulses of high frequency rectified current cannot flow through the windings of the telephones because of the impedance and reactance, one will wonder how it can be made to operate the telephones. A small by-pass fixed condenser is placed across the telephones to permit the radio frequency pulsations to pass *around* the windings and back to the filament and grid. The current flowing through the telephones or coils is an *average* of the pulsations. Due to the modulation of the radio wave, the point of maximum potential of the rectified pulsations varies, and this causes an average variation in the strength of the plate current. Assume that, in Figure 37, *A* is the carrier wave induced in the radio set and fed to the grid; *B* is the rectified modulated wave passing through the "B" circuit and by-passed through the condenser placed across the windings; and *C* is the average current flowing through the windings of the "B" circuit (telephones, etc.). It will be noted that the *shape* of the average current in the telephone receiver corresponds to the actual current set up by the voice fluctuations in the microphone at the transmitting station, which was impressed upon the carrier wave. This modulating current, at audio frequencies, will result in the telephone receiver diaphragm's suffering a displacement (*C*) to correspond. In other words, the receiver diaphragm will vibrate in unison with the microphone at the broadcasting station. This average current, which follows the points of successive maximum potentials of the unidirectional pulses of rectified radio frequency current, is applied as a varying potential difference across the terminals of the telephone receiver, while the rapid pulsations of the carrier current pass through the low impedance of the by-pass condenser.

Action of the Grid Condenser. In the detection of signals, better results are obtained if a small *grid condenser* is placed in the grid circuit. When the high frequency current is impressed on the grid, the latter begins to fluctuate about its normal potential (given by the battery) and this potential is increased and decreased equally with each alternation of the impressed radio frequency current. But, because of the presence of the grid condenser, the increase and decrease in current above and below the normal value with each cycle will change and, when the half-cycle is positive, the increase in grid voltage will be greater than the corresponding decrease in voltage below normal when the grid is negative. This tends to increase the charge on the side of the condenser connected to the grid. Such an increase in the charge on the grid must therefore *depress* the potential on the grid below its normal value and a decrease in the flow of "B" current will be noted. These changes in the grid cause little increase in the plate current, as that is regulated by the electron emission from the filament, but they do cause a *decrease* in the electron flow which produces a signal, apparently the same as an *increase* in the flow of the "B" current.

ACTION OF THE GRID LEAK. At the end of the wave train or the average modulated variation, there will *remain* a negative charge on the grid and, before the next wave train variation arrives, it must be disposed of. This is accomplished by means of a very high resistance, known as a *grid leak*. The time taken for the charge to leak off will depend upon the resistance of the leak, and the selection of a proper grid leak is, therefore, of first importance. The leak is usually shunted around the grid condenser, but may be connected between the grid side of the condenser to the negative "A" battery terminal. A few years ago the grid leak consisted of a pencil or ink mark across a sheet of paper, and the resistance embodied in the mark was crudely sufficient. Then small strips of carbon paper and cardboard painted with graphite were used. These resistance elements were placed within a glass tube or cartridge, so that they could be set into the supports made for them directly on the grid condenser. A new form of grid leak which is known as a metallic leak, of the same shape as the cardboard strip cartridge tube, has a much greater efficiency and resistance reliability. A metallic coating which forms the resistance element, is placed upon the inside of the glass tube. Such a leak is not affected by moisture or heat, and, when once sealed, its value remains constant. As it is non-inductive, it is of value to short wave receivers.

INTERNAL TUBE CAPACITY. A tube must have a low *internal capacity* as internal capacity may seriously interfere with its action and with the proper design of receiving circuits. Sets of low wave length have their natural wave lengths seriously increased by high capacity tubes and, in such sets, every bit of internal capacity must be eliminated. The capacity of a tube for electrical charges may be quite great. The various capacities to be considered in a tube when it is in operation are between the following: Plate to filament; grid to filament; grid to plate; and plate to grid to filament. Other sources of capacity are in the base and connecting wires. Usually the values of capacity in a tube are of little consequence, but sometimes, when a tube becomes unfit for further service and is replaced, the actual tuning of the set is slightly changed. This is due to the difference in the electrostatic capacity of the two tubes.

ADAPTABILITY OF ELECTRON TUBES. It is important that care and attention be paid to the selection of tubes for use in the radio receiver. There is a tube for *each* purpose, and such tubes operate at certain customary filament voltages; consume designated amounts of current; require plate voltages which vary with the tubes, whether detectors or amplifiers; and for each plate voltage there is a certain "C" voltage necessary to maintain the negative grid bias. In order to know the *adaptability* of a tube, it is necessary to measure its important constants. These characteristics are: The *effect* of grid and plate voltage on the flow of plate current; the *amplification factor* or *constant;* the *plate impedance* or resistance; and the *mutual conductance.*

TESTING ELECTRON TUBES. Meters suitable for measuring radio currents are described elsewhere. It is sufficient to state that two meters, the voltmeter and the milliammeter, are necessary to make these measurements. The voltmeter is set up in a simple tube circuit so that it is connected directly *across* the filament terminals. The battery rheostat is adjusted so that the filament voltage is that given by the manufacturer as proper for the tube. Without disturbing the resistance adjustments, the meter is removed and used to measure the voltage of the "B" battery, after which it is permanently connected between the grid and negative filament terminal so as to read the "C" voltage. By means of a potentiometer, adjust the "C" bias until the milliammeter in the plate circuit is just zero. By this means we find out how the plate current varies as we change the "C" battery or grid bias. Some tubes will show a greater variation than others.

THE AMPLIFYING CONSTANT. The amplification constant of a tube, usually designated as *MU*, is a measure of the relative effect of changing the grid bias *compared* to changes in the plate voltage. It may be roughly calculated as the change in plate voltage divided by the change in grid voltage. By increasing the plate voltage and again changing the grid bias, we may read the relative changes in the plate current.

PLATE IMPEDANCE. The *plate impedance* may be calculated as the *change* in plate voltage, divided by the change in plate current in milliamperes, and recorded in ohms.

THE MUTUAL CONDUCTANCE. The *mutual conductance* of a tube is said to be the effectiveness of the grid potential in *controlling* the plate current, and it is also the ratio between the amplification factor and plate impedance; also the relation between the voltage applied on the grid, and the resulting plate current.

REVIVING ELECTRON TUBES. Tubes having thoriated filaments gradually decrease in electron emission value and are rendered useless, even though the filament will continue to light up. It is often possible to put these tubes through a treatment that will again make them serviceable. The treatment is known as *reactivation* and may be accomplished by anyone with the aid of simple apparatus. A small transformer with a variable secondary voltage output, a tube socket and rheostat, or a complete manufactured unit, is all that is required. The tube is placed in the socket and from one to two volts over the rated amount is applied to the filament for about one minute. After that the voltage is reduced to the rated strength, and the tube lighted for about half an hour. After this treatment the tube will be found to give satisfactory operation again. No current is used on the plate while the tube is undergoing this treatment. Low voltage dry battery tubes, and others not having thoriated filaments, cannot be treated in this way. When such tubes have become useless there is no method of renewing their powers of electron emission.

FILAMENT CONTROL JACKS. While there is a tendency to control two or more tubes with a single rheostat, or an automatic thermal rheostat, there are times when a filament control *jack* should be incorporated in the circuit. It may be used in the plate circuit of the last audio amplifier tube so that the filament circuit of that, or the entire group of audio tubes, will remain open until the plug is inserted in the jack. At all other times, or when the telephones are plugged in the jack in the detector plate circuit, the audio tube filaments are cut off so that "A" and "B" current is not unnecessarily consumed. The jack in the detector plate circuit does not control any filament; it simply cuts out the primary of the first audio transformer, replacing it with the telephones. Such a jack is known as a *double-circuit* or *interstage jack.*

POTENTIOMETERS. A high resistance *potentiometer* finds extensive use in the radio circuit. Such a potentiometer is most valuable as a stablizer in a receiving set using several stages of radio frequency amplification. The potentiometer also finds use in circuits employing gas content detector tubes, where close variation of the plate voltage is necessary; the potentiometer accomplishes this by very gradually adding to or subtracting from the "B" battery the voltage of the "A" battery. When shunted across the "A" battery, it gives, by means of its third contact, a very fine graduation to the negative value of the grid of radio frequency amplification tubes.

MODERN ELECTRON TUBES. While many electron tubes have found their way into the radio market, not all can be accepted as dependable and efficient. Much depends upon the material, spacing arrangements, vacuum and gas content, and, most important of all, the radioactive material furnishing the electron emission. The tube characteristics, which are briefly summarized in the following paragraphs, may be regarded as representative of standard manufacture and as reasonably permanent.

OPERATING VOLTAGES FOR TUBES. Radio electron tubes have been standardized to operate on *6* volts, *3* volts and *1½* volts. While they are generally referred to as tubes of the above voltages, they actually operate on a slightly less potential. The battery which is used to furnish the current should have the voltage above indicated, but the potential is diminished before it reaches the terminals of the tube through the use of rheostats or resistance units. However, there are some rectifier, power, regulator, and alternating current tubes which operate on higher voltages, even as high as 110 volts.

DETECTOR TUBES. Such tubes are usually stable soft or gas filled tubes which are more readily ionized. At the point of ionization large changes in plate current occur with only relatively small changes in grid potential, and at this point the tube will be found to be super-sensitive. The operation of some tubes of this type is accompanied by a slight hissing sound which is not bothersome. A grid resistance leak of about 2 megohms is used, shunted by a small fixed condenser of 0.00025 microfarad capacity. These tubes operate on 5 volts, and consume only 0.25 ampere, and are referred to by the designating numbers *200-A* and *300-A*. No "C" battery is used in the grid circuit of a detector tube, and the plate voltages range from 20 to 45 volts.

DETECTOR AND AMPLIFIER TUBES. These tubes have been designed for general purpose operation and will either detect or amplify. They are the accepted standards of 6 volt storage battery tubes, and take 5 volts and .25 ampere on the filament. No "C" battery is used with the tube when it acts as a detector and very seldom used in radio frequency amplification. However, in the audio amplification circuits the "C" battery voltage may range from 3 to 9 volts, depending upon the amount of "B" battery. This latter battery voltage ranges from 22½ to 45 volts on the detector to 45 to 135 volts on the amplifier. These tubes are designated by the numbers *201-A* and *301-A*.

POWER AMPLIFIER TUBES. Special *power amplifier* tubes, when used in connection with the foregoing amplifier and detector tubes will give increased current flow without forcing or overloading. Almost all amplifier tubes operate on a 6 volt storage battery, but they draw quite heavily on the current supply. These tubes are designed to handle large input voltages on the grid, and to deliver heavy plate currents without distortion. The *112* tube is a loud speaker supply tube which may be used in the last stage of audio amplification in place of a *201-A* or *301-A* tube without any change in voltages. The use of a grid bias "C" battery of 9 volts in connection with a plate voltage of 135 volts is recommended. The tube takes 5 volts and 0.5 ampere. The *171* and *371* types of amplifier power tubes take 5 volts and 0.5 ampere also, but give higher power than the *112* type. This tube practically eliminates all possibility of signal distortion when used in the *last* audio stage. It will supply ample power for loud speaker operation without extremely high plate voltages. These tubes will handle a grid input voltage as high as 16 volts with only 90 volts on the plate. "C" battery requirements range from 9 to 20 volts.

HEAVY DUTY AMPLIFYING TUBES. Power amplifiers of high amplifying constants that are particularly suited for use in resistance and impedance coupled amplifiers are the *240* and *340* types. The high constant of about 30 helps to make up the deficiency in these methods of amplification. Plate voltages as high as 180 volts may be used with 5 volts and only 0.25 amperes in the filament. "C" battery requirements range from 12 to 22½ volts. There is another heavy duty amplifier, designed especially to operate heavy duty loud speakers, which is capable of producing loud speaker volume considerably in excess of that obtainable from the *112*, *171*, *371*, *240* and *340* types. It may be operated in conjunction with any type of receiver if proper voltages are supplied. Voltage requirements are a filament source of from 6 to 8 volts, preferably the latter if high plate voltages are used. This plate voltage may range from 90 to 425 volts, with a corresponding "C" battery of 4.5 to 35 volts. This power tube, known as *210* and *310*, may also be used for radio transmission purposes.

LOW VOLTAGE TUBES. Low voltage electron tubes to be used with dry cells instead of storage batteries are of two groups. One group operates on 3.3 volts and 0.063 ampere (3 dry cells in series) while another group operates on 1.1 volts and 0.25 ampere (a single dry cell). These tubes have filament constructions slightly different from those used in the storage battery tubes, but they are very efficient both as detectors and amplifiers at both radio and audio frequencies. In the 3.3 volt class the tubes are designated as *199* and *299* types. As a detector they require from 22½ to 45 volts on the plate with no "C" battery, while as amplifiers they require about 90 volts on the plate with a "C" battery of about 4.5 volts. In the 1.1 volt class the tubes are known as *11* or *12*, depending upon the type of socket—the *12* being a standard base. As low as 45 volts may be used for amplification and 18 volts for the detector, in the plate circuits. There is no power amplifier tube in the 1.1 volt class, but the *120* and *220* types are used in the last audio stage with the 3.3 volt class, or in connection with the *199* and *299* types. This dry cell amplifier tube will provide increased loud speaker volume and improved quality of reception from dry battery operated sets. The distortionless volume obtainable is even appreciably greater than that obtained from the *201-A* and *301-A* tubes when used with the same plate voltage. The plate potential used with the *120* and *220* tubes should be 135 volts. The "C" battery should be 22½ volts. All *199*, *120*, *299* and *220* tubes come with small standard bases and are interchangeable with larger tubes in sets equipped with standard sockets.

RECTIFYING TUBES. Among the several special purpose tubes are electron rectifying tubes. Such tubes are used as rectifiers for converting alternating currents into unidirectional currents, either for charging storage batteries, or to take the place of radio "A" and "B" batteries. In the rectifying class there are tubes known as half-wave and full-wave rectifiers. The latter rectifies both halves of the cycle, and thus takes the place of two separate tubes. It will pass as much as one-fifth of an ampere in some cases when 220 volts are impressed on the grid. Some rectifying tubes have no grid but have two anodes and one cathode and rectify both halves of the cycle. The half-wave rectifier will pass the same amperage but must then have twice the voltage on the grid. One full-wave rectifier equipped with a filament consumes 5 volts and 2 amperes and is capable of giving an output of 125 milliamperes with a plate voltage per anode of 300 volts. Another single-wave rectifying tube passing but 65 milliamperes and taking 7.5 volts and 1.25 amperes, is especially designed for use in rectifier units supplying amplifiers for high-voltage power loud speakers. A heavy duty half-wave rectifier that is particularly suited for high voltage power units takes 7.5 volts and 1.25 amperes. It will rectify voltages up to 750 volts giving an output of 110 milliamperes direct current. Two such tubes may be connected to give full-wave rectification with an output of 220 milliamperes direct current. A circuit showing the employment of a gas three-electrode filamentless rectifying tube has been indicated at *B* in Figure 18. This type of tube has been described in connection with "B" battery eliminators.

ALTERNATING CURRENT AMPLIFYING TUBES. Two tubes, known as *326* and *327*, have been devised to fill the requirements of receivers to be operated direct from the alternating current mains. They eliminate the use of expensive rectifier and filtering means to provide current for the tube filaments. They can be used only in radio and audio frequency amplifier circuits with 90 to 180 volts on the plate. The *326* type takes 1.5 volts and 1.05 amperes while the *327* type uses 2.5 volts and 1.75 amperes. These tubes give a *humless* operation and the *327* type may also be used as a detector on alternating current. The cathode of the tube is heated by a separate heater element instead of having current passed through the cathode element. The heating element consists of small tungsten wire coils wound on refractory tubes. Heat is generated in the elements and given off to a shell of nickel coated with a certain oxide having the ability to emit large quantities of electrons.

GENERAL PURPOSE TUBES. *Ballast* tubes serve to regulate the amount of current used by power amplifier sets when operating on alternating current, and are connected in series with the transformer primary. Variations in the line voltage will not affect the set when the ballast lamp is used. *Protective* tubes are designed for protection against short circuits in the plate circuit. They are made to be connected in the "B" battery circuit and will protect radio tube filaments against any possibility of accidental destruction through wrong "B" battery connections.

VOLTAGE REGULATOR TUBES. The most common use of the voltage *regulator* tube is on the output of "B" power units to obviate the necessity for variable voltage controls to compensate for load and line variations. When connected in a circuit, as shown in *B* in Figure 18, a constant voltage will be maintained. Such a tube is essentially a gas filled chamber containing three electrodes. The large cylinder is the cathode and the small cylinder is the running anode. The current drop between the anode and the cathode is always constant as it is possible to keep the gas in this chamber in a constant state of ionization.

ELECTRON TUBE SOCKETS. All electron tubes must be used in sockets of some kind, so that contact can be made with the various parts of the radio circuit. The base of the tube is fitted with four *prongs*, one each for the grid, plate and filament negative and filament positive connections. On the side of the base is a small pin which fits into a slot in the side-walls of the socket, so as to guide the tube into correct contact with the proper circuits. This is sometimes known as a *bayonet* socket. Tubes having the letter prefix C, WD and UV have these bases, and are now known as old type bases and sockets. A new type of socket has four holes to receive the four prongs of the new standard type of base. This method insures better contact between the tube and the socket. The filament prongs of the new standard base are somewhat larger in diameter than the prongs of the grid and plate terminals, to insure correct insertion of the tubes. The new standard bases and sockets are known as *CX*, *UX* and *WX* types. The sockets are often fitted with springs so that the tube is carried on a *floating* support. Thus the microphonic noises due to vibration are reduced to a minimum.

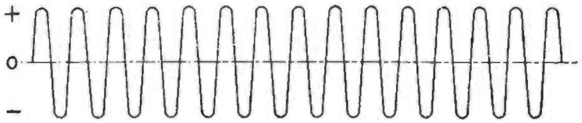
Electron Tube as an Oscillator. The electron tube as an *oscillator* is used to transmit radio signals, and to generate electromagnetic waves. The principle of operation will be described briefly to show how this state of oscillation may be utilized for the transmission of radio signals. After the electron tube was developed as a part of the receiving equipment, it was found to be an efficient transmitter of continuous waves having a radio frequency. The radiotelephone must have a steady and smooth high frequency current as a carrier wave, which can be modulated with a varying voltage having the voice frequency and associated characteristics. Transmitting tubes are similar to receiving tubes in general design, except that they must handle heavy currents. All gas must be removed to prevent damage to the filament since the tubes are operated on direct plate potentials ranging from 200 to 20,000 volts.

Producing Continuous Waves. To use an electron tube for the production of continuous waves of radio frequency, there must be a *feed-back* or regenerative action. This electrostatic feed-back arrangement is *between* the plate and grid circuits of the transmitting tube, and is generally produced by a condenser or capacity coupling. This condenser is varied until the tube starts to oscillate very slightly. A small oscillation produced in a grid circuit will, of course, cause corresponding changes in the plate current and reacting oscillations which are produced in a coil. They in turn produce oscillations in a coil in the grid circuit. This feed-back, as well as the condenser coupling, serves to increase the original grid oscillations. The plate current increases at a faster rate, and this acceleration would continue indefinitely if the tube did not become saturated. The voltage in the coil oscillates rapidly between positive and negative, and is a high frequency current. The frequency depends upon the set inductance and capacity. The coil is then coupled inductively to the antenna circuit, and the tube will sustain a continuous wave in the antenna. This wave must be modulated, so that its amplitude will vary with the rise and fall of the voice currents from the microphone transmitter.

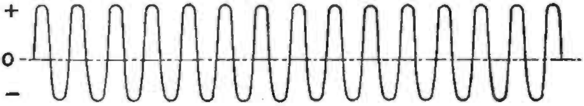
THE ELECTRON TUBE AS A MODULATOR. The carrier wave from a transmission circuit must be *modulated* before it can be adapted to voice or musical frequencies. An electron tube is also used for this purpose. The plate is supplied with direct current, and the voice frequency voltage is impressed on the grid by the microphone through an audio frequency transformer. As the plates of the modulating and transmitting tubes are connected through a high impedance choke coil, any variations in the modulator plate currents, due to the voice, are impressed on the plate of the oscillator tube. Therefore the transmitter plate potential is controlled in accordance with the audio or voice frequency, and the amplitude of the radio frequency carrier wave is given similar variations.

CRYSTALS AS CURRENT RECTIFIERS. A crystal is an element, sulphide or oxide, that has certain essential characteristics of what may be termed *unilateral conductivity*. This means that it is a rectifier of alternating currents, especially radio frequency currents. A device, whether a crystal or electron tube, possessing unilateral conductivity, has a greater resistance to a current flow in one direction than it has in the opposite. This resistance is also known as *asymmetrical resistance*, and a device having it is known as a *detector*. The term is not strictly accurate for the crystal does not detect, but makes evident the energy that is received, in the form of audible frequency waves. The crystal is, therefore, properly known as a rectifier. It possesses a high conductivity for an electric current of one polarity, but has a high resistance to a current of opposite polarity. A crystal having the *greatest* asymmetrical resistance will give the maximum signal strength.

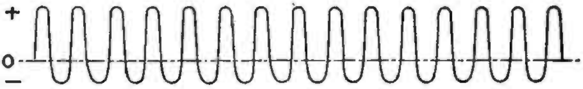
USES OF CRYSTALS. The crystal detector is well known, and before the day of electron tubes it was thought to be the last word in a receiving device. It is now hard to believe that practically all radio communication was once carried on by crystals. New circuits employing crystals are developed from time to time, and they can be relied upon to operate on nearby stations, and may be amplified many times by using electron tubes. Old time wireless operators could easily cover distances of one to two thousand miles with crystals. Of course, the power of the wireless transmitters was very high, while that used for radiophone transmission is relatively low. However, with the advent of so called *super-power* in the broadcasting field, the crystal, provided it is sensitive and carefully adjusted, may be used satisfactorily for moderate distances. A crystal detector has some advantages; it is inexpensive; it has no battery upkeep; it is easily arranged in simple circuits, and will bring in nearby signals with considerable volume and clarity.



A - NO RECTIFICATION



B - POOR RECTIFICATION



C - FAIR RECTIFICATION

D - EXCELLENT RECTIFICATION

FIG. 38. FORMS OF CURRENT RECTIFICATION BY CRYSTALS

THE CRYSTAL DETECTOR. A simple detector is made by placing two dissimilar solid substances into contact. Almost any substance will be found suitable, but some are better than others. For instance, a steel point pressing upon a piece of phosphor bronze will make a weak detector. Crystals seem to have a higher degree of asymmetrical resistance than metals. Such crystals operate with a sharp metallic point, usually bronze or steel, pressing with a varying intensity on some portion of the crystal. All crystals present what are known as *sensitive spots*, and one minute spot may have a high degree of asymmetry. The contact point seems to present a high resistance to the flow of a current from one direction, while there is but little opposition to a flow in another direction. The sensitive points should be located by trial while receiving signals. The high frequency alternating current (*A* in Figure 38) which is brought to the crystal from the antenna or antenna tuning circuit is thereby turned into a pulsating direct current. If a crystal passes a current (*B* and *C*) nearly as well in one direction as in another, it is unfit for radio rectification purposes. If it passes a current in one direction but absolutely blocks its flow in the other, the degree of rectification is very high, and the crystal makes an efficient detector. See *D* in Figure 38.

WAVE TRAINS THROUGH A CRYSTAL. As we have seen elsewhere, the diaphragm of a sound reproducing device cannot follow the extremely high frequency of the antenna alternating current, due to the mechanical inertia of the metal disc. Even after the alternating current has been brought to the crystal and passed through in one direction, the impulses are much too rapid to actuate the diaphragm of the receiver. These impulses vary from zero to the maximum potential, but are of one polarity only, either positive or negative, as the case may be. The effect of these pulsations is *accumulative*. As the carrier wave is sent out from the broadcasting station, it has the note or sound variations impressed upon it, which are carried in wave groups or trains. The averge of each of these wave trains, when rectified, is a pulsation of current. The *rate* of pulsations is, therefore, reduced to a frequency within the limits of mechanical reproduction, and reception by the human ear is made possible by the impulses given to the diaphram. See *C* in Figure 37. This is similar to the average current flowing through the telephones in the "B" battery circuit of the electron tube rectifier, except that it is much weaker as only the *original* antenna current is available to operate the receiver diaphragm in crystal receivers.

THE GALENA CRYSTAL. The *galena* crystal, which is lead sulphide, crystallizes in cubes, and is a blue gray color with a metallic luster. It is lead ore, carries considerable sulphur and breaks into clear fractures of bright surfaces. This crystal is perhaps the best in the group of natural rectifiers, and has enjoyed widespread popularity. It has not been the subject of patent and royalty rights and has therefore always been available at a moderate cost. Galena is best used with a fine bronze wire in light contact. The wire or *cat-whisker*, should be bent into a small spring so that a slight tension will press it to the face of the crystal. Considerable patience may be necessary to locate the sensitive spot on the crystal. The contact is easily disturbed, and may require readjustment from time to time if the set is subject to any vibrations.

THE SILICON CRYSTAL. *Silicon* makes a very good rectifier, although it is not quite as sensitive as galena. However, it retains its sensitivity over a long period of time, may be ground down and polished to a smooth flat surface, and, as it is not very sensitive to heat, may be mounted in a cup of soft solder. It is best used with a blunt brass point such as a screw, which may be placed on the crystal with considerable pressure. Silicon is obtained from rocks, and the best kind is that which is fused in an electric furnace from the proper material. Silicon rectifiers have been used for many years, and the material was at one time subject to royalty rights, and could be obtained only at considerable cost.

THE CARBORUNDUM CRYSTAL. When a rectifying crystal has a very high resistance to low voltages applied in the non-conducting direction, it results in decreased damping and increased selectivity. This is the case of the carborundum crystal. These crystals are produced in an electric furnace from coke, sand, sawdust, salt, etc., and fused into masses of gorgeously colored diamond-like lumps. Carborundum is also used to make resistance couplings for amplifiers and grid leaks, besides its familiar use as an abrasive. It is the only rectifying crystal that can be used under heavy pressure contact, and makes an excellent permanent detector. A dry cell, when connected in series with the crystal and telephones, will produce a strong click when connected in the right direction, and almost no sound when reversed. This is an indication that the crystal will function properly.

THE CARBORUNDUM DETECTOR BATTERY. When using a battery with a carborundum crystal, the former should be shunted with a high resistance potentiometer, and the two output terminals connected in series with the crystal in the correct direction, but also shunted with a small by-pass condenser. This battery, because of its fine regulation of voltage, will help increase the current, and is known as a *booster battery.* The carborundum detector may be obtained as a unit adaptable to all receivers, even replacing the tube as a detector, except in regenerative circuits. The detector impedance may be regulated by a potentiometer knob, while the necessary voltage is furnished by a small flash-light cell, that fits into a spring support. The two terminals are connected into the radio circuit as with any other crystal detector, since the battery, potentiometer and condenser are self-contained within the unit.

OTHER RECTIFYING CRYSTALS. *Iron pyrites* have been used successfully for detectors. These crystals are iron sulphide, and are found extensively in nature. Iron sulphide crystallizes in cubes and has a metallic yellow luster. While it is used in much the same manner as galena, it must have a heavier contact pressure. A detector that once was quite popular, and which should still be extensively used for local radio reception, is one made up of a combination of two crystals, one of *bornite* and the other of *zincite.* Bornite is a double sulphide or a combination of copper and iron sulphides, while zincite is a form of zinc oxide. It is generally arranged so that the piece of bornite is held stationary, and the zincite, with a sharp cleavage edge projecting, is held in a moveable arm so that the point may be brought to bear upon the bornite. This detector will give good results; it is easily adjusted, and will retain adjustment for a long time. The rectification action occurs at the point of contact between the two crystals. The rectifying principle of molybdenum, or *molybdenite,* is often used but it cannot be said to be satisfactory. However, sensitive specimens of molybdenite are sometimes found. They retain their adjustment, and may be permanently clamped between two metallic contacts.

CARE OF CRYSTALS. Crystals used for detectors should not be handled with the fingers but with a pair of light tweezers as their sensitivity is impaired by the natural oils of the skin. Some crystals are not injured by exposure to the air, but galena will soon lose its qualities, requiring frequent fractures in order to present new surfaces to the contact point. After a good piece of sensitive crystal has been selected it should be mounted on some type of *holder*. A satisfactory type is a small cup with a number of set screws which clamp the crystal in place, and make very good contact. This provides for the changing or removal of the crystal with the least delay. Crystals such as bornite, silicon, carborundum, etc., may be mounted permanently by using some soft solder. Ordinary solder should never be used as its fusing point is too high, and the crystals may become so heated as to destroy the rectifying abilities. A metal which melts in hot water or with comparatively little heat is best. Such a metal is known as *Wood's metal*, and the crystal is pressed down into a small brass cup partially filled with the soft heated metal.

THE ELECTROLYTIC DETECTOR. The *electrolytic detector* is a simple form of chemical rectifier; in fact, a miniature duplicate of the chemical rectifier used to charge storage batteries from alternating house current. The electrolytic detector can be used with excellent results on any radio set, and it will detect nearly as well as an electron tube. This type of detector consists of a small carbon cup holding a few drops of dilute sulphuric acid solution into which a very fine platinum wire barely projects. The wire may be as small as 0.0001 inch in diameter, and is silver covered so that it can be handled. The silver coating dissolves as the wire touches the acid. Best action is obtained when the end of the wire is raised so as to raise the surface of the acid by capillary attraction, for in this manner contact is just possible. A battery is connected across the carbon and platinum elements, with the telephones in series. The fine wire of the positive terminal becomes covered with minute bubbles which prevent the flow of electricity in one direction across the electrolyte. The current is, therefore, passed in one direction, while current from the opposite direction is blocked. This detector requires a fine battery and wire point adjustment. Powerful signals from nearby stations, and static outbursts tend to throw the point out of the electrolyte, and a readjustment is necessary.

CHAPTER VII

THE PRINCIPLES OF RADIO AMPLIFICATION

ELECTRON TUBES AS AMPLIFIERS. Electron tubes will amplify either radio frequency or audio frequency currents. The radio frequency currents alternate in polarity with the same frequency as the broadcast carrier waves, while the audio frequency currents alternate at a frequency much lower, within the range of the human ear. *Radio frequency amplification* consists of amplifying the radio current just *after* it is induced in the antenna, and *before* it is rectified or detected. *Audio frequency amplification* consists of the amplification of the detected current *after* it has passed through the rectifier. The use of radio frequency amplification makes it possible to receive extremely weak signals that could not otherwise be heard, even if audio frequency amplification should be used to the limit. The use of radio amplification makes it possible to use a small loop antenna for reception from radio stations thousands of miles away.

AMPLIFICATION OF POTENTIAL. We have seen how the electron tube acts as a rectifier and detector of an alternating current of high frequency when it has been impressed on the grid and which, therefore, produces unidirectional pulsations of plate current. While the tube acts as a detector in this manner—rectification—it will also act as an amplifier, and pulsations of *greater* potential are produced in the plate circuit in proportion to the alternating current applied to the grid. If the grid current is high, the plate unidirectional current will be correspondingly high and if the grid current is weak the plate current will be proportionately weak. If we can produce a stronger grid potential than is obtained from the original antenna current, we have produced amplification.

USE OF AMPLIFICATION. A radio set may be complete without any amplification whatever. The amplifier is separate and distinct from the actual reception of radio signals. It is not needed in the usual operation of the set, and is necessary solely for the production of signals of increased volume and for increasing the receiving range. Amplification of the radio frequency kind is used to increase the range of the receiver, while audio frequency amplification will increase the strength of the detected signals to any desired volume within reasonable limits. Fortunately, amplification is no complicated affair, consisting simply of an electron tube, a filament control or rheostat, which is not critical in its operation, a suitable transformer, and the necessary batteries. When considerable amplification is desired, regardless of whether at radio or audio frequencies, a number of amplifiers may be connected in series or *cascade* or *stages*, using the same battery supply for all of the tubes. However, if too many amplifying units are set up, the slightest distortion or noise is gradually increased through each unit, until the amplification has reached a practicable limit. This limit controls the number of amplifying tubes which can be used with satisfaction.

RADIO FREQUENCY AMPLIFICATION. The frequency of the electromagnetic waves used in radio broadcast work are very high because more energy is radiated by the antenna. If this current is passed through the coil windings of a telephone receiver, no sound will be produced, because the diaphragm cannot vibrate at such a high rate of speed. These frequencies range from 10,000 to 300,000,000 cycles per second, while the range of the human ear is from 30 to 10,000 vibrations per second. Radio frequency amplification is generally obtained by inductive transformer, resistance, or impedance couplings.

TRANSFORMER R. F. COUPLING. We know that electric currents can be transferred from one circuit to another, and the principle of this coupling is used in the inductive transformer. Two coils, a primary and a secondary, are wound on an open core. The primary winding receives a certain amount of energy and, through the action of its electrostatic field of force, certain currents are induced in the secondary coil. Radio frequency currents are very, very weak and are induced in the antenna by the passing electromagnetic waves sent out by the broadcasting stations. The antenna is filled with these currents, all flowing at various frequencies, and in order that the one desired may be picked out, a tuning arrangement or coil is needed to bring the circuit into resonance with the desired frequency. As this wave comes in

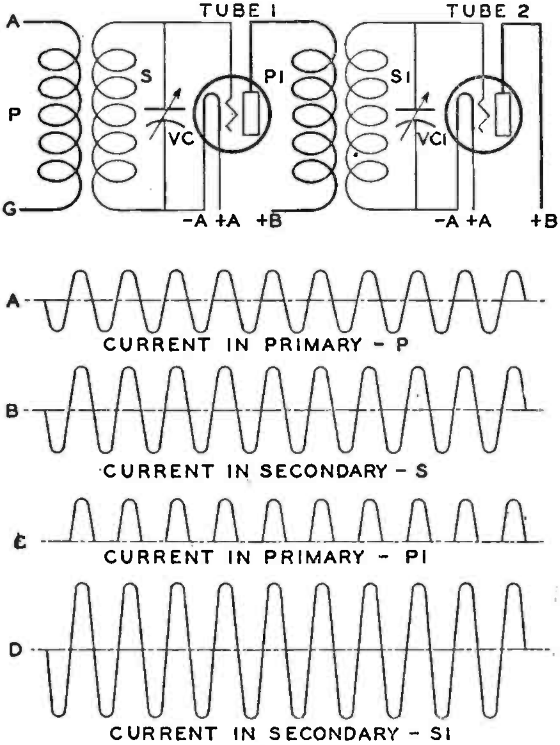


FIG. 39. TRANSFORMER COUPLED RADIO FREQUENCY AMPLIFICATION
(*A*) Form of Primary Current; (*B*) Form of Secondary Current; (*C*) Form of Rectified Current in Primary; (*D*) Form of Induced Alternating Current in Secondary and Impressed on Grid of Detector.

through the antenna tuning device, it may be desirable to amplify it. It is not necessary to detect the current first, as the radio frequencies can be transferred from one circuit to another by induction. Therefore from the tuning circuit the current (*B* in

Figure 39) is led immediately to the grid of the first radio frequency amplifying tube. See *1* in Figure 39. The tube is connected to batteries in the usual manner, except that at least 90 volts may be required for plate potential. The plate is connected to this "B" battery through the *low-loss* primary *P1* of a radio frequency transformer.

RADIO FREQUENCY TRANSFORMERS. The real use of the *radio frequency transformer* is to obtain an alternating current of radio frequency (see *D* in Figure 39) from the intermittent current (C) passing through the plate circuit. As has been indicated, this plate current flows in unidirectional pulsations, or from zero to maximum potential, but of only one polarity, because of the rectifying properties of the tube. The current in the primary of the transformer is therefore pulsating, but varies with each half cycle of the radio frequency grid current. The passing of the pulsating current through the primary of the transformer induces an alternating current (*D*) in the secondary having all of the characteristics of the original antenna current (*A*), but of a greater amplitude. The steady flow of the "B" battery current through the primary to the plate has no *inducing* effect in the transformer, but as soon as it begins to be interrupted or pulsate because of the suppression of half of each grid cycle, the magnetic field varies accordingly, and a radio frequency current is set up in the secondary. This greatly amplified current is now ready to be impressed upon another radio frequency tube or the detector tube.

LOSSES DUE TO CAPACITY. Transformer coupling of radio frequency amplification circuits is the most effective and desirable method. The principal necessity in radio frequency circuits is to keep away from all unnecessary capacities, as even a very small capacity is a good conductor of radio frequency currents, and some losses will result. It is, therefore, necessary to have a transformer which will have very small capacities in its windings as well as in the connecting wires. Every capacity loss in the radio frequency circuit tends to narrow the range of frequencies or wave lengths over which the amplifier will operate. There is in every electron tube a small capacity between the grid and the plate and, when the two are coupled through this capacity to almost the point of resonance there is a tendency to oscillate, as the tube does when there is too much feed-back. This is one of the inherent difficulties of radio frequency amplification. Some circuits prevent this to a great extent, the most popular of which is called the *neutrodyne* circuit. The coupling within the tube is neutralized by means of a small variable condenser placed between the two elements. Oscillation difficulties are overcome in this way, but there is some absorption of the signals, thereby reducing some of the amplification strength. Due to the capacity effect of a coil, the radio frequency current will leak across the turns of wire without passing through the entire length. There is present a condenser effect, and the full effect of the current passing through the wire is not obtained.

LOSSES BY ELECTROSTATIC COUPLING. There are losses in radio frequency amplification and detector tuning stages due to the intercoupling of the various circuits. The surrounding magnetic fields include other circuits, and considerable losses may result because of these couplings. About the only remedy is spacing of the various stages of amplification, or the complete *shielding* of each stage. Shielding is obtained by enclosing the stage within a tight metal box or container which is grounded. Any electrostatic fields that reach out to the metal shield are immediately stopped and grounded, and cannot interfere with adjoining circuits or stages. Certain wires of the circuit, when placed too close together, will produce serious *inter-coupling* losses, as well as distortion and feed-back.

TUNED RADIO FREQUENCY AMPLIFICATION. An example of *tuned radio frequency amplification* using two stages of coupling is shown in Figure 40. It will be noted that the first amplifying tube is connected across the receiving coils and tuning condenser. The output terminals of transformer *2* are connected to the grid and the filament circuit of the second tube. The plates of the two tubes are connected to the same "B" battery. The current received in the antenna tuning circuit (*A* and *B* in Figure 39) is impressed on the grid *G* of tube *1*. Its fluctuations produce corresponding fluctuations in the plate circuit, and a unidirectional pulsating current (*C* in Figure 39), is passed through the primary *P1*. An alternating current (*D* in Figure 39), is set up in the secondary *S1*, which is impressed on the grid *G1* of tube *2*. This grid current is stronger than that in tube *1* and, therefore, the "B" current fluctuations set up in the plate circuit of tube *2* are correspondingly greater, and the pulsating current in the primary *P2* of transformer *3* is still greater. The alternating current in the secondary *S2* has a strong amplitude and, as it flows into the detector through *G2*, is many times stronger than the original as received at *G*. Any number of stages of amplification may be used, but two or three seem to be the limits of practical reception. The secondary coil of each stage must be tuned with a variable condenser (*VC*) to bring each individual circuit into synchronous resonance. This means that the more stages, the more variable tuning condensers are necessary, and the greater the difficulty of tuning adjustments.

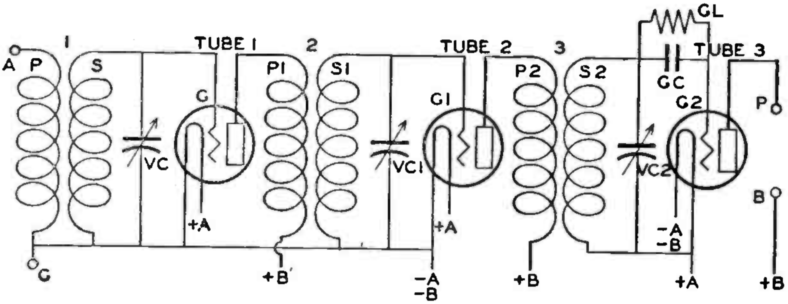


FIG. 40. TUNED RADIO FREQUENCY AMPLIFICATION

RADIO FREQUENCY RESISTANCE COUPLING. The difference between audio and radio frequency amplifiers is mostly in the frequencies of the current to be amplified, as the forms of coupling remain practically the same. The resistance coupled amplifier shown in Figure 42 will work also on radio frequency. Due to its high resistance and lack of tuning facilities, it is not nearly as selective nor efficient as inductance coupled amplifiers. But it may be fitted with a filtering device (Figure 45) to facilitate tuning.

AUDIO FREQUENCY TRANSFORMER AMPLIFICATION. We have seen that the original signals may be amplified before they are rectified. Now suppose that they have been passed through the detector, and it is desired to amplify them further to produce a much louder sound. It should be remembered that while any detected signal may be amplified to a certain limit of loudness, static and other foreign noises will also be amplified in proportion. In the early days of radio broadcasting, the transformer system of coupling was almost universal because the efficiency of this system was very high and not many tubes were required. *Transformer coupling* is remarkably efficient on weak signals; but its performance differs considerably from that of other systems of coupling, in the fact that high efficiency *decreases* very rapidly as the signal intensity is increased. This is a transformer characteristic which gives rise to considerable distortion on account of the fact that the weak signals are amplified more than the stronger ones. It is difficult to use more than two stages of transformer coupling because there is a marked tendency for audio frequency regeneration to take place, which not only increases distortion, but produces a howl or squeal in the loud speaker. Audio frequency amplification has become one of the most discussed factors in radio reception. The transformer used in audio frequency amplification is similar to that used in radio frequency in principle only. It is not necessary that the turns of wire be staggered so as to prevent capacity effects, as no radio frequency currents pass through the primary of these types of transformers. In order to check the flow of such currents and to provide a path for them, a small fixed by-pass condenser should be shunted across the primary of the first transformer stage.

THE AUDIO FREQUENCY TRANSFORMER. The transformer consists of a primary and a secondary wound on a closed iron core. The primary has a large number of turns of wire wound next to the core, and the secondary is wound over the primary and has a much larger number of turns of fine wire. The ratio of the number of turns may be as low as 1 to 2, and as high as 1 to 10. This means that the transformer has an amplifying power of two times or ten times the original signal strength, respectively. When an alternating current is sent through the primary of the transformer it induces a corresponding current in the secondary, but of a higher voltage, according to the turn ratio between the two coils. The function of the audio frequency transformer is to obtain an alternating current from the varying voltage or average current from the detector tube, or subsequent audio frequency tubes. It should transmit accurately to the secondary coil the characteristics of the low frequency current impressed on the primary. This may seem a simple thing; but to build or obtain a transformer which will reproduce *faithfully* at all frequencies within the audible range so there will be no distortion at both extremes of frequency, is quite difficult. The amplitude of the secondary voltage must be a true reproduction of the primary voltage at every instant. As all speech voltages transmitted through the transformer will be *equally* magnified in all their characteristics, distortion is likely to creep in. A poorly designed transformer will favor certain frequencies more than others and, consequently, it will amplify disproportionately the *tones* which correspond to those frequencies. The result is a loss of tone quality.

TRANSFORMER COUPLING AT AUDIO FREQUENCIES. Let us assume a two stage audio frequency amplifier as shown in Figure 41, and that *P* and *B* are the two input leads from the plate and "B" battery of the detector tube, as shown in Figure 40. The plate of the detector *P* is connected to one lead of the primary of the first audio transformer, and *B*, the detector "B" battery, is connected to the remaining lead. The average (*X–Y*) of the unidirectional current (*A* and *B* in Figure 41) in the plate circuit passes through the primary (*P*) of the transformer just the same as it passes through the telephones when they are connected in the detector circuit. This sets up in the secondary *S*, a low frequency alternating current which is impressed upon the grid *G* of tube *1*. As this current is now reduced to an audible frequency, the following amplification is simple. The alternations on the grid vary the plate current (*C* in Figure 40) of tube *1*, which passes through the primary *P1* of transformer *2*. A stronger alternating current of low frequency is then induced in the secondary *S1*, which is impressed on the grid *G1* of tube *2*. The plate voltage of this tube (*D*) passes through the telephones or loud speaker, and is relatively heavy. Proper "C" batteries must be used when the plate

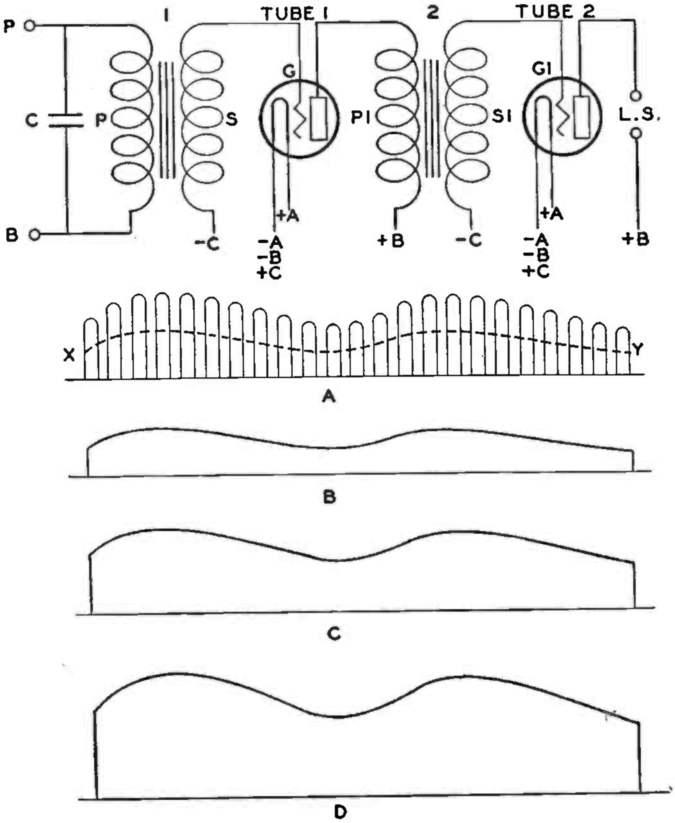


FIG. 41. AUDIO FREQUENCY AMPLIFICATION

potential is at least 90 volts or more. It is not necessary to use by-pass condensers across the primary of the additional transformer *2* as no radio frequency current flows in the following plate circuits. Such a current having the carrier wave characteristics flows only in the detector tube and preceding radio frequency amplifying tubes.

RESISTANCE AUDIO FREQUENCY AMPLIFICATION. *Resistance coupling* consists essentially of connecting the plate of an audio amplifier tube to the grid of another by means of a small condenser; supplying the plate current to the first tube through a resistance, and connecting the grid of the second tube to the negative filament (and "C" battery) terminal through a grid leak resistance. This system, although inefficient, has one advantage; it is capable of giving an excellent quality of reproduction, only so long as the signal intensity is not too great. Since there is no tendency for regeneration to take place between the stages, it is possible to use several stages, which makes it possible to procure sufficient amplification. This system has the disadvantage of inability to handle large currents or powerful signals, because the grids of the amplifier tubes accumulate charges too rapidly to be easily taken care of by the grid leaks. Furthermore, this effect is noticeable on signals of medium intensity, as manifested in a certain amount of blurring and distortion, which increases as the signal intensity increases. Special power tubes will reduce this overloading and better the reproduction.

A RESISTANCE COUPLED AMPLIFIER. The resistance units used in this type of amplifier should be made so as to have no internal capacity. An amplifier using this type of non-inductive resistance and which is arranged in three stages of amplification, is shown in Figure 42. The incoming rectified signals from the detector are made to affect the grid of tube *1* through a very high resistance *R*. The filament of tube *1* and its grid, are connected together through this high resistance and a condenser, shown at *C*. This coupling condenser is necessary to keep the high positive voltage from the grid of the following tube. It should have a rather large capacity if the amplifier is to bring out low tones. At the present time, a coupling condenser having a capacity of 0.1 microfarad is frequently recommended as meeting the requirements most satisfactorily. A much smaller condenser will cause the amplifier to show weak values for the low tones, and a much larger condenser may cause grid *blocking* with consequent poor quality amplification, unless the grid leak resistance is made so low in value that amplification is reduced. This leak resistance *L* is connected from the grid to the negative "A" filament. Any variations in the voltage between *P* and *B* will produce a *difference* which will be *impressed* upon the input circuit of tube *1*, and affect the grid accordingly. The variations of the voltage on the grid of tube *1* will cause a corresponding variation in the plate circuit of the tube and, therefore, a varying current will exist across the second high resistance *R1* of tube *1*, and between the points *a* and *b* of the circuit, with a potential difference of the same character. But tube *2* is connected similarily to tube *1*, with this high resistance *R1* across its grid and filament, and with the condenser *C1* between the resistance and the grid. The leak *L1* is similarily placed between the grid and the negative "A" filament (or negative "C" battery) and, therefore, any voltage variation between *a* and *b* will be impressed on the grid of tube *2*. In the same manner, the signal will be repeated to tube 3, through the resistance *R2*, condenser *C2*, and leak *L2*. In the plate circuit of tube *3* are placed the telephones.

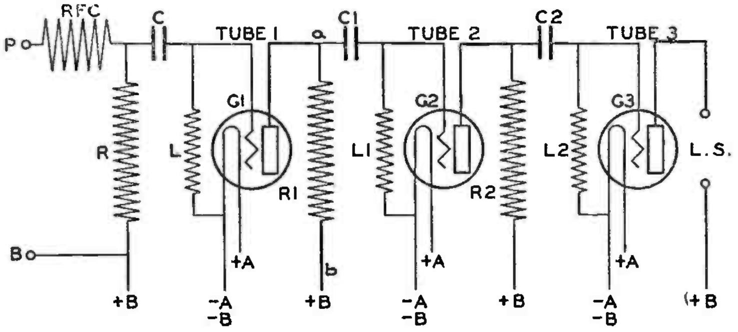


FIG. 42. AUDIO FREQUENCY RESISTANCE COUPLING

USE OF RESISTANCES AND CONDENSERS. The *grid condensers C*, *C1* and *C2* are used to insulate the grids of tubes *1*, *2* and *3* from the "B" battery. The *leak resistances L*, *L1* and *L2* are made necessary by the use of the condensers *C*, *C1* and *C2*. The operation of a tube is uncertain if the grid is insulated by a condenser in series with it, as the accumulation of electrons on the grid will force it to assume a high negative potential. In a short time this accumulated charge has no way to escape, and the tube becomes *paralyzed* or *blocked*, as the plate circuit cannot properly operate. This accumulated charge on the grid must be permitted to *leak* off, which it does by means of the high resistance leaks. These resistances (*L*) may vary from 4 to 10 megohms, while the large amplifying resistances (*R*) run from but 5,000 ohms to 1 megohm, according to the design of the amplifier. In all cases, the leak resistances should be as high as possible without blocking the tubes. There was formerly a good bit of trouble with resistance coupled amplifiers in that the resistances generally available were not accurate and permanent. This trouble has been overcome, and it may be expected that the newer types, which are explained elsewhere, will be quite satisfactory in this exacting amplifying circuit.

TRANSFORMER AND RESISTANCE COUPLED AMPLIFIER. There is a good use for a single resistance stage in combination with a transformer coupled stage that will enable anyone to use a very high ratio transformer to its best advantage. The resistance stage should be used right after the detector tube with a high plate voltage. The coupling resistance causes the plate voltage to be *reduced* to a value giving good results. The high ratio audio transformer will give the most pleasing tone quality when used in a two stage transformer coupled amplifier, but in combination with the resistance coupled stage may be expected to do very well. In most cases the resistance stages follow one stage of transformer coupled amplification, and thus secure amplification of greater volume, but with greater tone quality. Such an amplifier will handle good volume with usual plate voltages.

IMPEDANCE COUPLED AMPLIFICATION. The *impedance ampli-*

fier coupling differs from resistance coupling only in that the resistance, through which the plate circuit of the amplifier tube is supplied, is with this system replaced by a choke coil. The rest of the circuit is the same. This system, while it has an efficiency per stage somewhat higher than resistance coupling, has the same disadvantages in the tendency of the grids of the amplifier tubes to load up and introduce distortion as the volume of the signal increases. Unless a grid leak of very low resistance is employed, which *reduces* the efficiency of the system, this arrangement is not capable of giving the best results in volume. Figure 43 shows an impedance choke coil coupled circuit, suitable for use with radio and audio frequencies. It is principally used for amplification at *audio* frequencies. The impedance of the two choke coils *CC1* and *CC2* is very high, while its direct current resistance should be low. If this amplifying device is used for radio frequencies, the iron core of the coils should be eliminated, and variable condensers used to tune the coils to resonance with the incoming signal. But for audio frequencies, the improvement in tone quality readily justifies the addition of the extra stage necessary to obtain volume equal to that given by transformer coupled amplification. The variations of plate current from the detector tube between *P* and *B* are impressed upon the grid of tube *1*,

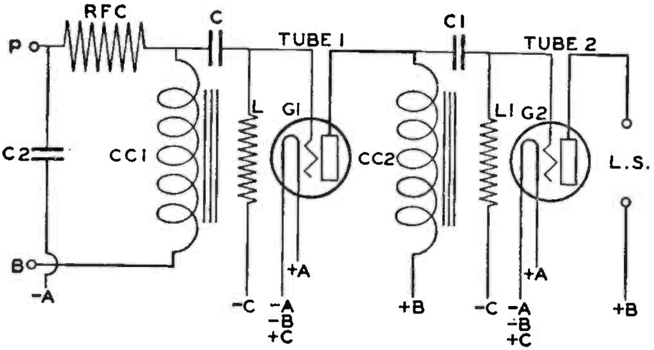


FIG. 43. IMPEDANCE COUPLED AMPLIFICATION

which in turn varies the plate current, causes variations in the impedance of the coil, and changes the opposition to the flow of the plate current through the coil *CC2*. Otherwise, the arrangement is similar to that used in resistance coupled amplification, as shown in Figure 42; the condensers *C* and *C1*, and grid leaks *L* and *L1* serve similar purposes.

DUAL-IMPEDANCE COUPLED AMPLIFICATION. *Dual-impedance* amplification, as shown in Figure 44, makes use of *twice* as many audio frequency choke coils or impedances as are used in the ordinary straight impedance amplifier. Sometimes the audio tubes have a tendency to block, and this, of course, is done away with in the case of double impedance. However, it requires more equipment and higher "B" battery, with the use of a power tube in the last stage. This method of coupling will give a better output than any other type of amplification used in the audio stage.

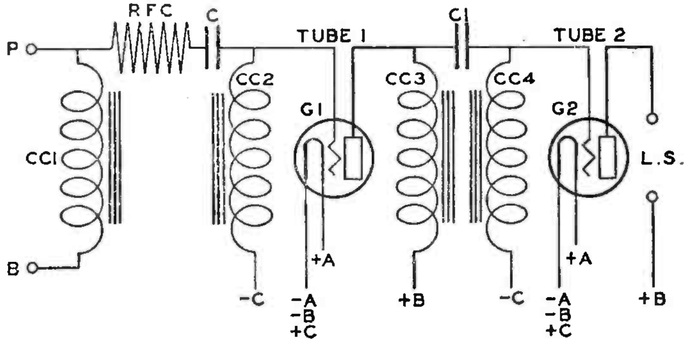


FIG. 44. DUAL-IMPEDANCE COUPLED AMPLIFICATION

USING RADIO FREQUENCY CHOKE COILS. In the case of impedance, resistance, dual impedance and transformer amplification, there is one feature that has been usually overlooked; it is the necessity of keeping the radio frequency currents out of the audio amplifier. For this reason the illustrations of these amplifier circuits show *radio frequency choke coils* (*R. F. C.*) in their proper locations. When these radio frequency currents enter the audio amplifier they usually have a very serious effect upon the operation of the amplifier. The use of a choke does away with these tendencies; and leaves the audio tubes free to amplify the low frequency alternating current exclusively. The use of a choke coil also tends to force the radio frequency current through the by-pass condenser to take the shortest path back into the tube filament.

Use of Filters in Amplification. In some radio frequency amplification systems it is advisable to use a *filter*. This is a combination of resistances, inductances and condensers which prevents amplification of any except desired signals. For instance, in the resistance and impedance coupled amplifiers described previously (see Figures 42, 43, and 44). The filter consists of an inductance coil *F* shunted by a variable condenser *VC* or a fixed condenser of determined capacity, as shown in Figure 45. The two leads of the filter are connected between the point *b* of the filament circuit and *a* of the plate circuit, but before it passes the fixed condenser *C2*. Another fixed condenser *C4* is placed between the point *a* and the filter connection just to the left of condenser *C2*. This condenser prevents any "B" current from getting into the device and the filament circuit. The action of the filter is due to its tuned impedance which will practically short-circuit the repeating resistance *R2* to all frequencies except the one to which it is tuned; and to the fact that the repeating resistance

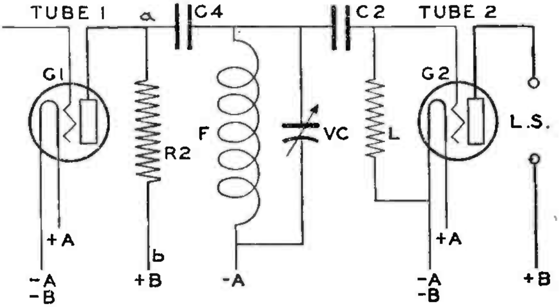


Fig. 45. Filter in Radio Amplifier Circuit

will give small amplification to any frequency except the desired one. Of course, the frequency *nearest* the desired one will be repeated, though not at all strongly, into the second tube. The output current will contain little more than the component of the original input currents of the desired frequency very strongly amplified, while the components of the other frequencies are very much weakened or totally suppressed. This type of filter not only acts as a barrier to unwanted audio and radio frequencies, but it holds down low frequency static interference to some extent.

AMPLIFICATION NOISES. An amplifier of the inductance and transformer type is likely to produce certain audio frequency noises or independent notes which are not identified with the incoming signals. This feature, known as *squealing* or *howling* is very objectionable, and hard to overcome. It is due to the fact that the circuits of the amplifying tubes are permitted to oscillate. The greater the amplification the more likely is it to set up squealing. It may be caused by the connection of the input and output circuits in some manner or too close proximity of the plate to the grid leads. There may be electrostatic fields which affect adjoining tubes, and energy from one circuit is absorbed by another, thus destroying the balance of the circuit.

PUSH-PULL AMPLIFICATION. Only a few stages of amplification are used on the audio side of the circuit due to its limitations and sometimes these few stages do not give the desired amount of amplification. If more volume is desired, especially from distant stations it is possible, without adding to the number of stages, to obtain pure tones by means of what is known as *push-pull power amplification.* Special power tubes are now made for use in the last amplifier stage, which handle heavy currents without overloading and blocking. They require the same "A" battery consumption but a higher "B" and "C" battery. These tubes, in connection with the push-pull circuit, provide a powerful amplifying unit. Their value lies in ability to handle heavy audio currents which would overload transformers of the average type, as special transformers must be used. When a current has been built up through at least two stages of straight audio amplification, the push-pull system can be made to apply. Where extraordinary volume is necessary, for outdoors or for large buildings, the push-pull power type of amplifier is of great value used as a third stage following the two straight audio stages. The system requires two transformers, each of a different winding, connected in a single circuit or stage as shown in Figure 46.

The Push-Pull Amplifying Circuit. The transformer used on the input side has the usual primary winding but has a double or split secondary winding. The inner ends of the two secondary sections are connected, and make the usual negative "A" battery or "C" battery connection. The outer ends of the windings are connected to the grids of *two* amplifying tubes. As each of the secondaries are connected to a separate tube, the energy of the transformer output is divided. But due to the winding of the transformer, the alternations of the current are also divided, one grid tube being negative while the other is positive. One tube, therefore, amplifies during the negative half of the cycle, while the other amplifies during the positive half. Hence, the term push-pull. The two tubes, each operating on opposite halves of the cycle, give an output of *twice* the energy of tubes connected in straight amplifications, and they now present two plates. In order to provide for this there is another special transformer which has a split primary, but a single secondary winding. Each section

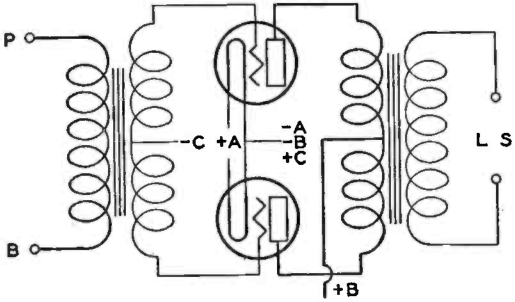


Fig. 46. Push-Pull Amplifier

of the primary receives the plate current from a tube, passing in through the two ends, which are plate connections, and passing to the common central terminal which is the "B" battery. Each half of the primary operates on opposite pulsations of the plate current in coördination with the alternate charging of the grids of the tubes, but no opposing magnetic fields are set up in the core of the transformer because of the arrangement of the primary windings. This feature eliminates any danger of distortion from heavy magnetic saturation. The secondary of the output transformer is connected directly to the loud speaker, as this type of transformer serves to couple the plate circuit to the loud speaker circuit inductively. The "C" battery to provide a negative bias to the grids of the two amplifying tubes is necessary, and is connected between the negative "A" terminal and the "A" connection of the secondary of the input (first) push-pull transformer.

FEED-BACK OR REGENERATIVE AMPLIFICATION. It is possible to secure considerable radio frequency amplification *after* the current has been rectified in the detector, by *reimpressing* this current upon the grid of the detector tube. This scheme is called the *regenerative* or *feed-back* circuit and its discovery revolutionized radio reception. By means of it one tube is made to perform the work of two. The feeding back of a part of the rectified radio frequency current in exact phase with the original grid current, will add materially to the strength of the incoming signal. It will give a stronger charge on the detector grid and consequently a greater variation in the plate current. By this method the electron tube is greatly increased in sensitivity as it really operates as a detector and amplifier combined. But, the feeding back of the rectified radio frequency component may be carried to an extreme, and this makes the circuit somewhat difficult to handle. When an extreme feeding back of the current is reached, the regenerative effects give rise to shrill whistles, squeals, howls and hisses as the tube is set in oscillation. This causes the receiver to *radiate* at whatever frequency it happens to be tuned to. When operated by an unskilled person the regenerative receiver can be a nuisance to its owner and nearby listeners. Of this trouble and interference more will be said later.

Regeneration by Tickler Method. There are various ways of feeding back a portion of the unidirectional radio frequency component into the grid circuit. The most popular is the *tickler coil* method of regeneration, while another method is the use of a capacity coupling. The tickler coil, consisting of a few turns of wire, is inserted in the plate circuit of the detector tube. It is placed within the electrostatic field of the radio frequency transformer secondary, the output of which is impressed upon the detector grid. The tickler, therefore, is inductively coupled to the grid circuit, and any current flowing in the former produces a magnetic flux with the coil in the grid circuit. See Figure 47.

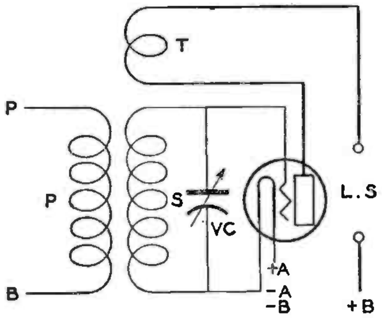


Fig. 47. Regeneration with Tickler Coil

As the magnetic field of the tickler coil is stronger than that of the radio frequency transformer primary, it will add to the original current induced in the secondary. But as the currents in the transformer primary and the tickler are so nearly in phase and act together, both have a combined effect on the secondary. If the currents are not synchronous there may be *distortion* and *bucking* between the two fields of force acting on the secondary. If regeneration by the tickler is carried too far an inductive field is forced upon the grid coil, and oscillations will be set up, resulting in annoying radiation. The grid coil which is the secondary of the radio frequency transformer, has in reality, *two primaries*—the regular transformer primary and the additional tickler coil. The tickler coil is made moveable so that its magnetic field can be gradually moved toward the grid coil, thereby slowly increasing the inductive action in that coil by cutting it with additional lines of force. It is akin to a *variable* transformer action. Amplification of this sort, when used in connection with the standard radio frequency amplification, will produce astounding results if carefully adjusted.

Regeneration by Variometer. Another method of producing regeneration is by the use of a *variometer* coil in the plate circuit. This instrument serves to tune and feed back into the grid some of the added plate voltage. The uses and principles of the variometer are described elsewhere.

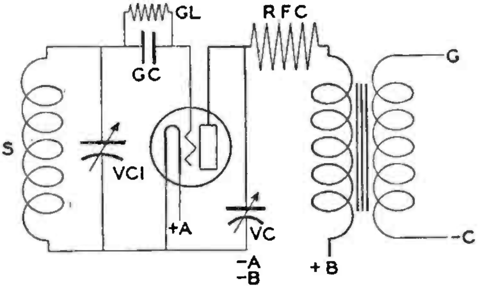


Fig. 48. Regeneration with Condenser

Regeneration by Condenser Action. Another and quite satisfactory method of controlling regeneration, is by means of a small or midget variable condenser connected between the detector plate, and the lower end of the grid coil. This method of regeneration has two advantages over the moveable tickler coil. The control is very much smoother, and it tends to better the quality by lowering the value of the shunt capacity which is otherwise placed across the primary of the first audio transformer or the telephones. Such a shunt capacity will provide a path for a portion of the audio frequency currents, especially if the primary has a high impedance. The loss of some of the low frequency alternating current lowers the strength of the signal to be amplified, and the result is considerably less volume. The use of a midget condenser affects the circuit in the same way as the fixed condenser, but as its value is so much less than that of the fixed condenser normally used, its effect is not nearly so detrimental. It is difficult to specify an exact value for this variable condenser because of the differences in transformer impedances; the proper capacity is best found by experimentation. Figure 48 shows how regeneration is procured by means of the midget condenser instead of the usual tickler coil.

CHAPTER VIII

RADIO INDUCTANCE COILS AND CONDENSERS

SELF INDUCTANCE. The number of lines of force about a coil of wire depends upon the strength of the current flowing through the coil. Any change in current strength will immediately change the number of lines of force. Whenever a *change* in the number of force lines occurs an electromotive force will be induced in the coil. When the circuit is broken, the lines of force collapse suddenly, and a great amount of energy is returned to the coil. This means that a large voltage will be developed in the coil. The potential may be many times greater than that of the original current, and is known as the *counter electromotive force.* A small current makes possible the storage of a large amount of energy in the surrounding magnetic field and, when the field collapses, this energy is released suddenly, and a potential of considerable strength is the result. A heavy spark will occur between the contacts when the current passing through the coil is broken.

MUTUAL INDUCTANCE. When a transfer of electrical energy between two circuits which have no electrical connection occurs, it is accomplished by *mutual inductance.* Two coils, placed close to each other, will be inductively connected if a current flows through one with a varying voltage. Any changes in the number of magnetic lines of force about one coil will change the strength and direction of the current induced in the second coil. The magnitude of the induced current depends upon the *rate* of change and number of lines of force about the current-carrying coil. The mutual inductance falls off rapidly as the distance between the two circuits is increased. Mutual inductance is greatest when the two coils are parallel or wound one over the other, and smallest when their axes are at right angles. If iron is placed between the coils, it has a *shielding* effect, and reduces the magnetic field which links them. Inductance is of particular importance in radio circuits, and is the essential principle involved in radio reception.

THE HENRY. The unit of inductance is the *henry*. It is the inductance of a circuit when an electromotive force of one volt is induced and when the *inducing current* varies at the rate of one ampere per second. In practice, smaller units are used, the *millihenry*, or one one-thousandth of a henry, and the *microhenry* which is one one-millionth of a henry.

INDUCTIVE REACTANCE. When a current flows through a coil of wire it meets with no opposition except the material resistance of the wire. But as soon as the current changes in direction or intensity, this is no longer true, as the current is opposed by the induced self or counter electromotive force which occurs in the coil when the least change occurs in the inducing lines of force. If the inducing current changes rapidly in direction it is met with a greater opposition from the induced e.m.f. and, consequently, the greater is the *inductive reactance*. It is this reactance that prevents an alternating current from flowing through a coil having inductance. This is due to the fact that the induced e.m.f. flows in the same direction as the original current and, occuring after the current stops and the magnetic field collapses, will try to prevent the current from flowing in the opposite direction with the next alternation of current. A coil has reactance only to an alternating current or a steady current which pulsates in voltage variations.

IMPEDANCE. The total reactive opposition to the passage of an alternating or pulsating current through a circuit, both by coils and condensers, is called the *impedance*. But, as we have seen, the inductive reactance of a coil is highest with high frequency currents, and the capacitive reactance of a condenser is lowest at high frequencies. If the inductance in a coil, and the capacity in a condenser are present in a circuit, they tend to *offset* each other in their effects. The proper combination of these two reactances provides the tuning arrangements of a radio circuit so that it may be brought into a state of *resonance*.

RADIO FREQUENCY INDUCTION. As the radio frequency current flows through the windings of a coil, the magnetic field about it constantly changes direction, because it has been tuned with a variable capacity and its impedance reduced to zero or a state of resonance to the frequency flowing. If another coil is brought within the vicinity, it will be cut by the magnetic lines of force building up and collapsing about the first coil, and an electromotive force will be induced in it. This will cause a similar radio frequency current to flow in the windings of the second coil if it is also tuned to resonance. This induced current will have the same frequency as the current flowing through the first coil, because it is induced by a magnetic field having the same frequency as the current. The coil containing the original current is called the primary, and the second coil containing the induced current is the secondary. This generation of an electric current in a coil, through the change in strength of the original magnetic field, places the two coils in a type of connection, which is known as *inductive coupling*. Such coupling may be either close or loose, depending upon the position of the primary magnetic field in relation to the secondary. Therefore, we have *loosely coupled* and *closely coupled* radio frequency circuits.

RADIO FREQUENCY TRANSFORMERS. The amount of energy received by the antenna is very small, and it has become the practice to transfer this energy from the antenna circuit to the actual receiving set by means of inductive coupling through a *radio frequency transformer*. As this current is so small, and it is necessary to obtain as much induced current and as strong a magnetic field as possible, the windings of the coils are made up of the proper number of turns of relatively fine wire. The wire is insulated with cotton or silk or enameled covering, and the turns are wound close together. But in many cases it is advisable to leave a slight space between each turn. This method is now obviated to a degree, as will be explained later. The coils used in radio reception are very simple, but there are many factors to be taken into consideration. It is not the practice to introduce any iron in the magnetic field of a radio frequency transformer. Because of the high rate at which the alternations keep up, the gain in efficiency is not to be compared with that when iron is used with low frequency transformers.

Unbalanced Impedance in a Coil. While it is impossible to force an alternating current through a coil because of the self inductance and reactance, the internal and distributed capacity between the adjacent turns of wire will be such as to cause considerable capacative reactance. These two reactances tend to offset each other, and the radio frequency current will pass through the coil. Internal capacity in a coil is not desired as it cannot be regulated, and the coil, therefore, cannot be tuned carefully to resonance. In order that a coil be made to present nothing but inductive reactance to the flow of the radio frequency current it must be carefully and scientifically wound.

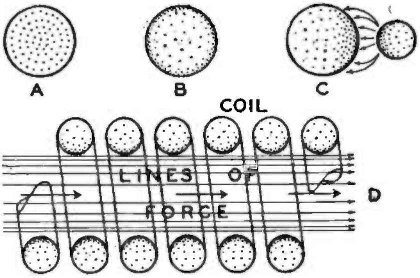


Fig. 49. Distribution of Electricity in a Wire

(*A*) Direct Current in a Wire; (*B*) Alternating Current Skin Effect; (*C*) Distorted Skin Effect; (*D*) Skin Effect Distribution in a Coil.

Skin Effect. When a wire carries a steady or direct current, its resistance to the current is directly proportional to its cross sectional area, other factors being equal, thus showing that the conduction of current is uniform throughout the density of the wire. See *A* in Figure 49. But if a high frequency current is passed through, only a very thin portion of the surface of the wire will carry the current, as shown at *B*. If the wire is replaced by a tube having the same outside diameter, and of the same material, the resistance of the latter would be the same. This tendency of the radio frequency current to *concentrate* upon the surface of the conductor is due to *skin effect*. If no other conductors are near by, the distribution over the surface of the wire will be uniform, but if another conductor is close and parallel, the distribution of the high frequency current will be irregular, as shown at *C* in Figure 49. It will be seen that any distribution of current, other than a regular and uniform distribution over the surface of a conductor will result in a great increase in resistance. It is important to bear this in mind when constructing inductances. In radio coil construction use is profitably made of a wire which will partly eliminate this skin effect. It is known as *litzendraht* or *litz* wire, and has a low radio frequency resistance. It is made up of a number of fine insulated wires, braided together so that each strand comes to the surface at regular intervals.

SKIN EFFECT IN A COIL. Knowing what skin effect is, and the ability of a high frequency current to distribute itself unevenly over a conductor, it is evident that the distribution will be subject to greater distortion if the conductor is made into a coil, than when it is a single straight wire. When a wire is wound into a single layer *solenoid* there is a distribution of the magnetic lines or flux through the coil. Because of this magnetic density within the opening formed by the turns of wire the current will tend to *crowd* itself on that part of the wire which is inside the coil. See *D* in Figure 49. This crowding of the high frequency current on one side of the wire, together with the capacity or condenser effect of the adjoining turns of wire, makes a solenoid coil more or less unfit for efficient radio reception, especially when wound tightly with turns having no air space.

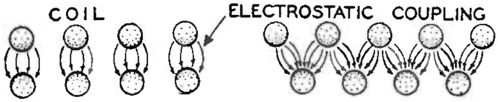


FIG. 50. INTERNAL CAPACITY BETWEEN TURNS OF WIRE

INTERNAL CAPACITY IN A COIL. Every coil has *internal capacity*, as the windings are roughly equivalent to the plates of a condenser. Coils which are wound with two or more layers of wire are not satisfactory for radio work, as the distribution of current by internal capacity is too high. See Figure 50. Therefore, coils are usually wound so that the turns are crossed at regular intervals. Such coils are used for tuning radio circuits or bringing them into resonance with the frequency of the desired wave. It must be remembered that the inductance of the coil is that which controls tuning, as a coil of high inductive reactance will respond to low frequencies, while one of low reactance will respond to high frequencies. Coils which are adjustable are, therefore, variable over a considerable range of wave lengths. What we desire in a coil is nothing but inductive reactance, and theoretically this would be the case in a scientifically perfect coil. *Internal* or *distributed capacity* is undesirable, as already indicated. Skin effect should be eliminated as far as possible. Leakage and absorption of high frequency currents through the material forming the frame and insulation of the coils cause considerable losses.

LOW LOSS COILS. The term *low-loss* has been brought into use for radio apparatus, and means that the vital parts are supported with few dielectric materials, and that internal capacity has been reduced to a minimum. In order to provide nothing but inductance in a coil, the wires should be arranged so that they prevent distributed capacity, and, consequently, prevent distorted skin effect. The material and insulation for supporting the winding of the coil may be *eliminated* by making the coil *self-supporting*, and with just sufficient material to attach the coil to the radio set. Coils of this construction are quite fragile, but very effective.

TUNING COILS. The *tuning coil* is now obsolete, and has been replaced by various types of coils which have greater efficiency. Tuning coils are principally of two well known forms; one, a straight solenoid coil with a single layer of wire, and the other with a moveable secondary *sliding* within the primary, known as a *loose-coupler*. The former coil had a *slider* that moved along the top and made contact with each turn of wire so that any number could be added to the circuit, this increasing or decreasing the inductive reactance, and regulating the wave length to which the coil would respond. The loose-coupler consisted of a tube on which was wound a number of turns of wire as a primary, and was

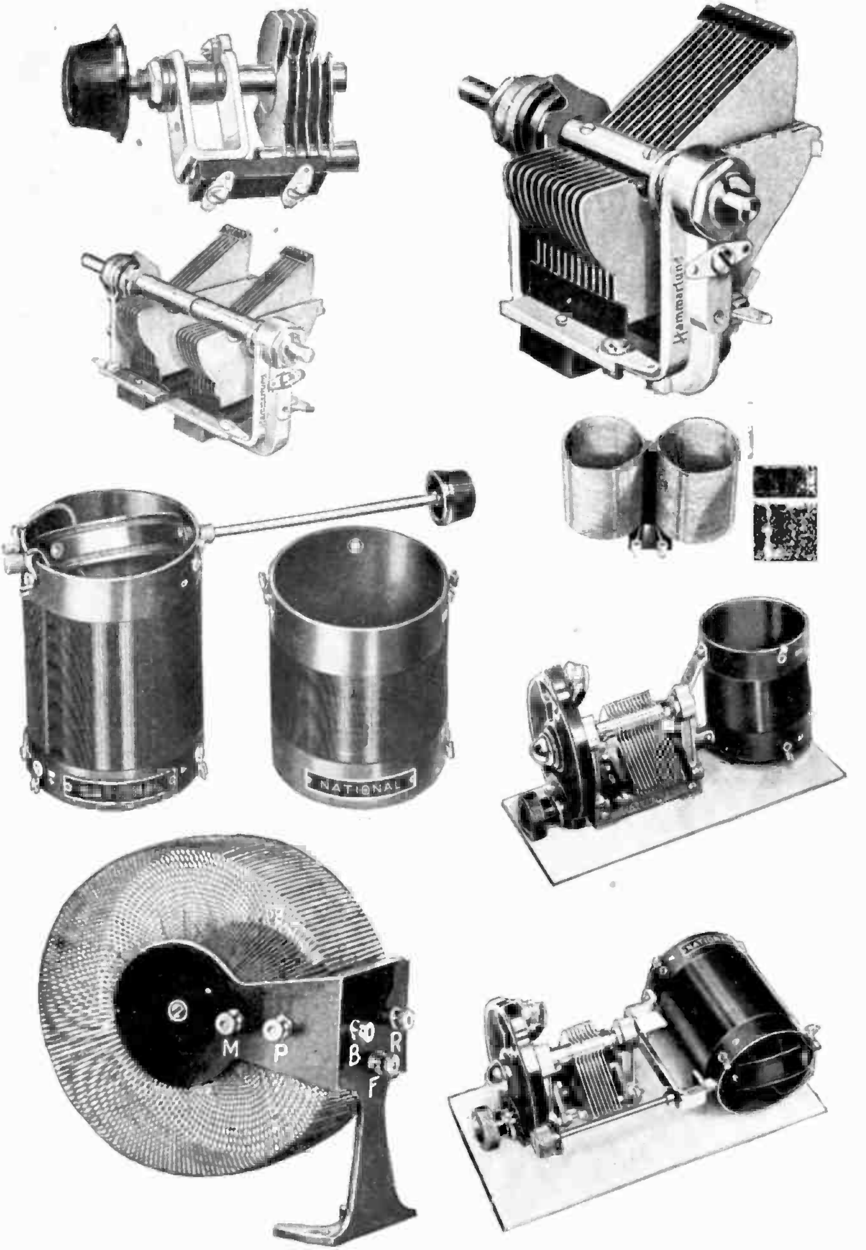


PLATE 3.

Top: Variable condensers—courtesy Hammarlund Company. *Center, left:* Solenoid coils—courtesy National Company. *Lower, left:* Toroid coil—courtesy Bremer Tully Company. *Center, right:* Binocular coil—courtesy Benjamin Electric Company. *Lower, right:* Condenser and coil tuning units—courtesy The National Company.

connected between the antenna and the ground. The coil had a slider fixed to it to regulate the number of turns of wire. Taps were taken off from groups of turns, and regulated by a series of switches, which, with the slider, varied the number of active turns of wire. The secondary was a smaller tube made to slide in or out of the primary tube, and it was fitted also with a turn varying device, roughly to regulate its inductance. The loose-coupler was the forerunner of the modern tuning inductances such as the vario-coupler and variometer.

THE VARIO-COUPLER. It is often desirable to have a *continuously variable* inductance for tuning a radio circuit, and the *vario-coupler* has become a standard of coupling between the two circuits. It consists of a primary coil wound on a tube, and having a number of connections so that the turns of wire on the primary may be varied. A wooden ball or frame mounted on a rotating shaft and wound with a number of turns of wire forms the variable secondary. It may be placed in such a position with respect to the primary winding that its coupling is variable throughout a long range. The primary of this type of coil is of sufficient size to respond to signals within the broadcast band, and the secondary should have an inductance which, when tuned by an average variable condenser, will respond to wave lengths within the same limits.

THE VARIOMETER. Another type of inductance that is used in certain radio circuits is called the *variometer*. It finds extensive use in vacuum tube circuits, while the vario-coupler may be used in crystal circuits as well. This type of inductance consists of two spherical windings, connected in series and arranged so that the inner coil rotates within the outer or stationary coil. There is no real primary or secondary to this instrument, and it is connected in series in the circuit. When the windings of the stationary and rotor coils are parallel they are then connected so that electricity flows through them in the same direction, and the magnetic lines of force, which are about each coil independently, are *added* to each other. In this position the inductance is at its maximum. But if the inner coil is turned on its shaft even a small distance, its lines of force also move and do not act completely in phase with those about the stationary coil, but at a certain angle to them. The effect is that a number of the lines of force are lost, and the inductance is decreased. Further rotation of the coil will decrease the inductance more and more until the two coils again become parallel, but opposing each other. The lines of force of the two coils *neutralize* each other, and the inductance is then at a minimum.

Fixed Inductances. All other types of inductances are not variable, and have a broad tuning characteristic at a certain fixed wave length. But by shunting a variable condenser across the terminals of the coil its inductance may be *increased* or *decreased* according to the variations given the condenser. Thus resonance is changed within the limits of the coil and the condenser. If the inductance is used in the antenna circuit and the condenser connected between it and the antenna, the inductance and wave length to which it will respond may be reduced. Such inductance coils are compact, may be made self supporting, and suffer very small losses because of resistance, distorted skin effect, or internal capacity.

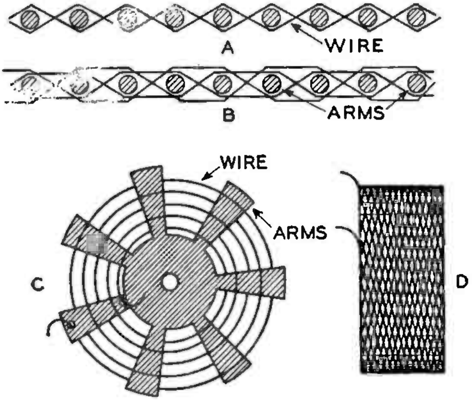


Fig. 51. Non-Capacitive Coil Windings

TYPES OF COILS. Multilayer coils are desirable in radio work because of their compactness and concentrated electrostatic and electromagnetic fields. In order to eliminate the distributed capacity they are wound in a form which resembles a *lattice* work. This winding is variously known as *lattice-wound, basket-weave, honey-comb, diamond-weave, banked-winding,* etc. See *D* in Figure 51. The wires are so staggered that they constantly cross each other at regular intervals and tend to neutralize any capacity effect between turns. See *A* and *B*. There are also flat coils wound on discs which have radiating arms arranged like the spokes of a wheel. They are known as *pan-cake* and *spider-web* coils. See *C*. The coil begins at the center and is wound until it reaches the outer extremities of the arms. An *odd* number of arms must be used so that the turns are properly staggered. Some coils are wound so that the wire passes over and under adjacent arms, as shown at *A*, while others are wound so that the turns pass over and under two arms at one time, as shown at *B*. Both methods have the effect of practically eliminating distributed capacity; the latter, however, being of a more compact form with a stronger magnetic field.

SPACE WOUND COILS. The lowest-loss coil is the single layer solenoid, in which the winding is spaced approximately one-half the diameter of the wire, and the whole made self-supporting. This is a *space-wound* low-loss coil. Such a coil is difficult to construct and a perfect coil is mechanically impractical. Space windings upon forms may be easily obtained, however, by winding a string or wire of suitable diameter between the turns of wire as they are put on. The spacing material is unwound after the coil has been completed. In some cases the wire is wound in a spiral groove cut into the surface of the tube, and in others it has no support except a very small clamp strip on one side of the coil. which takes on the appearance of a solenoid spring.

BINOCULAR TUNING COILS. *Binocular coils* are simple solenoids which are set up in two halves in binocular shape. The field set up by these coils is self confined, thus helping to prevent oscillations due to inter-coupling effects in the receiving set. The use of these coils is limited as they are somewhat larger than the usual coils and require more space within the set. Binocular coils are used to considerable advantage, but due to the careful balancing necessary in their construction, have not met with the widespread applications that they merit.

THE TOROID COIL. All coils are subject to influence from external magnetic fields, and where several coils are used in a radio receiving set, it is proper to place them at different angles so that their inductive fields will not seriously affect each other. Undesirable currents are often induced in other parts of the circuit. It was to eliminate this fault that a *circular* coil, called the *toroid coil,* was devised. See Figure 52. It is wound somewhat in the shape of a doughnut; a cylindrical solenoid coil without apparent ends. The magnetic field of the coil is, therefore, entirely self-contained, and the secondary windings which are an integral part of the toroid, are always within the full strength of the magnetic field. See Figure 52. Thus maximum induction is assured, and there is a freedom from external induction from nearby magnetic fields. The wire turns are electrically opposed to each other when cut by an external field, and there can be no coupling with other coils in the set no matter how closely they may be placed. The turns of wire are all separated by space winding, and the self-supporting nature of the coil prevents any insulation losses or absorption. The continuous circular magnetic fields, entirely confined within the toroid, cannot create *stray* fields

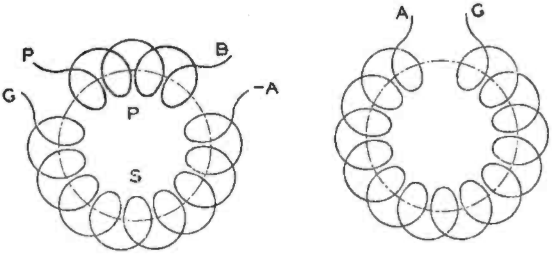


FIG. 52. THE TOROIDAL COIL

which so often cause self oscillations and squealing by inter-stage coupling in the set, something that practically all other types of coil will easily produce.

THE LOADING COIL. When the inductance of a radio coil is not sufficient to tune to the wave length desired, a *loading coil* may be used. It is a small coil, having inductance, which is placed in the circuit (usually the antenna circuit) and therefore tends to increase the inductive reactance of that particular portion of the circuit so that it will respond to lower frequencies and higher wave lengths.

THE TICKLER COIL. Some coils are made for regenerative purposes. They are similar to the vario-coupler except that the rotating coil, instead of being the secondary, is a small coil that is connected into the plate circuit. The primary and secondary coils are wound on the stationary frame, and are loosely coupled, while regeneration is obtained in the secondary stationary coil by turning the *tickler coil* so that its magnetic field will *aid* that of the secondary and increase its strength. The secondary of the coil is generally tuned with a variable condenser, while the primary is connected between the antenna and the ground. The same effect is obtained by using separate honeycomb or spider web coils, one for the primary and another for the secondary which is placed in close inductive relation with the first, while a moveable coil is used for the tickler. The magnetic field of this tickler coil can be brought near the secondary by moving it to or fro with respect to the latter.

CHOKE COILS. *Choke coils* are used to prevent alternating currents from getting into a certain part of a circuit through which a direct or low frequency current should flow. A radio frequency choke coil presents a high impedance to radio frequency currents. Like all high frequency coils, choke coils are simple air-core solenoids, and in some instances, are self-supporting. Audio frequency coils are made by winding many turns of fine wire on an iron core. These pass direct and low frequency currents, but have an effective reactance against higher frequencies. Choke coils are used in many places in radio circuits and always in impedance coupled amplifiers. In many cases the primary or secondary of an audio transformer may be used as a choke coil.

COMPENSATING RADIO FREQUENCY TRANSFORMERS. In order that an inductance transformer may function properly in a radio frequency amplification circuit there must be an *equal* transfer of energy between the primary and secondary inductances at all wave lengths within the range of the primary. This is not absolutely true in all fixed radio frequency transformers, but only with those having variable primaries. The *equamatic* system of equalizing the coupling provides for a constant relative change in inductance coupling at the same time that the variable condenser is operated. The primary coil of the radio frequency transformer is attached to the shaft of the condenser and is adjusted in its relation to both the condenser plates and the secondary of the coil. Such an arrangement provides the necessary variation in the impedance of the inductance according to variations in frequency. As impedance varies with frequency, and energy transfer from primary to secondary varies with impedance, a definite relation

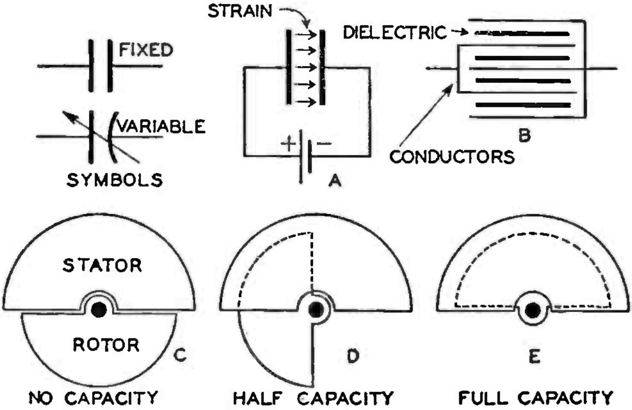


FIG. 53. THE ELECTRIC CONDENSER

(*A*) Dielectric Strain; (*B*) Condenser Arrangement; (*C*, *D* and *E*) Variable Condenser.

between the condenser and primary setting must be maintained. When the coils and condensers are carefully adjusted, this system provides automatic changes in impedance and inductance, and gives a perfect electrical transfer of energy at all frequencies within the limits of the inductance as the condenser is rotated.

DIELECTRIC STRAIN. A *dielectric* is an insulating substance; that is, it prevents the passage of an electric current. Some materials are better insulators than others, but dry air is the best dielectric known. In a dielectric a steady or direct current cannot flow. But if we have two conductors separated by an insulator, as shown at *A* in Figure 53, and apply an electric current to them, a momentary flow of current will take place. This current flow is quite different from that flowing through a conductor. It may be likened to a strain or deflection which takes place when the current is applied to the two conductors. This *strain* is not due to the passage of a current, but is an electron *displacement* by which energy is transmitted without any movement whatever. When a dielectric is in this strained position it possesses electrical energy in an *electrostatic* form.

THE ELECTRIC CONDENSER. When this electrostatic displacement is brought about by a dielectric placed between metal plates, and the plates connected to a current source, the apparatus is called a *condenser*. See *B* in Figure 53. When a battery is connected to a condenser, a displacement current begins to flow until it reaches its *steady* value. This strain or displacement is equivalent to the presence of a certain quantity or charge of electricity in the condenser. The electrostatic *capacity* of a condenser is the quantity of electricity stored for a certain voltage or potential difference between the two plates or surfaces making the condenser conductors. It is expressed in *farads*. A condenser has a capacity of one farad when one coulomb of electricity is required to raise its potential from zero to one volt. The *microfarad*, or one one-millionth of a farad, is generally used in radio work.

ACTION OF A CONDENSER. The electric strain in the dielectric of the condenser represents a certain store of *energy*. The potential between the plates of the condenser is equivalent to a force acting equally at all points in the dielectric, and is called electric field intensity. The space within which this intensity acts is called the electric field. The condenser, therefore, has the ability to store up a quantity of electricity in its electrostatic form, and to discharge it into a circuit. An alternating current can flow in a condenser in the form of this displacement strain or dielectric current. For instance, if a certain voltage is applied to the plates of a condenser, a charging current flows into it until the potential difference between the plates rises to the same value as that of the charging current. If this charging current is suddenly removed and the condenser circuit completed by a wire, a discharge current flows *out* of the condenser in the *opposite* direction to that taken by the charging current. The discharge ceases when the two plates have no further potential difference. When an alternating current is impressed in the condenser circuit, an alternating current is constantly flowing *in* and *out* of the condenser to keep the potential difference between the plates equal to the voltage of the impressed current. No energy is dissipated in a condenser, but it is stored in the dielectric while it is being charged, and is *restored* to the circuit when the condenser discharges.

CONDENSER RESISTANCE. The lower the frequency of an alternating current the greater is the resistance of a condenser to its flow. A condenser offers much less obstruction to a flow of high frequency current, and, therefore, will cause a much larger current flow when the alternations are very rapid than when they are slow. This resistance in a condenser to a flow of current is called its *capacitive reactance.* The reactance is measured in ohms and decreases as the frequency of the current increases. The relation of impedance, reactance, and resonance in radio circuits in connection with condensers has been discussed previously.

CONDENSER DIELECTRIC. There is a wide variation in the substances which may be used for condenser dielectrics, and the material will determine to a great extent the capacity of the condenser to store electrical energy. These materials seem to be perfect insulators, but they do have a very small electric conductivity. If a condenser is charged and allowed to stand, the charge will gradually leak off at a rate that depends upon the dielectric in use. Dry air may cause plates to retain their charge for a long time, while paper may allow it to leak off within a few seconds. Dry air, glass, mica, hard rubber, synthetic chemical compounds, etc., make the best dielectrics. The capacity of a condenser may be increased by enlarging the area of the plates and by diminishing the distance between the plates or thickness of the dielectric, or by using better dielectric material with higher insulation values.

CAPACITY EFFECTS. It is not necessary to have two or more plates separated by some dielectric to form a condenser. The earth, or any ground connector, frequently replaces one plate of a condenser, and a wire suspended above it forms the other plate, while the air between is the dielectric. Two wires of a connected group will have certain capacity relations between them. A radio antenna forms a condenser with respect to the earth beneath. In radio receiving apparatus, very small capacities will have important bearings upon the sensitivity and tuning of the set. Even the capacity between two short parallel wires or between the turns of wire on a coil, will have a decidedly detrimental effect on the efficiency of the receiver. These slight capacities have the ability to become charged and discharged, and upset the delicate balance that is so necessary for the proper functioning of a radio receiver.

ELECTRICAL LOSSES IN CONDENSERS. When a condenser is used in a high frequency (radio) circuit there are various losses which occur. Such losses should be carefully avoided as far as may be practicable. They are caused mostly by leakage through the insulation separating the parts, and the dielectric between the plates; also by *corona* discharges around the sharp edges of the plates. In order that these losses be eliminated as far as possible, condensers should be carefully made and of the *low-loss* type, having the supports and terminals few in number and of excellent insulating material. This is now the case with variable air dielectric condensers. Solid dielectric condensers (fixed) are apt to become unstable under certain conditions of heat, moisture and strain. These condensers usually use mica, glass, paper or rubber for their dielectric. The loss in a good mica condenser is quite low.

CAPACITIVE REACTANCE IN A COIL. Reference has been previously made to the capacity reactance in a solenoid type of coil, and how the windings must be so arranged as to neutralize these bothersome capacity and skin effects. Coils of this type sometimes act as condensers when subjected to very high frequencies, instead of having only inductance; the higher the frequencies, the more similar to a condenser the coil may become. This peculiar behavior is due to the distributed capacity of the windings of the coil. In this way the current, instead of passing *through* the wire of the coil from one end to the other with an even distribution over the outer surface of the wire (true skin effect) will pass *between* the turns of wire by the capacity effect. See Figure 50. The absence of such a flow through the entire coil renders it useless as an inductance. The necessity for winding coils so that internal capacity will be prevented is obvious.

THE VARIABLE CONDENSER. It is extremely desirable to use condensers which are *continuously* variable in their capacity. The inductance of a coil need not be so variable and, in fact, it is impossible to obtain the fine degree of variation in a coil that is possible with a condenser. This type of condenser is known as a *variable condenser* (see Figure 53) and the tuning of a radio circuit is generally accomplished by using some sort of fixed inductance with this type of condenser. The condenser is made so that one set of plates rotate within another set of fixed plates, both sets being made semicircular in form. When the movable set is entirely without the stationary set, see *C* in Figure 53, the condenser capacity is at its minimum, and when they are entirely interleaved (*E*), the capacity is at its maximum. The condenser is operated by a dial that is graduated to read from 0 to 100 through 180 degrees, as half a revolution of the dial changes the capacity of the condenser from zero to maximum. No variable condenser has an absolute zero capacity, as there is a certain inherent capacity because of its construction features.

VARIABLE CONDENSER LIMITS. If a condenser is used in a circuit that is to respond to the average wave lengths used in broadcasting, 200 to 550 meters, it should operate satisfactorily over that wave length band in connection with proper inductances. The separations of the stations on the dial should be quite even throughout its full rotation. If such is the case the capacity of the condenser will vary directly with its rotation, and a resulting calibration *curve*, if plotted, should be a straight line. See Figure 54. A tabular record of stations may be made, and is useful in

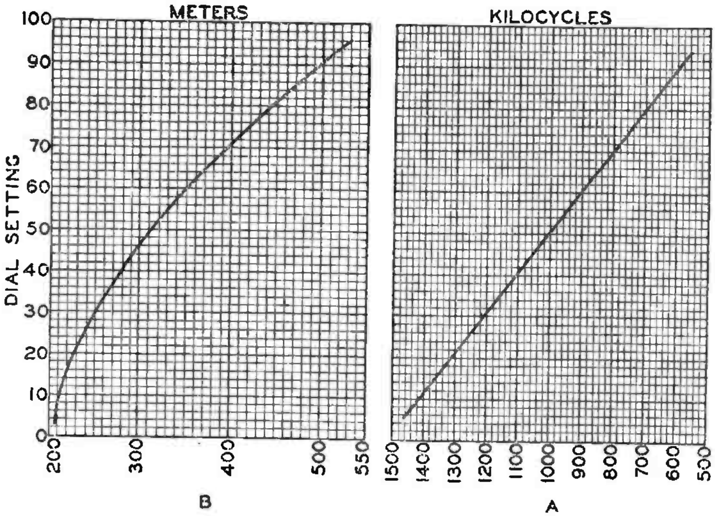


FIG. 54. TUNING GRAPHS FOR VARIABLE CONDENSERS
(*A*) Straight Line Frequency Graph; (*B*) Ordinary Wave Length Graph

resetting the dial to any particular station, or if the wave length of the station is known, its setting on the dial may be calculated. However, the setting of a dial so that the condenser reactance will be in resonance with one of the many hundreds of stations broadcasting within the narrow limits available, is a difficult matter and considerable heterodyne effect is sure to be observed. For best dial setting it is advisable to use separate vernier condensers, midget condensers, or geared micrometer dials.

VARIABLE CONDENSER TYPES. Some variable condensers will provide a series of dial readings which, when properly plotted, will give a *straight line wave length* graph (*B* in Fig. 54); others plot *straight line frequency* curves (*A*), while poorly designed condensers will not plot true calibration curves of any kind. If the plates are properly shaped so that their areas will intermesh very slowly at the lower capacities and more rapidly at the higher, it will be found that the stations will be *spread equally* over the dial, and throughout the frequency band. The practice of separating stations by frequencies instead of wave lengths has been long looked upon with favor. When broadcasting stations are spaced 10 kilocycles apart the separations will come at regular intervals over the dial, if the condenser has the straight line frequency characteristic. This arrangement eliminates confusion and makes resonance and tuning much easier for the operator. Therefore, it is recommended that variable condensers having constructional features which will permit them to make straight line frequency graphs, be always used.

PLOTTING TUNING GRAPHS. The plotting and reading of curves may seem difficult, but nothing is easier. The advantages are the elimination of searching for new stations, and the keeping of a permanent calibration list of all stations which have been heard. A sheet of *cross-section* paper should be procured, and one scale used to represent radio frequencies in kilocycles, beginning at 500 and running upward to 1500, each section of the paper representing 10 kilocycles. See Figure 54*A*. The other scale running at right angles should begin with 0 and end at 100, each section of the paper representing one division or point on the condenser dial. The frequency of the station being received should be located on the proper axis, and the dial setting should be located on the other axis. Carry out the two readings along their respective axes to the point at which they intersect; there a dot should be made and the station call-letters inserted. When a number of stations have been so located, the dots should be joined together with a line. If the chart has been carefully plotted and the condensers are correct, this line should pass through all of the dots and be perfectly straight. However, it may be possible that some of the dots will be either to one side or the other of the line, due to the fact that these radio broadcasting stations are operating on slightly different wave lengths than that of record. Any unknown station may be instantly located by following its recorded frequency along its respective axis until the plotted line is intersected. By projecting along the axis encountered, the proper dial number setting will be obtained. Set the condenser dial to this number, and the station desired should be heard if on the air at the time, or within range of the receiver. To change a kilocycle reading into its corresponding wave length in meters, simply divide into 299,800, or refer to the conversion table shown in another chapter. The same method should be followed if wave lengths are to be converted into kilocycles.

FIXED CONDENSERS. *Fixed condensers* are permanent capacity condensers of many sizes which are used extensively in radio work to *block* direct currents but to pass alternating currents. They are also known as *by-pass* condensers. It will be recalled that when a radio frequency current is passed through a detector it is rectified but still retains the high frequency unidirectional pulsations in potential. The telephone receiver possesses considerable impedance to these rapid pulsations, but permits the low frequency variations in voltage, or average current, to pass easily. It is, therefore, impossible to send this rapidly pulsating rectified plate current through the telephones. By *shunting* the telephones with a small by-pass fixed condenser, it is possible to pass the radio frequency component *around* the telephones and back into the tube filament. The average low frequency pulsations are forced through the telephones because of the blocking effect of the condenser. Fixed condensers are used in other places in the radio circuit whenever it is necessary to pass a radio frequency current by the shortest practical path. In certain types of amplifiers condensers are used to block the "B" battery current and to permit the audio frequency pulsations to pass. They are used as filters in battery eliminators with the use of house lighting current, and in many other phases of electrical and radio operation.

Using Fixed Condensers. It is essential that fixed or by-pass condensers be used at several locations in the receiving set. This condenser is absolutely necessary *across* the primary of the first audio transformer which is, of course, connected in the plate circuit of the detector tube, just as the telephones would be if they were used with no amplification. The condenser should be placed across the resistance of the detector plate circuit, as its function is to return the radio frequency currents by as short a path as possible to the tube from which they originated. If this is not taken into consideration the use of a by-pass condenser will be worthless. Therefore, one side of this condenser should be connected to the plate end of the inductive resistance, and the other side to the filament terminal of the tube to which the current is to be returned. When this connection is used in place of the direct shunt across the impedance, which is so often erroneously used, the radio frequency currents are returned directly to the filament, and do not have to pass through the "B" battery. The condenser should not be larger than necessary to give good results. In many cases a capacity as low as .00025 microfarads is sufficient. A large capacity by-pass condenser should be placed across the "B" battery so that any stray currents may be passed around. A condenser used to shorten the path of the radio frequency currents in a stage of radio amplification will often be of value. It should be connected at the lower or positive "B" end of the primary of the radio transformer, and to the filament terminal. When such a condenser is not used the radio frequency currents, in returning to the filament, must pass through the many wires, connections and "B" battery. The other uses of fixed condensers are discussed in connection with the various radio circuits.

Connecting Variable Condensers. When variable condensers are connected into a circuit care must be taken to connect the *rotary* plate contacts with the low potential side of the circuit. This side in that which is nearest the "A" battery and ground connection of the circuit, and the high potential side is that nearest the grid of the tube. If this is not done there will be some difficulty in obtaining stable tuning due to the body capacity of the hand as it touches the dial and affects the grid lead. The dial shaft and rotary plates should never be connected in the grid lead. The stationary plates of the condenser are always connected to the grid or high potential side.

CONNECTING CONDENSER CAPACITIES. It may be convenient at times to connect several fixed condensers in series or in parallel. However, the capacity of a group of condensers is not calculated in the same manner as the voltage of batteries or the resistance of coils. Condensers connected in parallel are under the same impressed voltage and they total up according to the sum of their respective capacities since parallel connection is equivalent to increasing their plate areas. If several condensers are connected in series, the same charge is given each condenser in *ratio* to their capacities, and a series connection always gives a smaller capacity than that of any one in the group. In this case it may be said that the joint capacity is the reciprocal of the sum of the reciprocals of their individual capacities.

CHAPTER IX

IMPORTANT FUNDAMENTAL RADIO RECEIVING CIRCUITS

TUNING A CIRCUIT TO RESONANCE. The fundamental principle of radio reception is that of *resonance.* The receiving circuit is *tuned* to present no resistance to one particular electric current induced in the antenna. This extremely feeble current immediately builds up a comparatively strong oscillation in the circuit of the receiver. The type of receiver and the circuits involved determine the degree of strength which these induced oscillations reach. To cause the set to oscillate at the desired frequency it must be adjustable through the use of variable inductances and capacities. With no provision for bringing a radio set into resonance with the incoming frequency, the efficiency of the receiver must be low. All signals induced in the antenna will pass through the detector and, if several powerful stations within range are working at one time, they will all be heard, but cannot be intelligibly separated. If we provide even the simplest type of tuning arrangement, it will be possible to give some one station a slight advantage over the remainder. By changing the impedance of a circuit through variations in the inductive and capacity reactances, it can be brought into resonance to one particular frequency, while there will be a high impedance to unwanted frequencies. When this state of resonance is sharp, the tuning is critical, and stations are more easily separated.

ACTION OF A SIMPLE RECEIVER. A receiving set with very limited applications, but which is perfectly feasible for reception from nearby broadcasting stations is shown in Figure 55. A crystal detector *D* is used in series with the telephone receivers *T* which have been shunted with a small fixed condenser *C*. As previously shown, the crystal detector will permit the high frequency current to pass in but one direction. Without this detector no sound could be produced in the telephone as its diaphragm cannot follow the very rapid alternations of the current. The cumulative effect of the groups or trains of radio frequency waves, due to modulation at the broadcasting station, causes the condenser, which is placed across the telephone, to make a *discharge* into the telephone windings and produce one click to the diaphragm. The number of such clicks per second is equal to the number of wave trains or audio vibrations passing through the detector. The intensity of these clicks varies with the intensity or amplitude of the audio component of the received wave.

ACTION OF WAVE TRAINS. If waves of 300 meters length are passing through a detector, and have, let us say, 1,000 wave groups per second, the radio frequency of the wave is 1,000,000, and the audio frequency, 1,000. Therefore, the series of clicks or diaphragm displacements per second give the *note* to the received signal. If, as is the case in radiotelephony, the wave is modulated, the *intensity* of these pulsations to the diaphragm will vary and produce a tone that varies in accord, and which may be either voice or music. For instance, if the sensitive telephone receiver is replaced by a sensitive galvanometer or current indicating apparatus, the hand of the instrument is deflected with the passing of *each* wave train; the degree of deflection depending upon the intensity of the modulation. The movement of the hand fluctuates in accord with the variations in the audio or sound wave.

SIMPLE TUNING ARRANGEMENTS. The objection, as already stated, to this type of circuit is that it cannot be tuned to exact resonance with any wave passing from the antenna. The natural wave length of the antenna and circuit fixes the wave length that the circuit will respond to and, in theory, it will operate only at that particular wave length. This method, while satisfactory for demonstration purposes, is very inefficient as a radio receiver. While the capacity of an outdoor antenna can be made very large due to its length in respect to the surface of the ground beneath, its inductance is low. The addition of a small coil of wire to the antenna will greatly increase the antenna inductance; much more than if a straight wire were added. If this inductance is made variable so that its range will be considerable, the set may be made to respond to many frequencies. If we add to the circuit a tuning coil *TC* made of a number of turns of wire wound in a single layer on a tube, with a sliding contact (single slide tuning coil) so that additional turns can be cut out or added to the circuit, as shown in Figure 56, better resonance adjustments are possible. The tuning is much *sharper* than that possible with the circuit shown in Figure 55.

A FUNDAMENTAL RECEIVING CIRCUIT. The action of the detector and telephone is identical with that of the previous circuit (Figure 55), but more energy is passed through the detector as a current flows with its full strength through a resonant inductance, and the received signals will not only be clearer but louder, while signals from stations which are not in resonance are tuned out. It should be noted from this description of Figure 56 how simple is the apparatus actually needed for radio reception. The *four* pieces of apparatus; telephone receiver, by-pass condenser, crystal detector and simple tuning coil, together with the antenna and ground connection, are all that are necessary to receive radio signals from nearby stations. It should be remembered that

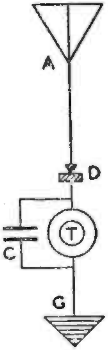


FIG. 55

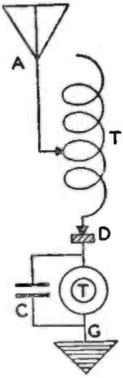


FIG. 56

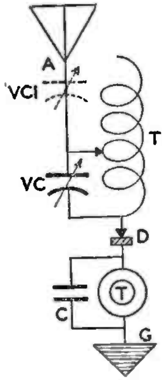


FIG. 57

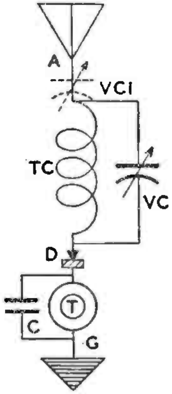


FIG. 58

FIG. 55. SIMPLE UNTUNED RECEIVING CIRCUIT
FIG. 56. FUNDAMENTAL TUNED RECEIVER
FIG. 57. TUNED ANTENNA CIRCUIT
FIG. 58. STANDARD TUNED ANTENNA CIRCUIT

this is the basic radio receiver circuit. It may be elaborated upon to produce sharper and better tuning, and the signals may be strengthened both before and after rectification. While there are many hundreds of radio receiving circuits, and new ones are constantly brought forth, they all are based on the fundamental principle of resonance and rectification. It is necessary to describe, in the following text, only the important fundamental circuits in order that one may understand further refinements made from time to time on these fundamental circuits.

Tuned Antenna Circuit. Still sharper tuning may be obtained if the coil *TC* shown in Figure 57 is shunted by a variable condenser *VC*. The condenser may also be placed in series with the inductance and the antenna, as shown by *VC1*. In either of these cases, a small inductance coil *without* variable inductance adjustment may be used, and the resonance variations produced entirely by the variable capacity of the condenser, as shown in Figure 58. In either of these examples, the circuit is known as a *tuned antenna* circuit.

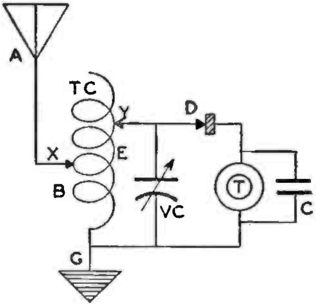


Fig. 59. Simple Direct Coupled Circuit

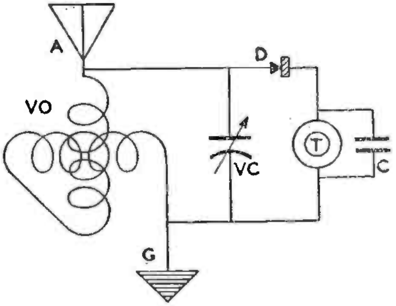


Fig. 60. Circuit Using Variometer

Simple Direct Coupled Circuit. A further improvement in the above circuit may be obtained by placing another sliding contact on the tuning coil *TC* (two slide tuning coil) so that *two* adjustable connections will be provided. In this circuit, which is shown in Figure 59, there is a *variable coupling* between the antenna and detector circuits, and, while the antenna tuning is not changed, the coupling between the two circuits may be altered. The addition of a variable condenser *VC* to this circuit makes for still further improvement. This is known as a *direct coupled* circuit in which the coil is used to form a coupling between the primary and secondary circuits. That the parts of this circuit may be better understood, a more definite explanation follows.

DESCRIPTION OF CIRCUIT COUPLING. Observe Figure 59. *B* is the inductance of the antenna circuit, and exists between the ground *G* and the antenna contact *X*. This circuit is called the *primary* and is the tuned antenna circuit. *E* is the inductance of the closed circuit, and *VC* is the variable capacity by which it is tuned. *Y* is the slider with which the coupling is changed. This is the *secondary* or closed oscillating circuit. The antenna circuit is tuned to resonance by the slider *X*, and the energy is then passed into the secondary end which is tuned to resonance by the slider *Y* and the condenser *VC*. Relatively large oscillations occur in the secondary, which are rectified by the detector *D*. Fairly sharp tuning may be obtained with this circuit.

ANTENNA TUNING WITH VARIOMETER. The variometer is capable of varying its own inductance, and for that reason may be used in the antenna circuit, although the tuning will not be very selective. It is especially adapted to short wave tuning. Figure 60 shows a circuit using a variometer *VO* as an antenna inductance, and the remainder of the circuit is similar to that shown in Figure 59.

SIMPLE LOOSELY COUPLED CIRCUIT. The elementary circuits indicated above are all direct or close coupled. Each is an advancing step toward an increase in signal energy because of better resonance. In Figure 61 there are shown the connections for an *inductive* or *loosely coupled* circuit which may be taken as standard. All others are merely elaborated schemes for securing signal strength and increased resonance. This set makes use of separate coils in the antenna and detector oscillating circuits, or primary and secondary, respectively. The two inductance coils *TC* and *TC1* are made so that their inductance is continuously variable;

also their distance apart may be varied. In this case the secondary *TC1* can be moved with respect to the magnetic field set up about the primary coil *TC*. The connections in this circuit are the same as shown in Figure 59, except that the primary and secondary are entirely separate. The antenna coil *TC* is tuned to resonance with the incoming signal frequency by means of the slider *X*, and if very sharp primary tuning is desired, the addition of the variable condenser *VC1* will provide fine adjustments. The secondary coil *TC1* is tuned to resonance with the primary by means of the slider *Y* and the variable condenser *VC*. The coupling or inductive position, where *TC1* is best cut by the lines of force about *TC* is controlled to procure the sharpest tuning. The coupling of this type of set is procured by the use of the *loose-coupler* or the *vario-coupler*, both of which are described in a preceding chapter.

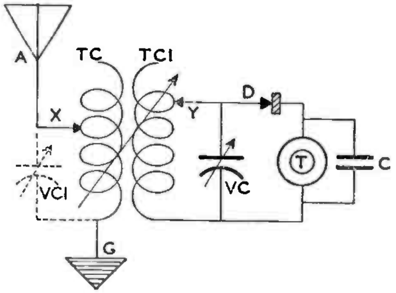


Fig. 61. Simple Loosely Coupled Circuit

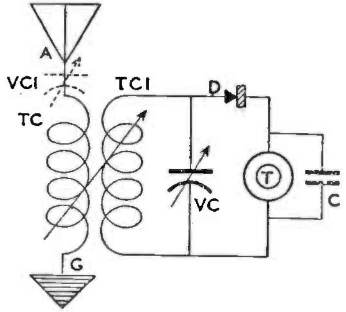


Fig. 62. Standard Loosely Coupled Circuit

Standard Loosely Coupled Circuit. Figure 62 shows how an inductive coupled receiving circuit is made by using inductance coils having no distributed capacity, such as honey-comb, spider-web, diamond-weave and similar types. In this scheme there are no variable contacts, and all of the tuning is done by means of one or more variable condensers; the coupling is obtained by moving the coils toward or away from each other. This system is fundamental to nearly all radio circuits. Certain elaborations permit amplification and regeneration (possible only with an electron tube detector). While there have been, no doubt, thousands of variations in radio circuits, they are all based on the principles shown in the above circuits.

LONG WAVE RECEPTION. For receiving longer waves in the primary circuit than is possible by using *all* of the primary inductances and the natural antenna wave length, a series inductance, called a *loading coil,* is added between the primary inductance and the antenna. It may be shunted with a variable condenser for finer tuning purposes or it may be made in the form of a long single slide tuning coil. The latter is the better practice since it permits a continuously variable inductance and fine tuning. If the wave lengths to be received are extremely high, it is necessary to insert another loading coil in the secondary circuit, to *balance* the two circuits. The addition of more inductance to the circuit presents a higher impedance, and short waves having higher frequencies cannot pass. The greater the inductive reactance of the circuit, the lower the frequency that it will pass.

SHORT WAVE RECEPTION. If shorter waves are to be received, below the lowest inductive value that is possible with the circuit, a variable condenser is inserted either in the ground or antenna circuit, in series with the primary inductance. It should be noted, however, that this method of receiving on the lower wave lengths is not satisfactory. It will not compare with the use of a set especially designed to operate on short waves, as the usual internal capacity of the coils will tend to offset the wave length reducing qualities of the condenser. A condenser's reactance is just the opposite to that of an inductance coil. A conductive reactance will easily pass high frequencies (short waves) and block the lower frequencies (long waves).

FUNDAMENTAL ELECTRON TUBE RECEIVER. In the above circuits the detection and rectification of radio frequency waves have been accomplished by means of a crystal of some kind. The disadvantage of this type of rectifier is that it will not stay in adjustment and even if perfectly adjusted weak signals from remote stations cannot be heard. A set using a crystal rectifier is limited in its range. Figure 63 shows exactly the same connections as in Figure 61, but the crystal detector has been replaced by a three electrode vacuum tube rectifier. The operation of these tubes has been described in a previous chapter. The current from the tuned secondary, instead of passing into the crystal, passes to the grid of the electron tube, and thereby controls the flow of electrons between the filament and the plate. The telephone receivers *T* are connected in the plate circuit, and the signals received will be much louder than in the circuit shown by Figure 61. A grid condenser *GC* is placed in the grid circuit, and is shunted by a small high resistance leak (*GL*), the purposes of which have been previously explained.

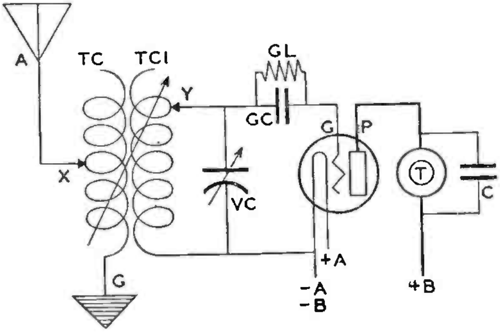


FIG. 63 SIMPLE ELECTRON TUBE CIRCUIT

SIMPLE FEED BACK CIRCUIT. Let us take the circuit shown in Figure 63 and add two variable inductances, *L* and *M* as shown in Figure 64. This is one of the old original *feed-back* circuits. Variometers are used for these continuously variable inductances. The primary inductance *TC* need only be roughly tuned, but the two additional inductances *L* and *M* must be very carefully adjusted. A variable condenser is not required, nor a sliding contact on the secondary coil. The primary *TC*, and the secondary *TC1*, may be those respective coils of a vario-coupler. The variometer *L* is inserted in the grid circuit, and the variometer *M* in the plate circuit. The latter tunes the plate circuit so that it will be in proper relation with the grid circuit, and regeneration will take place. The variometer L in the grid circuit tunes that circuit to the signal received in the secondary $TC1$. In all simple electron tube circuits, the use of a variometer in the plate circuit will bring it in resonance with the grid circuit, and it will also *feed back* some energy into that circuit. This is due to the coupling effect of the variometer, direct from the plate to the grid connection. In most cases it is advisable to *shunt* the entire "B" battery with a by-pass condenser so as to provide a path for the radio frequency current which is fed back into the grid circuit. A regenerative or feed back circuit will receive over a greater range and give louder signals than the simpler type of tube circuit.

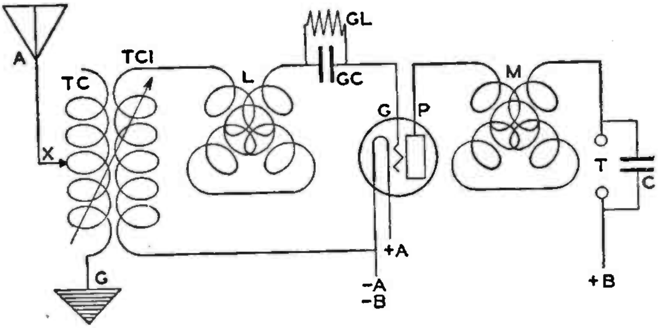


FIG. 64. SIMPLE FEED BACK CIRCUIT

REGENERATIVE CIRCUIT. The simplest method of *regeneration* is shown in Figure 65. The antenna and grid circuits are inductively coupled by the same inductance TC. This may be the primary of a variocoupler. A variable condenser VC is placed in series with the antenna, and is used to tune the antenna inductance, as well as the grid circuit. A movable coil O, which may be the rotating secondary of the variocoupler, is connected in the plate circuit between the plate, telephone receivers and "B" battery. This coil is called the *tickler* coil, and is adjusted so that its lines of force will aid in the regenerating of additional current in the coil *TC*. Therefore the strengthened original current in *TC* will be impressed on the grid of the detector tube with renewed energy. (See Amplification, Chapter 7.) This type of circuit is in widespread use today as it is highly selective and sensitive. Its greatest drawback is that, in the hands of an inexperienced user, it *radiates* on the frequency to which it is tuned. If the regeneration action of the tickler is carried too far, the tube will commence to oscillate as a transmitter.

UNTUNED ANTENNA REGENERATIVE CIRCUIT. Figure 66 shows still another fundamental but more powerful regenerative circuit, that will pick up distant signals with considerable intensity. The antenna circuit is an *untuned* or *aperiodic* coupling. The secondary coil *TC1* is wound on the same tube with the antenna coil *TC*, and is inductively coupled to it with a variable separation. The secondary coil *TC1* is tuned by means of the variable condenser *VC*. The tickler coil *O* is either a rotating coil placed within the primary and secondary coils, or a third separate coil, and is used to feed back energy into the secondary coil *TC1* by means of its electrostatic coupling. The circuit shown in this diagram is more sensitive than that shown in Figure 65.

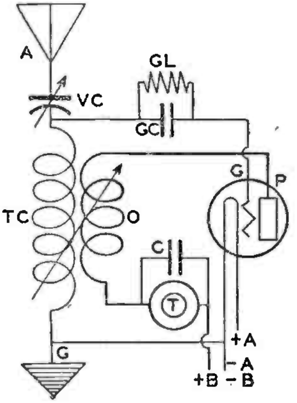


FIG. 65. REGENERATIVE CIRCUIT

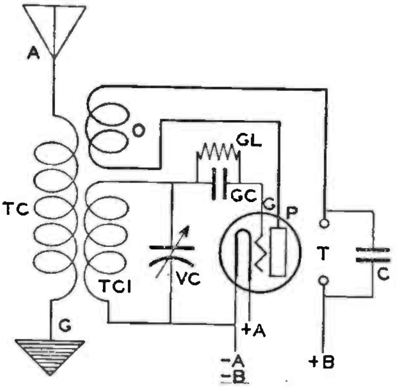


FIG. 66. UNTUNED ANTENNA REGENERATIVE CIRCUIT

TICKLER COIL RESISTANCE. It is desirable in some circuits to eliminate the audio frequency resistance of the tickler coil from the "B" battery and telephone circuits. This is obtained by the use of a small fixed condenser and a radio frequency choke coil (*RFC*) as shown in Figure 67. The telephone connection is made at the plate as usual but a small by-pass condenser *C* is placed between the plate and the tickler coil *O*. In this way the radio frequency currents pass through the tickler, but the audio frequency surges cannot flow along the same path because of the blocking condenser and action of the choke coil.

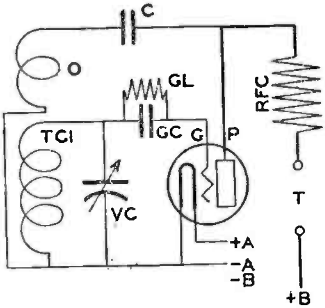


FIG. 67. ELIMINATING TICKLER RESISTANCE

ANNOYANCE OF REGENERATIVE CIRCUITS. The effect of regeneration is to reduce the effective resistance of that particular circuit. If this regeneration is pushed too far, that is, if the plate and grid circuit coupling is *increased* beyond a critical value (depending upon the individual inductances and tube capacities) the effective resistance becomes zero, and there arises self-sustained oscillations of a certain frequency. The adjustment of the coupling between effective reception and this spontaneous oscillation is of great importance, and is extremely fine. Nothing short of patient manipulation will suffice; otherwise the set will give rise to squeals, and the surrounding radio listeners will hear these radiated oscillations. At the present time regenerative sets remain the most efficient but, unless properly *neutralized*, they often prove a nuisance. Methods of reducing radiation are discussed fully elsewhere.

RADIO FREQUENCY AMPLIFYING CIRCUIT. We have seen that it is possible to *increase* the energy of the signals as they pass through the antenna circuit, and before they are rectified by the detector tube. Figure 68 shows a circuit, such as that shown in Figure 63, but with *one stage* of *radio frequency amplification* added. This stage will increase the original strength of the incoming signal so that the detector will rectify and deliver it to the telephone receiver with greater volume. Amplification of this sort will bring in signals from stations which otherwise cannot be heard, and may be carried through several stages, three sets of radio frequency transformers being the usual limit. The antenna circuit is tuned as usual and also the secondary circuit by the condenser *VC*. The energy from this circuit is impressed upon the grid of the radio frequency amplifying tube *1*, and a stronger current flow in the plate circuit is the result. This passes through the primary *P* of the transformer *RFC* and sets up a radio frequency alternating current in the secondary *S*, which is then impressed with increased intensity on the grid of the detector tube.

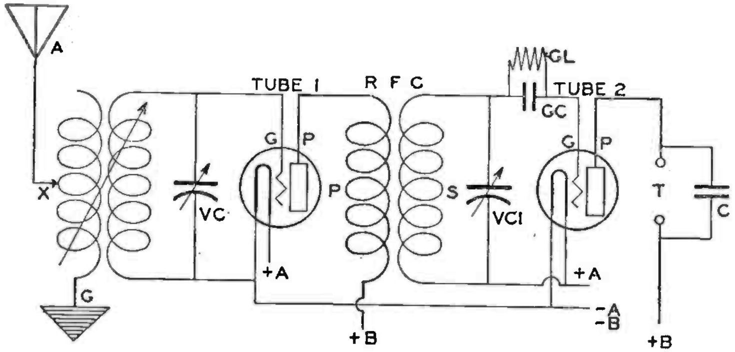


FIG. 68. CIRCUIT WITH RADIO FREQUENCY AMPLIFICATION

AUDIO FREQUENCY AMPLIFYING CIRCUIT. Figure 69 shows one stage of audio frequency transformer amplification *added* to the circuit shown in Figure 68. The radio amplification stage may be eliminated, and the addition made to the original circuit shown in Figure 63. The audio frequency stage may be added to any of the units shown above, but a separate circuit for use with the crystal detector is given in Figure 76. The rectified current

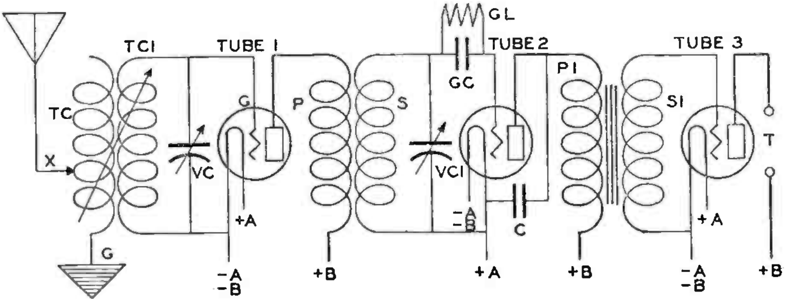


FIG. 69. CIRCUIT WITH AUDIO FREQUENCY AMPLIFICATION

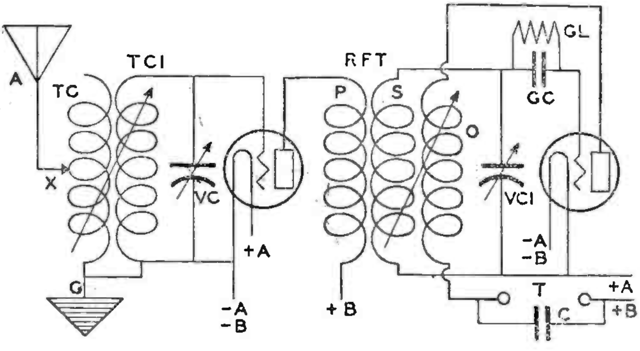


FIG. 70. REGENERATION WITH RADIO FREQUENCY AMPLIFICATION

(Figure 69), instead of passing through the telephone receivers as in Figure 68, passes into the primary *P1* of the audio frequency transformer and induces a stronger alternating current in the secondary *S1*, which is then impressed upon the grid of the audio amplifying tube. The flow of current through the plate circuit of this tube is much stronger than in the other circuits, and the telephones may be replaced with a loud speaking device. (See Amplification, Chapter 7, for details.)

REGENERATION WITH RADIO FREQUENCY AMPLIFICATION. Radio frequency amplification and regeneration may be combined in the detector circuit, and the result is an extremely efficient and selective receiver. Figure 70 shows how the diagram in Figure 68 may be rearranged so that regeneration may be applied. This will greatly increase the intensity of the signals impressed on the detector grid. Radio frequency amplification is obtained by means of one radio stage, and also by the feed-back from the plate of the detector tube to the secondary *S* of the radio frequency transformer (*RFT*) by the action of the tickler coil *O*. The tuning is done by means of the variable condensers *VC* and *VC1*, and the tickler *O*. Audio frequency amplification may be added as shown in Figure 69, placing the primary *P1* of the audio transformer where the telephones (*T*) are shown in Figure 70.

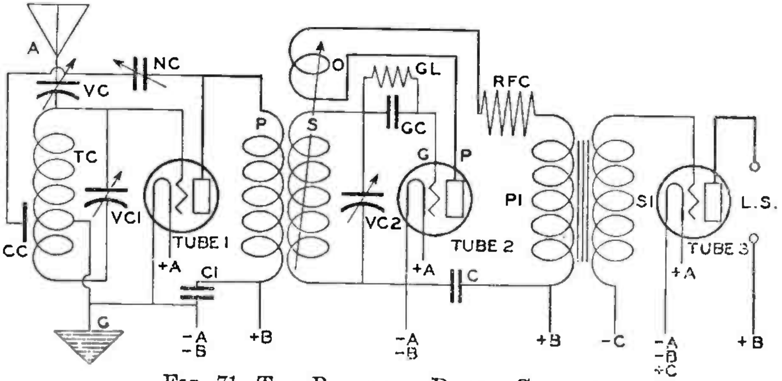


FIG. 71. THE BROWNING-DRAKE CIRCUIT

THE BROWNING DRAKE CIRCUIT. A very efficient circuit employing a *single* antenna inductance and one stage of radio frequency amplification with regeneration in the detector circuit, and *neutralized grid capacities*, is shown in Figure 71. This is the *Browning-Drake* circuit which has given universal satisfaction. The antenna inductance consists of a small coil (*TC*) that is connected to the antenna through a small variable condenser *VC*. The coil *TC* is shunted by a variable condenser *VC1* for fine tuning, and the radio frequency current is impressed upon the grid of tube *1*. The primary *P* of the radio transformer is connected with the plate of the first tube, thence to the coil *TC* by a small neutralizing condenser *NC*, through the capacity *CC*. This method of neutralizing the tubes prevents self-oscillation to a great extent. Regeneration is obtained by using a tickler coil *O* in the plate circuit of the detector tube. One or two stages of audio amplification will provide a set that will work a loud speaker very well on distant broadcasting stations.

THE HAMMARLUND-ROBERTS CIRCUIT. The *Hammarlund-Roberts* circuit combines a neutralized stage of radio frequency amplification to a regenerative detector. In this circuit the original antenna current is increased in strength by passing it through a radio frequency amplifier before it is rectified by the detector. It is then partially fed back into the radio frequency circuit by means of regeneration, after which the fully rectified current from the detector is amplified at audio frequencies by means of an ingenious and powerful system for loud speaker operation. Figure 72 shows this efficient circuit. The antenna currents are coupled to the circuit through the first transformer coupling coils *TC* and *TC1*. The secondary is tuned with the variable condenser *VC*, and the energy is impressed on the grid of tube *1*. Because of the amplifying properties of the tube, the current is again strengthened before passing into detector tube *2*, through the secondary *S* which is critically tuned by the variable condenser *VC1*. By use of proper neutralizing through the midget condenser *NC* the ratio of step-up in potential between the antenna circuit and the detector is materially increased, and radiation is prevented. The current is rectified in tube *2*, and a portion of it is passed back into the detector grid circuit by means of the tickler coil *O*.

THE POWER AUDIO FREQUENCY AMPLIFIER. After the signals pass through the plate circuit of tube *2*, Figure 72, they actuate the primary coil *P1* of the first audio frequency amplifying trans-

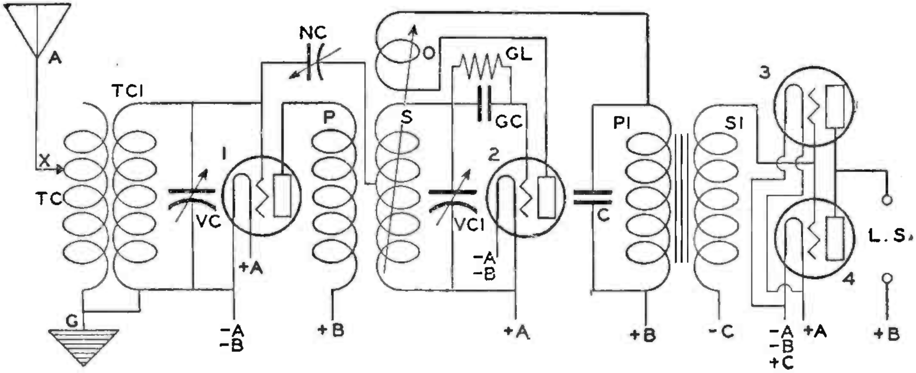


FIG. 72. THE HAMMARLUND-ROBERTS CIRCUIT

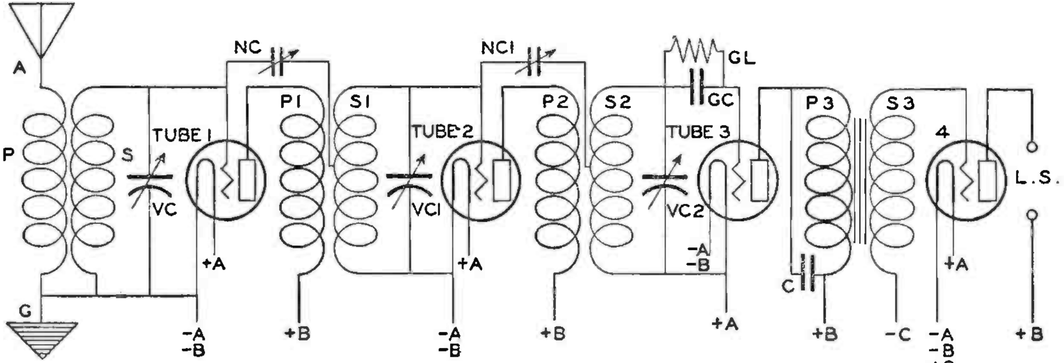


FIG. 73. THE NEUTRODYNE CIRCUIT

former, and induce alternating currents in the secondary *S1*. The current is sufficient to be *divided* between the grids of two additional amplifying tubes, *3* and *4*. The *combined* output of these tubes is passed on into a common high potential plate circuit of which the loud speaker is a part. A heavy grid negative bias must be given to the grid current that is induced in the secondary *S1*.

THE NEUTRODYNE CIRCUIT. The so-called *neutrodyne* circuit, developed under the *Hogan* and *Hazeltine* patents, has met with universal success. Perhaps the most outstanding is the *Atwater Kent* radio apparatus with its single dial simplicity and stability.

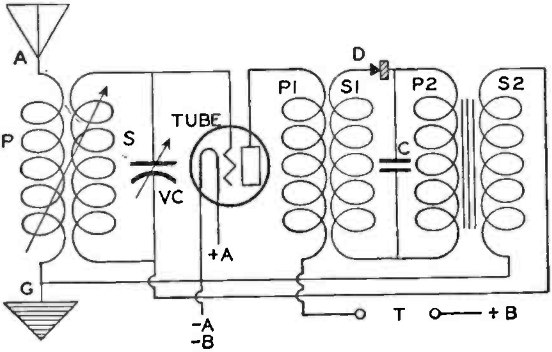


FIG. 74. A CRYSTAL AND TUBE REFLEX CIRCUIT

It has been very popular because of its dependability and freedom from unstable oscillation. If the tubes are carefully neutralized, tube oscillation will be entirely absent. The connections of the neutrodyne circuit are shown in Figure 73. It is relatively simple, being a circuit embracing two stages of radio frequency amplification, a detector and two stages of audio amplification, with the grids of the first three tubes completely neutralized. The secondaries of the three radio frequency transformers *S*, *S1* and *S2* are tuned by three variable condensers and, if the set has been carefully designed, the dials of each condenser should have *identical* settings. It is because of this feature that a single dial control may be used, each condenser rotor being mounted on a common shaft, or otherwise connected, so they may be operated by the one dial. The grid of the tube *1* is connected with a place on the secondary coil *S1* through the neutralizing condenser *NC*, and the grid of the tube *2* with the secondary *S2* through the condenser *NC1*. Nearly all radio frequency transformer coils, whether binocular, solenoid or toroid types, are provided with connections for the neutralizing condenser for the suppression of self-oscillations in the radio frequency stages.

THE REFLEX CIRCUIT. A circuit that combines the good qualities of the electron tube and the crystal detector, is known as the *reflex circuit.* In this circuit the audio frequency currents are fed back into the tube for *reamplification.* In other words, the tube of a reflex circuit will perform a double duty, and act both as a radio and audio frequency amplifier, instead of amplifying only the radio frequency current. Figure 74 shows a reflex circuit. The antenna is coupled to it through the primary *P* and the secondary *S*, which is tuned with the variable condenser *VC*. The radio frequency current impressed upon the grid of the tube sets up variations in the plate current which flows through the primary *P1* of the radio frequency transformer. Stronger radio frequency alternating currents are set up in the secondary *S1*, and flow through the circuit in which the crystal detector *D* is placed. The crystal rectifies this current, and the average is passed through the primary *P2* of the audio transformer, while the radio frequency component is by-passed through the condenser *C*. Audio frequency alternations are set up in the secondary *S2* and these are *reflexed* back into the secondary *S*, and are reimpressed upon the grid of the tube as audio frequency currents to be amplified. The tube, therefore, is amplifying the *original* radio frequency current from the antenna coupler, and the *reflexed* audio frequency current as well. Thus all of the advantages of the crystal detector are obtained without the oscillation and tube noises which are present when a tube is used as a detector. Several applications of the reflex system have been developed, some of them employing several tubes for additional radio and audio frequency amplification, so that loud speaker reception may be had from distant stations.

THE TUBE REFLEX CIRCUIT. The *tube reflex* circuit differs but little from the circuit using a crystal as a detector. However, when a tube is used as a detector, regeneration may be employed, and a powerful circuit may be developed. The circuit shown in Figure 75 shows one stage of radio frequency amplification, a regenerative detector and reflexed audio frequency currents. The primary *P2* of the audio transformer is placed in the tickler circuit of the detector tube plate, as usual in regenerative circuits, but the secondary *S2* feeds into the radio frequency secondary *S*. This amplified current is, therefore, reimpressed on the grid of the first tube which acts as an audio amplifier as well as a radio amplifier. The telephones or loud speaker are in the plate circuit of this double-duty tube, and if a stage of audio amplification is added, the telephones should be replaced by the primary windings of the audio transformer. The reflex and regenerative circuit shown in Figure 75 is the most powerful set using two tubes that is known to radio. A well known but slight modification of this type of circuit is the *Robert's Reflex* circuit.

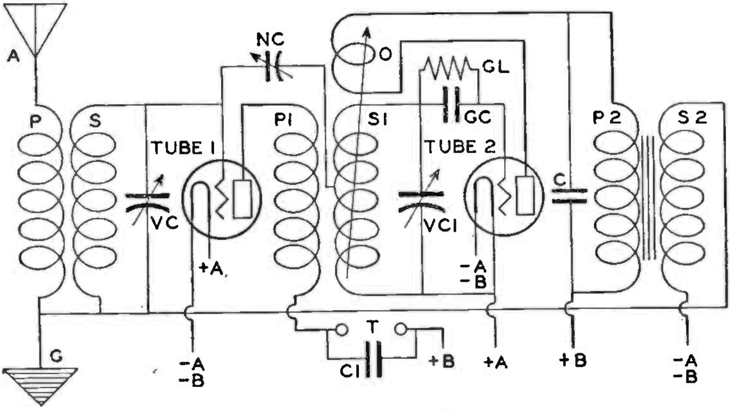


FIG. 75. THE REGENERATIVE REFLEX CIRCUIT

CRYSTAL AMPLIFICATION CIRCUIT. When a crystal detector is used for nearby stations its signals may be amplified a number of times. The quality of the tone is good, as all of the characteristics of the crystal are retained, but loud speaker volume can easily be obtained. Figure 76 shows how one stage of audio frequency amplification is added to a crystal set, using the connections shown in Figure 61. The telephone receiver is replaced by the primary *P* of the audio frequency transformer. Stronger alternating currents are set up in the secondary *S*, and are impressed upon the grid of the tube. The telephones are then connected in the plate circuit as shown. Another stage of audio amplification may be added, and a loud speaker used in place of the telephones.

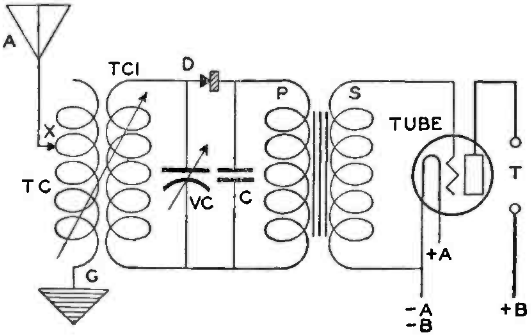


FIG. 76. AUDIO AMPLIFICATION WITH A CRYSTAL CIRCUIT

BEATS. When two adjoining piano keys are struck simultaneously, a peculiar sound occurs which has a tone different from that given by either of the two strings. If we take two *tuning forks* with similar vibration periods and lower the natural period of one by placing a particle of wax on one prong, a similar result ensues. In either case, we have two *slightly* different sources of sound waves, vibrating simultaneously, but with a slight difference in frequency. We hear a peculiar wavy or throbbing sound, caused by the alternate rising and falling in loudness or intensity. These alternations in intensity are called *beats.* Beats are usually produced through interference between two sound, or electromagnetic waves.

THE PRODUCTION OF BEATS. In Figure 77 the continuous wavy line *AB* represents a series of sound waves set up by the vibrations from the tuning fork that has been loaded with the wax ball, and the dotted line a series of sound waves emitted by the natural frequency fork whose vibratory period is slightly greater than the one which has been loaded with wax. The waves from the two forks start together at *A* but, as the waves from the loaded fork are given less frequently, they are correspondingly longer and *lag* behind those from the natural fork. At certain regular periods (*X* and *Y*) the waves of the two forks will meet again; also at certain intervals, as at *C*, the two waves will completely *interfere* and produce a momentary silence, too short to be perceived. When they meet, as at *Y*, they are again in *harmony*, and the sound swells to its highest volume, but the period is too short to be perceived at the instant. The sound as received by the ear is, therefore, correctly represented in the second part of Figure 77 by the curved line *A1–B1*.

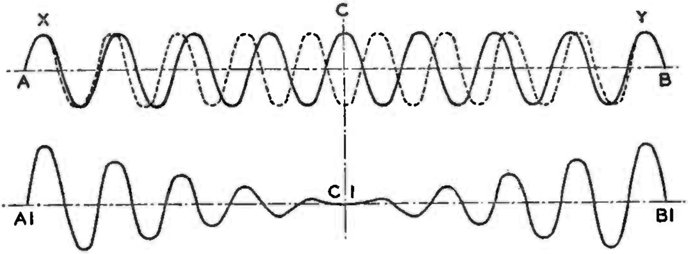


FIG. 77. BEAT PRODUCTION

INTERFERENCE BETWEEN WAVES. Let us further assume that the natural frequency fork makes 250 vibrations per second, while the one that has been slightly loaded with wax makes 249 vibrations per second. It is apparent that once every second the cycle from one fork will coincide at *X* and *Y* with the cycle of the other fork, producing a *maximum* intensity of sound, and once during the same time the cycle of one will be opposed with the cycle of the other as at C and $C1$, producing a sound of *minimum* intensity. This produces one beat per second. If there is a difference of two vibrations per second between the two forks, there will then be two beats per second. In every case the *number* of beats per second due to two tones is equal to the *difference* between their respective vibration numbers. Two sound producing sources, one having a frequency of 1,000 and the other 1,500, will produce beats at the rate of 500 per second. The sensation of beats in music is spoken of as *discord;* in radio it produces *interference*, called *heterodyning.* However, if properly handled, beats will provide us with one of the most efficient methods of obtaining highly selective and sensitive radio reception.

HETERODYNE EFFECTS. If two sources of continuous radio frequency waves of constant amplitude are arranged to act at the same time on the same circuit, and if one has a frequency of 1,000,000 cycles per second and the other a frequency of 1,100,000 cycles, the amplitude of the resultant frequency rises and falls alternately at the rate of 100,000 times per second. There are 100,000 beats per second—the difference between 1,000,000 and 1,100,000 cycles. In this case the wave length of the beat is 3,000 meters, as against wave lengths of 300 and 275 meters for the two separate oscillations which act to produce the beats. Therefore, the wave length of the incoming signal may be *raised* without impairing its audio frequency characteristic or modulation, to any satisfactory unit at which the radio set will best operate, and all reception is then accomplished on this particular wave length. This method of obtaining beat frequencies by means of two opposing radio frequencies is called the *heterodyne effect.*

THE HETERODYNE RECEIVER. We have seen that in most radio receiving circuits it is necessary to amplify the incoming signals at radio frequencies before they are detected, in order to procure sufficient intensity. In the heterodyne circuit, no attempt is made to amplify at the high frequencies. After they have been *reduced* to a somewhat lower radio frequency (but still above the audible range) they can be passed through as many stages of this *intermediate* radio frequency as may be necessary. The radio transformers, if properly designed, will be relatively free from outside noises, and will not be sensitive to signals of other wave lengths that may attempt to pass. The beat frequency depends upon the difference between the frequencies of the two waves, and if the frequency difference is very slight, the beat frequency will be low, while if there is a large difference, the beat will be high. However, the frequency of the received wave is fixed according to the existing conditions, and its variation is beyond the control of the operator; by varying the frequency of the local applied oscillating current, the beat frequency may be changed at will.

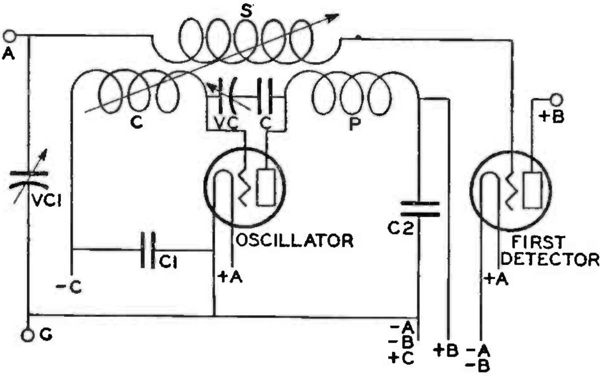


Fig. 78. Local Heterodyne Oscillator

The Local Beat Oscillator. To produce a beat frequency, a local radio frequency current must be *applied simultaneously* with the received frequency. This current is best obtained from a *local oscillating circuit* which is inductively coupled to the antenna circuit. The antenna current frequency meets in unison with the impressed local current of a different frequency, and sets up a beat frequency in the antenna circuit because of the interference of these two high frequency currents. The result is that but one current flows in the antenna circuit; this is the beat current which sets up the intermediate radio frequency oscillations in the secondary coil of the antenna coupling, as will be explained further. Figure 78 shows a simplified method of connecting a local oscillating current to the antenna circuit. This is accomplished through the coils *P* and *S* and *C*. The tube is made to oscillate by means of the coupled inductances and the variable condenser *VC*. This condenser controls the frequency of the oscillations, and the coupling between *P*, *S* and *C* should be of sufficient value to induce an opposing current in the antenna circuit about equal to that received in the antenna from the sending station. If the entire set has been designed to operate on a certain frequency, the adjustment of the condenser gradually brings into opposition an *induced* frequency considerably more or less than the one being received, so that the beat frequency is just right and the whole set will immediately respond to it.

THE FIRST DETECTOR. The antenna is tuned by condenser *VC1* (Figure 78) to bring it into resonance with the wave that is desired. The local oscillator is tuned by the condenser *VC*, and a beat frequency produced which is correct for the designed resonance of the receiver coils. This beat frequency is then passed on to the *first detector* tube. The beat frequency is then rectified into high frequency pulsations of current, which are passed through the following tubes and transformers for amplification always at one frequency. The original modulation characteristics are not altered because of the production of beats.

THE INTERMEDIATE RADIO STAGES. This unidirectional rectified current from the first detector is passed through the primary of an *intermediate radio frequency transformer*, and the current is then amplified in the same manner as in all other radio circuits. These intermediate transformers are designed to operate on but one frequency, that passed from the first detector, and they have a filtering effect on any other frequencies which may creep in. Because the resonance to the set beat frequency is fixed in the designed inductance of the transformers it is not necessary to tune them with variable condensers. The heterodyne circuit operates on but one wave length throughout, and its radio amplification coils should be carefully made to pass only the one wave length.

Because of the difficulty in manufacturing coils to operate perfectly on only one frequency, they must have sufficient *broadness* to be sure of passing the signal without uncertainty. Such construction is not desirable, but it is extremely difficult to design a circuit to pass only one frequency without a band on either side to assure resonance. As this band covers other frequencies, these frequencies are likely to interfere. If each coil could be tuned separately by a variable condenser, then each coil could be brought into perfect resonance and filter out all other interfering frequencies. This is impracticable as it introduces too many moving parts requiring manual adjustment, and tuning is a tedious undertaking.

THE SECOND DETECTOR. After the current has been sufficiently amplified by passing through the intermediate radio stages, it is necessary to repeat the detecting or rectifying process, using what is known as the *second detector.* This detector is a simple radio detector equipped with a grid leak and condenser, and capable of rectifying at the wave length used in the circuit. As this wave length never changes, regardless of the original wave length of the station broadcasting, the grid leak capacities may remain constant. Otherwise, the detector action is exactly the same as in any other type of radio receiver circuit.

TUNING THE HETERODYNE CIRCUIT. It should be noted that the heterodyne method requires very sharp tuning adjustments. It is also best adapted to long waves, and the beat frequency should be relatively low. In use with short waves or a high beat frequency, the tuning required to obtain an audible signal is very difficult to attain. The capacity effects of the different parts of the set will also greatly affect the tuning at short wave lengths. If the receiver is made to produce a beat frequency of at least 100,000 cycles (100 kilocycles), which may be easily amplified with radio frequency amplification, the output may be treated by usual methods of detection and amplification.

SUPERIORITY OF THE HETERODYNE CIRCUIT. While this circuit appears complicated, it is in reality comparatively simple. It is easy to operate, and has greater selectivity and sensitiveness than any other known type of circuit. The invention of the

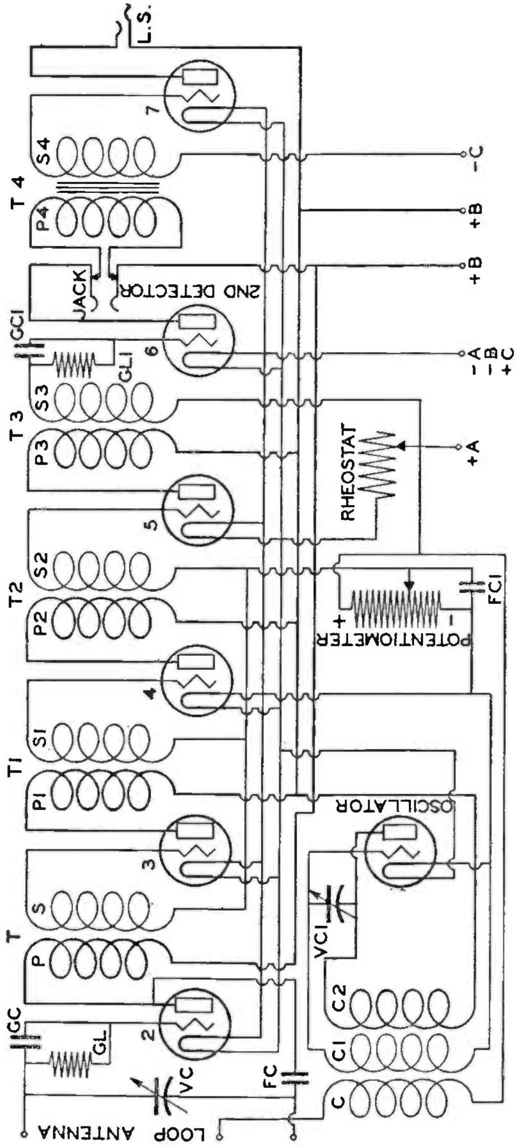


FIG. 79. THE SUPER-HETERODYNE CIRCUIT

heterodyne dates back to 1918, since which time it has been widely used, and is responsible for many remarkable accomplishments in long distance reception. One of the great advantages of the circuit is that it can be used on a very small loop antenna. A set comprised of 8 tubes, located on the Atlantic Coast, will receive signals from stations on the Pacific Coast, using a small loop for receiving, and giving very good loud speaker volume. The only factor which determines reception audibility is that the signal intensity must be above the level of the atmospheric and interfering noises.

THE SUPER-HETERODYNE CIRCUIT. Figure 79 shows a conventional *super-heterodyne circuit.* Some manufacturers have made slight changes in the method of producing local oscillations, and the coupling to the antenna circuit to produce the beat oscillations. The local oscillator tube is inductively coupled to the antenna circuit through the coils *C*, *C1* and *C2*. The signals from the broadcasting station are picked up by the loop antenna, which is tuned with the variable condenser *VC*, and the frequency of the local oscillating current is controlled by the condenser *VC1*. The beat frequency, when once developed, is detected by the first detector, tube *2*. These rectifications of the intermediate radio frequency current pass through the primary *P* of the radio transformer *T* and set up stronger alternating currents in the secondary *S* which are, in turn, impressed upon the grid of the first radio frequency amplifying tube *3*. The amplified currents then pass through the transformer *T1;* tube *4;* transformer *T2;* tube *5;* transformer *T3;* and thence into the second detector, tube *6*. Audio frequency amplification is then procured by passing the rectified current through the audio frequency transformer *T4* and into the audio amplifier, tube *7*. The loud speaker is placed in the plate circuit of this last tube. A telephone jack should be placed in the plate circuit of the second detector, tube *6*, for use with telephones.

THE AUTODYNE CIRCUIT. In a regenerative circuit the same tube may be used as a rectifier and also as a *generator* of local oscillations for beat reception. Such an arrangement is known as *autodyne* reception, and beats may be produced having an audio frequency equal, of course, to the difference between the received and local frequencies. In this circuit, the antenna is tuned to the signal and the oscillator is slightly detuned so as to produce beats. The autodyne method of beat reception is much more sensitive than other circuits described in this chapter, with the exception of the heterodyne circuit. An autodyne circuit is shown in Figure 89.

CHAPTER X

THE ELECTRICAL REPRODUCTION OF SOUND

SOUND. *Sound* is a form of vibrational energy, which when propagated by a wave motion from some vibrating body, acts upon the ear to produce *audible* effects. The wave motion producing sound must originate with some vibrating object, and it must be conducted by some physical medium. Sound cannot be passed through a vacuum. The conducting medium may be a solid, fluid or gas. The latter, in the form of air, conducts practically all sound that is known to man, and sound velocity and intensity varies according to the *density* of the air.

VIBRATIONS. A *vibration* is a recurrent change of position by a material substance, and the number of changes of position which take place in a given unit of time, is called its frequency. The vibration imparts a wave motion to the conducting medium which in turn strikes some object capable of being set into vibration. This object will then vibrate in *unison* with the original vibrating body. When this occurs, the vibrations are called sympathetic vibrations, and the two objects are said to be in *harmony* or *resonance*.

INTERFERENCE. When a body is subjected *simultaneously* to two or more impulses, due to two or more trains of waves, the motion of the body is the resultant of the impulses, and the re-vibration is termed *interference*, which may either intensify or nullify the vibration. The sensation of *discord* is caused by an irregularity in the impulses received, and the inability of the ear to distinguish any one pitch.

PITCH. The *pitch* of a sound depends upon the frequency of the vibrations of the body; that is, the greater the number of vibrations in a unit of time, or the shorter the wave length of the motion through the transmitting medium, the *higher* the pitch. The lower the number of vibrations or the longer the wave length, the *lower* the pitch.

TONE. The character of a sound is called *tone*. It is charac-

PLATE 4

Top, left: Cone speaker—courtesy Crosley Radio Corporation. *Top, right:* Horn speaker—courtesy Atwater Kent Manufacturing Company. *Center:* Telephone receivers—courtesy Federal-Brandes Company. *Lower:* Modern single control receiver—courtesy Atwater Kent Manufacturing Company.

terized by its pitch and force, and, generally speaking, is the opposite of discord. A tone always has some regularity of vibration which is pleasing to the ear. Most sounds are composed of two or more tones, the components of which are the predominating *fundamental tones* determining pitch, and the *overtones* or *harmonics* which give tone quality and *timbre* to a sound.

BEAT NOTES. A sound that alternately swells and falls at regular intervals is a *beat note* caused by interference between two vibrating bodies with different frequencies. See Figure 77 and Chapter 9, for a more complete description of beats. Beats are the chief causes of interference and heterodyning between radio waves.

SOUND VOLUME. *Volume* or *loudness*, which is a measure of the *intensity* of sound, varies with the intensity (not pitch) of the vibrations which set up the motion in the transmitting medium. If we take two bodies each with the same vibration frequency but differing slightly in size, and vibrate them, the resultant wave motion will show *identical* wave lengths and frequencies. The height of the crest of the wave from the larger body will be greater than that reached by the wave from the smaller body; in other words, the *amplitude* of the wave motion will be greater. This amplitude varies, therefore, with the strength of the vibrating body and controls the degree of energy transmitted by the sound wave. The *intensity* of the sound obtained from a wave motion may be either *loud* or *faint*, according to the amplitude of the wave. It must be remembered that although frequency and wave length are directly related, as explained elsewhere, amplitude is separate and distinct. Amplitude always represents the energy of the wave motion, whether it be sound, water, or radio waves.

CONDUCTION OF SOUND WAVES. For example, consider a familiar toy, shown in Figure 80, known as the string telephone. It is composed of two short tubes each open at one end and covered at the other with tightly stretched parchment paper or membrane. The tubes are connected with a long string that passes through a small hole in the center of each membrane covering, and held so that the string is stretched tightly without touching any intervening objects. A person speaking into one of the tubes throws the air within into a wave motion which is transmitted to the membrane, and throws it into vibration. These impulses are communicated to the string, and are carried along it to the membrane of the second tube which is caused to vibrate in unison with the first. If another person places his ear over the open end of the second tube he may distinctly hear the words which are spoken by the first person. The vibrating membrane of the second tube sets the air between it and the ear into a wave motion, thus forming a means of communication between the two persons. The membrane of the receiver actually takes the place of the speaker and duplicates his voice.

Sound Wave Motion. The string between the two instruments is indicated in *A* of Figure 80. When transmitting sound waves, it takes the form shown at *B*, which the graph, of course, greatly exaggerates. *L* represents the wave length between crests, and *E* the amplitude transmitted. The standard for *sound wave motion* or *velocity* in air is 1,083 feet per second, and if the number of wave crests occurring in that distance in one second could be counted, the result would represent the frequency of the pitch transmitted. The frequency multiplied by the wave length equals approximately 1,083 feet, when a *second* is used as the time unit.

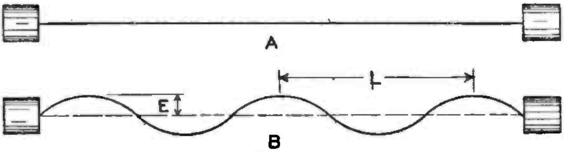


Fig. 80. Conduction of Sound Waves

Sound Transmitted Electrically. If some mechanical instrument can be rendered sufficiently delicate to imitate these minute movements of the membrane or of the vocal cords, sound may be transmitted by mechanical motion. This actually can be accomplished over great distances by a pulsating electric current representing the sound wave variations of amplitude.

THE ELECTRIC TELEPHONE. The device by means of which this is accomplished is called the *telephone.* The instrument that provides the current variations is called the *microphone* or *transmitter,* and the device that converts these variations into sound is called the *telephone receiver.* In radio reception we have to deal especially with methods of reproducing sound at greatly intensified volumes. The microphone used in radio transmission has been described fully in another chapter.

THE TELEPHONE RECEIVER. For the conversion of electrical energy into sound we must have a surface which, when moved in accordance with the changing electrical impulses, will set into motion the air column in front of the surface, so that sound waves may be set up in the surrounding air. The principle of a *telephone receiver* is shown in Figure 81, and consists of a thin iron *dipahragm* D that is centrally mounted over a permanently magnetized bar of steel B with a small air gap between it and the end of the bar. A coil C, consisting of many turns of fine wire is wound around the magnet, and the two ends are connected directly to the pulsating electric current coming from the microphone. The diaphragm, however, is clamped at its edge and only vibrates to its greatest extent in the center. Such a vibration has a certain mechanical period to it, with the result that stresses within it prevent true tone reproduction. The permanent attraction of the magnet will slightly curve the center of the diaphragm and the outer surface will, therefore, be slightly concave. If a slight current is sent through the coil of wire, its lines of force will alternately *aid* and

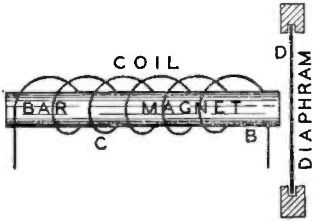


FIG. 81. SIMPLE TELEPHONE RECEIVER

oppose the magnet's own lines of force. The magnet is slightly weakened and intensified alternately, and the sensitive diaphragm, being susceptible to the slightest change in the attraction of the magnet, immediately springs outward or closer to the magnet. As this motion takes place suddenly it produces a single vibration, but the vibrations, occurring rapidly, set the air in motion and develop sound waves which affect the ear.

THE WATCH-CASE TELEPHONE RECEIVER. The above description fits the general principles of an elementary telephone receiver, and is a fair representation of the ordinary telephone receiver in commercial use for wire telephony. In radio work, or where telephones must be used for hours at a time, with the hands free, the receivers are made very light and attached to a *headband* so that they may be worn on the head. This type of receiver, shown in cross section in Figure 82, is called a *watch-case receiver*. It is in universal use in radio work and consists essentially of a permanent steel magnet *M* with two separate pole pieces *N* and *S*. Coils of very fine wire (*C*), of many thousands of turns, are placed over each pole piece. The pulsating average current passes through these turns of wire, and meets only with its natural resistance, and also whatever inductive reactance may be present according to the rate of current pulsations. The diaphragm *D* is placed adjacent to the poles, and when no signal is being received it is under constant pull from the two magnetic poles. Currents

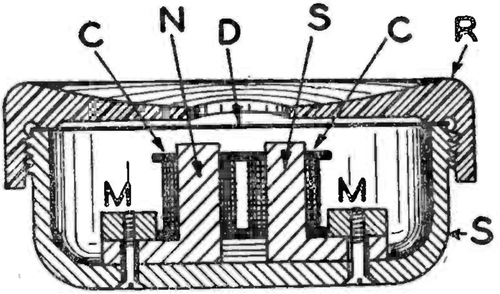


FIG. 82. WATCH-CASE RADIO TELEPHONE RECEIVER

of pulsating amplitude or potential will upset the magnetic balance and cause the diaphragm to vibrate. The amplitude of the vibration of the diaphragm will be in accordance with the amplitude of the current that is passing through the coils over the telephone magnets.

TELEPHONE RECEIVER RESISTANCE. The resistance of a telephone receiver to a direct current will be the total resistance of the wire when measured in ohms. The average receiver has a resistance of from 1,000 to 1,500 ohms. But its resistance to an alternating current will, of course, be much greater, often many thousands of ohms. However, as the average current that flows in a telephone is always pulsating, the telephone receiver will present a resistance considerably higher than its natural resistance. This reactance to the flow of the current will vary as the amplitude and frequency of the telephone current varies, thus making it impracticable to obtain a receiver that will show an even and true proportion between the amplitude of the diaphragm and of the current. In order to prevent this trouble as much as possible the telephone receiver, when used in the detector plate circuit, is always shunted with a small fixed condenser with little or no reactance to the flow of the radio frequency current. This action has been fully explained elsewhere.

DISTORTION OF TELEPHONE RECEIVERS. Speech transmitted by telephone is not always natural in tone or amplitude. The vibrating parts, the diaphragms of the microphone and receiver, may produce *distortion* during the passage of the current. The diaphragm of the receiver must be of the correct weight; it must be heavy enough to vibrate slowly at low frequencies, and light enough to vibrate rapidly at high frequencies. In order to be sensitive it must respond to the weakest variations in the magnetic intensity of the permanent magnetic poles. Other forms of distortion may be caused by poorly balanced magnets, unequal air gap spacings between pole tips and diaphragm, unequal reactance in the two coils, and in general, a poor receiver design.

RADIO HEAD SETS. When two receivers are equipped with a *headband,* they are then termed a *head set,* and are connected in series electrically with the plate and "B" battery current. Receivers used in head sets should be very light in weight and matched in tone. The positive terminal of one receiver should be connected to the positive post of the "B" battery. Otherwise the current flow may be in an opposite direction, and instead of strengthening the magnetic lines of force about the poles, it will oppose them and eventually cause the permanent magnets to become *demagnetized*.

THE BALDWIN TELEPHONE RECEIVER. The shell of this receiver is slightly larger than in other head telephones. The diaphragm is not moved directly by the change in the magnetic strength of the poles, and it is very responsive. A balanced armature of soft iron is suspended between two poles of opposite polarity, on each side of the pivot suspending the armature. When no signal is being received, the armature is balanced in its neutral position, but if a surge of current passes through the coils the magnetic balance of the armature is changed, and a pull in one direction or another, will occur. The armature is connected by means of a short *link* to the center of a *mica* diaphragm. This motion may be slightly increased by the mechanical lever action of the link, and a small signal current will produce a relatively greater change in the diaphragm. Also, because of the magnetic action at each end of the balanced armature, a *double* motion is produced which gives a more positive movement. Its rigid connection to the diaphragm produces an increased deflection, and thus the signal strength is intensified.

TELEPHONE RECEIVER SENSITIVITY. The *shell* (*S* in Figure 82) of a telephone receiver should be made of aluminum or hard rubber and threaded to take the hard rubber *cap R*. This cap screws over the top of the shell and clamps the diaphragm *D* around the edge of the shell. The cap has a small hole *H* to release the sound waves which are set up by the vibrating diaphragm. The close application of the receiver to the ear permits the hearing of very weak sounds; in fact, a sensitive receiver will click if the two metal terminals of its connecting cord are placed to the tongue, or to the moist skin of the body. The natural acids and the metal of the tips produce a battery current sufficient to send a current through the coils. This is a good test of a receiver.

TELEPHONE RECEIVER ACTION IN A RADIO CIRCUIT. Telephone receivers are made, of course, for use on pulsating direct or low frequency alternating currents. The diaphragm cannot follow variations in the electric current flowing through the coils if the frequency is too high, but it can follow audio frequency variations as given out by the microphone. The placing of a receiver directly in the antenna circuit produces no sound because of the impedance of the windings as the high frequency current is choked out. To eliminate this difficulty, some rectifying agency, such as a crystal or electron tube detector, is placed in the circuit and the radio current is permitted to flow in one direction only. This current, as has been explained, is unidirectional at a radio frequency in its pulsations, but has the audio frequency slow pulsations built up from the rapid radio frequency pulsations. While the rapid rectified pulsations cannot pass the telephone windings, the slower group surges of audio current, which are the average of the rectified pulsations, readily pass through the telephones and actuate the diaphragm. Thus we have two components of current, one passing the telephone windings, and the other by-passing the windings through a small fixed condenser.

INCREASING THE VOLUME OF SOUND. The ordinary type of telephone receiver does not set a very large volume of air in motion through the vibration of its diaphragm and, therefore, does not meet the requirements when sound is to be carried over some distance. If we attach a *horn* of some kind to the front of the receiver, the vibrating diaphragm will force a much larger amount of air to move with the result that the signals are audible at a greater distance. This is possible because of the expanding area of the horn by which larger air surfaces are set into motion and, when they communicate to the free air at the end of the horn, much volume is given because of the powerful sound waves set up.

LOUD SPEAKERS. *Loud speakers,* as a rule, are not simply telephone receiver cases attached to the neck of a horn, but are specially constructed units. The diaphragm is larger and the coils are capable of carrying heavier currents from the plate of the tube. The operating mechanism of the speaker is inclosed in the base, and the diaphragm opens into the neck of a horn of rather large dimensions. A powerful magnet is produced by a heavy current of electricity from a battery passing through an electromagnet placed in the base. This is in the form of a circular magnetic field enclosing a balanced coil having many turns of wire. This balanced coil is mechanically connected to the center of a large diaphragm. The average audio current flowing in the plate circuit is passed through the primary of a step-up transformer, and induces an alternating current in the secondary which is connected with the balanced coil of the loud speaker. This coil is compelled to move in accordance with the magnetic field fluctuations, vibrates the diaphragm and produces audible sound. The transfer of energy from the electric circuit to the diaphragm sets great quantities of air in the large air column of the horn in motion, and the horn reproduces faithfully the most complex sounds. Smaller loud speakers consisting of special telephone receiver units using heavier currents do not, as a rule, reproduce faithfully, but have a tendency to *blast* and distort on high notes or heavy currents. Sometimes, this tendency is not due entirely to the faults of the speaker, but to the inability of the tube to handle heavy currents. In such cases power electron tubes should be substituted for the lower capacity tubes.

CONE TYPE LOUD SPEAKERS. The *cone type* of speaker is entirely different from the horn, in that the electrically vibrated surface communicates directly with the free air. Large diaphragms, such as used on the cone speaker, will produce sound waves of greater amplitude than is possible with a horn of similar power. The cone speaker is a sort of *plunger surface* which moves the air immediately about it, and gives off sound waves of high amplitude. If the frequency of the applied electric current is low, the cone will be, in fact, a plunger, moving back and forth in its entirety. But as the frequency increases, the inertia of the outer edges of the cone is such that they remain still while the center, or apex, moves. A surface that will freely respond to all frequencies of vibration without mechanical stress, is thus obtained.

CONE SPEAKER CONSTRUCTION. The constructional detail of a cone speaker is shown in the half-section, Figure 83. A *conical* diaphragm *D* is supported at its periphery by two clamping rings *R*.

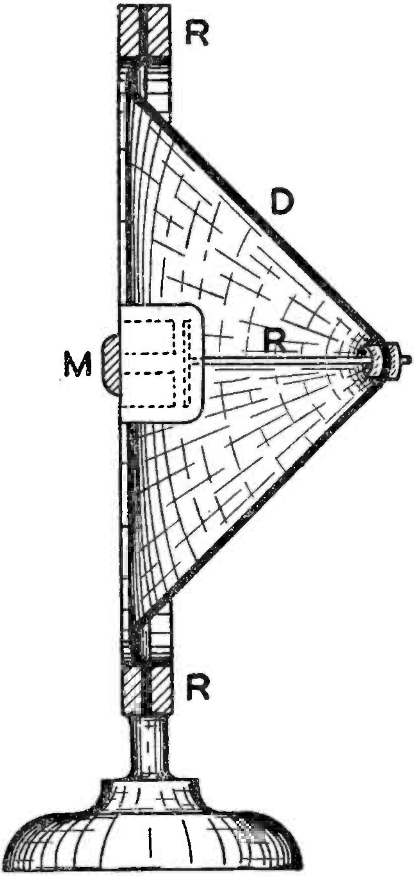


FIG. 83. DETAILS OF A CONE LOUD SPEAKER

Supported in the rear center of the cone, within the concave surface, is the magnet *M* and its windings. This magnet actuates the diaphragm, which is attached to the driving rod *R*. The rod passes through the apex of the cone, which is reinforced at that point, and is attached by a variable lock-nut arrangement so that the *tension* may be regulated from the front of the cone. Most cones are constructed from *fibrous paper* or a very thin veneer of wood. Hard finish papers do not give good tones and are not used. Pulp papers permit the cone to reproduce frequencies more uniformly, and seem to absorb the tinny sound prevalent when hard surfaced papers are used. If sufficient "B" plate current is used on the audio amplifier, *dissonance,* which is so common in horn speakers, will be practically absent.

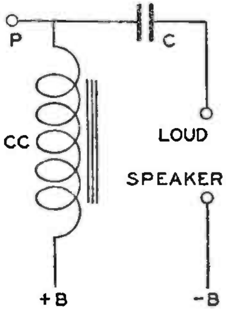


FIG. 84. OUTPUT CIRCUIT FOR LOUD SPEAKER

TELEPHONES VERSUS LOUD SPEAKERS. Loud speakers have yet to be built which duplicate the faithful reproduction of a good telephone receiver. Times may arise when every sound of some broadcast affair is desired, in all its original purity, and the telephone receiver provides the only ideal method of listening. The head telephones are more economical to operate than a loud speaker, and they also shut out external noises which might annoy or distract the listener. When telephones are used, it is desirable to use a *plug* and *jack* so as to connect them directly into the plate circuit of the detector tube, or at the most, in the first audio frequency amplifier stage. When a pair of telephones is plugged into the detector circuit the distortion due to amplification is eliminated, and better tones are obtained. Weak and distant stations may be clearly heard on the telephones at times when they would be drowned out by amplified noises if a loud speaker were used.

Output Circuit for Loud Speaker. A method of arranging the output circuit of the last audio stage which is coming into general use is shown in Figure 84. This circuit keeps the direct current of the plate circuit of the last tube out of the loud speaker windings. Generally it helps the quality of received signals, but with some types of speaker little difference will be observed. The loud speaker connections between the plate and the "B" battery are replaced with an impedance or audio frequency choke coil (*CC*) having an inductance of from 30 to 100 henries. The direct current is kept out by a large blocking condenser *C*, and the remaining free end of the loud speaker is connected to the negative terminal of the "B" battery.

CHAPTER XI

MODERN APPLICATIONS OF RADIO TRANSMISSION AND RECEPTION

RADIO TRANSMISSIONS. We have seen, in the chapter on How Radio Works, that radio signals are sent out by a modulated continuous carrier wave from the broadcasting station. This wave is of similar form in either telephone or telegraph transmission, except that the former is voice modulation, while the latter is code—dots and dashes. The most important use of the radio telephone is the broadcasting of music, voice and entertainment for the benefit of the public. The radio telegraph is used entirely for business, such as ship to shore, ship to ship, trans-oceanic and cross-country communication. A great army of enthusiastic radio amateurs communicate with each other every night over thousands of miles, using low wave lengths.

BROADCASTING PROGRAMS. The programs which are broadcast are either arranged in the *studio* of the station or are picked up from some outside point. Such places are then connected to the station by telephone lines or special wires, and much preliminary work is necessary in order properly to place and test the *pick-up* equipment. The programs, when picked up from some outside point, are amplified before sending them over the connecting wire; also again at the radio station. In this case a portable *control* equipment is used, by means of which the operator controls the volume needed to suit the conditions existing during the program.

INTERCONNECTION OF RADIO STATIONS. The *interconnection* of radio stations for the simultaneous broadcasting of a single program has made rapid progress. For instance, late in 1927, fifty of the leading radio stations in the United States were connected for the broadcasting of a single program from New York City. It was estimated that between 20,000,000 and 30,000,000 people were listening to this program. The first interconnection by means of land telephone wires was in 1922 when a football game played in Chicago was broadcast from a New York radio station. The use of wires in interconnecting broadcasting stations is the result of the desire of radio managers to add to their programs events which could not be brought to the stations' studios. The greater events of public interest can now be made available to remote stations.

RADIO CHAIN STATION NETWORKS. The *National Broadcasting Company*, the first organized radio broadcasting system in the world, operates a large chain of stations over the United States, through which radio programs can be simultaneously broadcast. This company was organized in November 1926, and since that time has broadcast programs furnished by practically all of the prominent manufacturers of the country, as well as all the outstanding events of interest. The radio station chain is divided into two sections, the *red network*, and the *blue network*, the former including about 25 radio stations, and the latter about 10 stations. These networks cover practically the entire country, and when special events are broadcasting, the chain is extended by about 15 stations in other sections. Approximately 7,000 miles of interconnecting wires are required to link these radio stations with the central at New York City. Programs originating in New York are carried by telephone circuits from the Bell Telephone headquarters over various circuits feeding New England, the Middle Atlantic States, Ohio Valley and Tennessee, South Atlantic States, Upper Plains States and Lake Region, and the lower Mississippi and Plains States, and Texas. Vacuum tube repeaters are used to amplify the signals traveling over the circuits in order to make sure that practically the same signal strength is delivered to each station in the network.

RADIO RELAY CONNECTION OF STATIONS. The *radio relay* scheme, whereby a program from a central station is broadcast, received and *rebroadcast* by other stations, has been successfully tried out. In September 1923, a radio station in Nebraska first rebroadcast a program from Pittsburgh. By such a relay system programs from the United States may be sent to other countries for rebroadcasting. Rebroadcasting of programs from London has been accomplished in the United States. The great disadvantage of radio relay broadcasting is that all interference and receiver noises are also transmitted. Fewer and better broadcasting stations with widespread nets of interconnection will greatly improve the American broadcast situation, and provide the public with programs of a high standard.

THE BROADCASTING STATION. Broadcasting by radiotelephone differs in a great many respects from the commercial methods of radiotelegraph communication. In the latter case more powerful equipment is used, and the construction must be essentially different, as distant communication must be maintained day and night. Radiophone broadcasting stations operate on but a small part of the power used at commercial stations. The modern radio station is a very complete organization. It is compact, with power plant, studio, offices, reception rooms, telegraph office, etc., in a relatively small space. Each part is operated and supervised by members of the station personnel. In case the plant is located some miles from the studio it is operated by long distance control. The upkeep cost and the number of employees of the modern broadcasting station is very large.

THE BROADCASTING STATION STUDIO. As practically all broadcasting is done from the building in which the station is located, or from some permanent place known as the *studio,* it is necessary to provide suitable facilities. If you strike a piano key in an empty room, you do not obtain a pure note. The sound has a more or less strange quality. This is because the hard surfaces of the room easily reflect the sound waves, and the true sound is immediately followed and distorted by countless *reverberations.* That these reverberations may be eliminated in the radio broadcasting studio everything is made sound or reflection proof. This is accomplished by placing heavy carpets over the floors, hanging the walls with heavy draperies, and covering the ceiling with loosely suspended felt or draperies. Every piece of furniture has a heavy cloth covering. The walls are set with a number of red lights so that those within will know when the station is operating, as any sound made in the studio will be broadcast along with the program.

THE MICROPHONE. The sounds in the studio, whether voice or music, are transmitted to the broadcasting apparatus in the station, by means of a pick-up device or *microphone*, often referred to as *mike*. These pick-up instruments are of different types, the most common being similar to the ordinary telephone transmitter, except that it is larger, and much more sensitive. This is one of the most important units in the station since it is depended upon to reproduce the efforts of the artists and speakers in a form of electrical energy which can be greatly amplified and sent out through the broadcasting apparatus. The *carbon transmitter* consists of a carbon disc covering a space that is filled with fine carbon globules. When the disc is set in motion by the sound waves, it varies the pressure which these carbon grains exert against each other. An electric current is passed through the material and, when the parts are perfectly still, the resistance is uniform, and quite high. As soon as the disc vibrates, the resistance is decreased accordingly, and variations in the current strength are developed. The *magnetic microphone* has certain advantages over the carbon microphone as its changes in current are uniform, and not subject to mechanical failure of the carbon grains to maintain a correspondingly uniform resistance. In this type of microphone, the disc is set in motion by the sound waves; the disc transmits the motion to a coil which is in a magnetic field; and the currents induced in it are impressed on the grid of an amplifying electron tube. As many stages of amplification may be used after the first tube, the original sound may be amplified many times without loss of true tone value. The microphone is necessarily portable since it must be moved about to get in the best pick-up position. Sometimes a number of microphones are necessary to proportion the various instruments and tones used. The use of an extra microphone assures certain transmission in case one fails to function.

THE BROADCASTING APPARATUS. The electric current passing through the microphone, with its attending variations, is passed on to the *broadcasting apparatus*. This is a very complicated affair resembling, in a general way, a gigantic receiving set. It operates, however, in an opposite manner. The oscillating currents are produced by special vacuum tubes, and a high voltage current is necessary to supply these tubes for the generation of radio frequency waves. The methods of producing radio waves have been described in previous chapters.

Operating the Broadcasting Station. When the broadcasting station is ready to start operations, the transmitting equipment is turned on, and the carrier wave is transferred to the regular antenna. The station is started up by first turning on the cooling apparatus for the oscillating tubes. This is usually in the form of a flow of circulating water through the plate, which otherwise would become dangerously hot. In many cases several thousands of volts are applied to the plate, and the plate current may also be considerable. The filament current is next slowly turned on, and then the plate current. This brings the tube into oscillation. The modulating tubes are then turned on, and the operator makes some preliminary announcement while watching the radiation meters for maximum energy transmission. When all is satisfactory, the announcing microphone is thrown off and the studio microphone connected. At the same time the operator closes the switch which signals the studio announcer by means of the red lights that the station is transmitting. The program then begins.

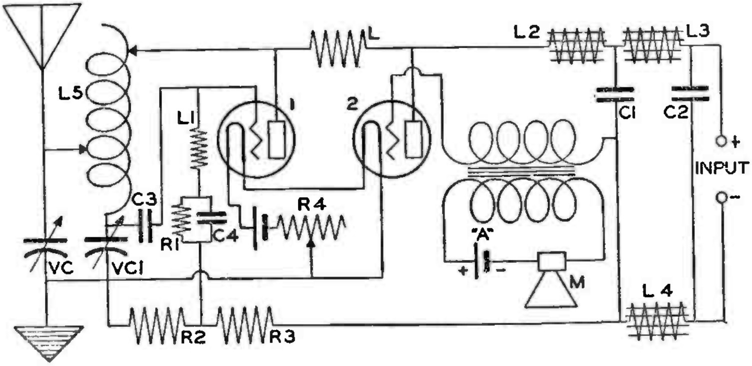


Fig. 85. A Standard Transmitting Circuit

The Radiophone Transmitter Circuit. Figure 85 is a standard diagram for a transmitter circuit. Tube *1* is the transmitting oscillating tube, and tube *2* is the modulating tube. The circuit *A* is the modulating circuit, which, through the audio amplifying transformer, causes voice frequency variations to the grid potential of tube *2*. The choke coils *L* and *L1*, and condensers *C1* and *C2*, are filters for eliminating the direct current ripple of the input circuit. The condensers *C3*, *C4* and *VC1*, together with the coils *L* and *L1* and resistance *R1* are used to produce the necessary feed back and operating characteristics. The resistances *R2* and *R3* serve to keep the grid of the modulator tube *2* negative, and cuts down the plate voltage from the input. The choke coils *L2*, *L3* and *L4* prevent the radio frequency currents from passing back into the input circuit. The coil *L5* and condenser *VC* are used to tune the antenna oscillating circuit. A resistance *R4* is used to vary the supply to the tube filaments, but in many cases every tube has its own control.

COMMERCIAL RADIOPHONE SERVICE. Every telephone and radio expert has long dreamed of a commercial radiophone service over wide areas which the commercial telephone could not reach. Early in January of 1927, actual commercial service was established between New York and London. Powerful stations operating on 5,000 meter wave lengths keep up two way conversations. A person in the United States may be connected to a person in England through the present New York and London radio centrals, using the ordinary commercial telephones. The two way communication is similar to land line telephony except that static will interfere at times. It will not be long before similar service will be maintained between other places, and this method of conversation will be world-wide.

THE RADIO COMPASS. Few marine disasters occur during clear weather. It is during fog, snow or mist that strandings and collisions occur, when surrounding shore lines and other objects are totally obscured. Locations cannot be determined unless the sun, stars, or familiar marks or lighthouses can be seen. *Radio-compass* stations scattered along the shores now enable mariners to obtain true locations regardless of the condition of the atmosphere. When a vessel requires a bearing, which it cannot otherwise obtain, it calls the nearest radio compass station. Radio waves are independent of fog and other weather conditions, and can be transmitted much farther over water than over land.

DIRECTIONAL RECEPTION. It is well known that loop antennas will receive better from the direction in which they point. The radio compass station is equipped with a large loop antenna which is rotatable. When the plane of the loop or coil is parallel to the direction from which the radio signal on the ship emanates, the *intensity* of the signal will be greatest. As the coil is rotated, the intensity of the signal diminishes until a minimum of sound is reached when the plane of the coil is at *right angles* to the signal direction. If the battery current is reduced so that the signal is heard faintly at only one point, an accurate reading may be made. The operator at the shore compass station takes this reading, and makes a line on a chart running out to sea from his own station. An operator at another station some miles farther along the coast is also making a simultaneous reading, and he passes his results on to the first operator who then makes another line on the chart to correspond with the second station reading. The point at which these two lines cross at sea is the *location* of the ship. See *A* in Figure 86. The first land station operator calls the ship and gives the correct location in latitude and longitude. This whole proceeding takes but a few minutes.

RADIO COMPASS BEACONS. This method of giving locations involves the use of two stations for each observation. As there are many thousands of miles of coast, the number of compass stations required for complete coverage would be large. A trained operator must be on duty at all times at each station. A new scheme, which may eventually replace the present method, is to establish at certain coastal points, automatic radio compass *beacon stations.* They will operate continuously and transmit characteristic sounds or combinations of dots and dashes on certain non-interfering wave lengths at regular intervals. The ship listens to two of these beacons and, knowing their calls and locations, may plot its location at sea.

Determining Ship Location with a Loop. A type of radio compass on board ship, which may be operated by anyone without any knowledge of the radio code, consists of a rotating loop, calibrated compass and scale, and an ordinary radio receiving set. The operator puts on the headphones and rotates the coil by means of a hand wheel, during which the characteristic signals of the shore radio beacon transmitters are heard with varying degrees of intensity. When the plane of the coil or loop is at right angles to the shore beacon station the signals should fade out. This position of silence is critical and, therefore, indicates with great accuracy, the position of the line of direction of the source. By means of *cross bearings* on another station, the position of the ship may be determined. See *B* in Figure 86. In order to procure absolutely accurate bearings, any number of readings may be made on several stations. The plotting of the ship's location on a chart by simple radio triangulation is as accurate as sight bearings on known landmarks along the shore. It is not necessary to make use of radio-compass automatic beacon stations along the coast. Signals from any radio station may be used, provided one knows the code and can decipher the call letters. Even this is not necessary, for if the radio set is an ordinary radiophone receiver, bearing readings can be taken on two or more of the radio broadcasting stations,

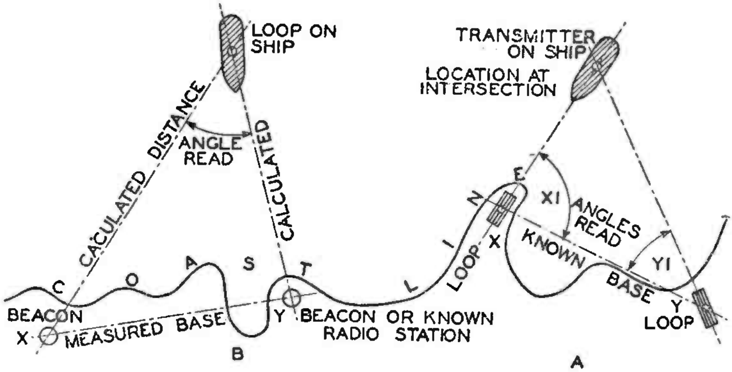


Fig. 86. Obtaining Ship Location by Radio Compass

the positions of which are known and indicated on the chart used to plot the ship's location.

SHIP COMPASS LOOP ANTENNA. The loop or coil antenna of a ship radio compass set is usually a frame mounted upon a vertical shaft. The shaft is supported in a ball bearing pedestal so that the coil may be easily rotated about its vertical axis. The lower end of the shaft is fitted with a large substantial handwheel and, at the extreme lower end there is a horizontal sighting wire which rotates in a horizontal plane over the surface of a compass card or degree scale. By means of this, the *angle* of the plane of the coil, which is overhead and outside of the building or pilot house. is clearly indicated with relation to the points of the compass. The loop frame is from four to six feet square and about fifteen inches wide. It is wound with about 12 turns of wire, usually the multi-conductor Litz.

ACCURACY NECESSARY IN RADIO BEARINGS. The importance of *accuracy* in preparing radio bearings for ship masters can not be too strongly emphasized. If a ship requests bearings it must be assumed that the master is in doubt as to his location, and the radio compass operator must well consider the safety of the passengers, crew and vessel. There are cases in which, due to night effect, nothing the operator can do will bring about a good minimum of signal. The operator then turns the coil slowly, and by listening carefully, he hears *two* different notes or tones to the incoming signal from the ship. The point of change should be noted in these tones, and the bearing of the ship can be closely located. Considerable experience is needed, however, before one may locate this tone change point. In all cases the coil must be turned very slowly as the minimum cannot always be easily located, and jerky movements may cause the operator to pass by the true bearing point.

DISTRESS SIGNALS. Perhaps the greatest thrill which a radio operator can experience comes with the sounding of the S. O. S. call. Listening mechanically to the usual calls and messages flying back and forth through space, the operator springs into action as his telephones suddenly ring with an S. O. S. If he is a ship operator he quickly glances at the chart, and if the stricken vessel is within a reasonable distance, he immediately notifies the navigating officer. The operator calls the ship that sent out the S. O. S., to say that aid is coming, and asks certain necessary questions. Within a few short hours, or less, the rescue is effected, and the world is given the news by radio. Since the first rescue at sea by radio distress calls, there have been many daring and simple rescues and aids made. Rarely does radio fail to effect aid unless storms or sudden sinking prevent. Ships seldom founder instantly, and the ship tracks of today nearly always have some vessel within a few hours steaming distance.

BROADCASTING STOPS WITH A DISTRESS CALL. All broadcasting stations are required by law to have an operator on duty who listens in for distress calls. As soon as an S. O. S. is heard, all nearby stations immediately stop broadcasting so as to leave the air clear.

THE S. O. S. CALL. The call, S. O. S., is not some chance group of letters, but has been carefully selected because of its characteristic combination when sounded in the air. *Dot, dot, dot; dash, dash, dash; dot, dot, dot* sounds the S. O. S. call, always easily recognizable. Formerly the call C. Q. D. was generally accepted as a distress call, but it lacked simplicity and the ability to attract instant attention, which is manifest in the S. O. S. combination.

MARINE WEATHER REPORTS BY RADIO. The mariner not only uses radio for locating his position, commercial ship to ship and ship to shore communication, distress calls, etc., but he keeps in touch with the weather by intercepting the daily weather broadcasts. The United States Weather Bureau issues daily forecasts of wind and weather for the Atlantic, Gulf, Caribbean and Pacific coastal areas, and for the Great Lakes, and storm and hurricane warnings whenever necessary. This information is disseminated from many coöperative naval, commercial and private radio stations. While many of these broadcasts are made by telephone, the majority are made by telegraph in code. The Weather Bureau has devised a special code so that very complete weather data can be broadcast with the use of a relatively small number of code signals. Vessels within a particular area may obtain the forecast for the next 24 hours by tuning in on a local radio weather schedule. When tropical hurricanes and other storms dangerous to navigation impend, all radio stations within range of the affected area immediately begin to broadcast the warnings as soon as issued by the Weather Bureau. Vessels at sea furnish daily reports of the weather for the section in which they happen to be, to the Weather Bureau by means of radio messages to coastal stations. These observations are used in connection with the usual land observations upon which the Weather Bureau bases its wind and weather forecasts.

WEATHER FORECASTS BY RADIOTELEPHONE. Over one hundred and sixty of the country's leading radio telephone broadcasting stations now include the daily *weather forecasts* in their programs. These forecasts are supplemented at times by special warnings of storms, cold waves, heavy snows, rains, frosts, forest fire weather, etc. The radio broadcasting of the weather forecasts undoubtedly saves farmers and navigators, as well as others, millions of dollars annually through warning of the coming weather changes. Aviation is now taking up radio reception of weather information, and the locations of cloudy and storm areas may be given to fliers while in the air. Danger areas may be flown around and additional safety is given to flying activities. The broadcasts of weather forecasts are made for each state in the United States, and are made from radio stations within the state. However, in a number of cases, powerful stations which are easily heard in a number of surrounding states, include in their weather schedules forecasts for other states and ocean areas. Anyone within the United States is within range of some station that gives out the forecast applicable to the residence of the listener.

AGRICULTURAL RADIO BROADCASTS. Farmers not only get the weather reports by radio, but the Department of Agriculture has an extensive system of cooperative radio broadcasting stations which include daily market and live-stock prices and reports. Recently there has been organized a series of short talks of interest to the farmers and their wives. These are prepared by experts, and are furnished to the stations to be read by the announcer on duty.

CODE TELEGRAPH SIGNALS. In radio-telegraphy some means of regulating the flow of current must be provided in the circuit. This is done with a sort of switch, easily operated, known as a *key*. Signals are transmitted by pressing the key (closing the circuit) to make *dots* and *dashes*. The dash is equal in length to three dots, and the dot is made by pressing the key for an instant. The key is a movable lever fitted into a supporting frame and carrying a make and break contact point. The hand key has an insulated knob that is held by the operator to make the code signs.

THE RELAY KEY. The standard hand key, however, will handle only small currents. When it is desired to use larger currents, as in nearly all radio stations, the hand key is used to operate a *relay key*. It is a magnetic device and consists of a lever which is actuated by an electromagnet operated by a small current passed through the hand telegraph key. Very large contacts on the lever control the heavy currents of the radio set, and it is possible to handle the current by several relays in parallel and operated by one hand key at some distant point. These types of keys, however, limit the speed at which signals may be transmitted.

THE HIGH SPEED RELAY. There are certain *high speed relay keys* for use with high speed or automatic transmitters. Such keys operate on the solenoid principle, in which a steady current in one coil works on a floating electromagnet. When a current is sent through the floating coil, it either is repelled or attracted to the permanent electromagnet, thus making or breaking the heavy circuit contacts. This principle gives a very rapid action, as the floating of the contact control coil and the lightness and smallness of its windings give very little resistance to its motion.

AUTOMATIC CODE TRANSMITTERS. The transmission of radio-telegraph signals by hand has certain limitations—the speed of the sender and the ability of the receiving operator. *Automatic transmitters* utilize a strip of paper tape that has been run through a perforating machine which punches the dots and dashes in the paper. This machine has a standard typewriter key board so that the operator need not be experienced in the code. The tape is then run through the transmitter which has a sliding or rolling contact that passes through the punched perforations of the tape so as to close an electric circuit. The length of contact is controlled by the amount of space provided by the punched dots and dashes and, therefore, the dots and dashes are transmitted as long and short contacts. As the tape may be used again, it is a simple matter to repeat the message if desired. Great speeds may be obtained with perfect accuracy.

AUTOMATIC CODE RECEIVERS. The speed of transmission is limited by the physical ability of the operator at the receiving station. An *automatic receiver* consists of a magnetically actuated pen or air blown spray of ink which touches a moving strip of paper tape, and registers the incoming dots and dashes. The operator then translates this received message at his leisure, and need not be skilled in ear reception of code signals.

PRODUCING DAMPED SIGNALS. In all transmissions employing a key for the production of radio telegraph signals the method used depends upon the type of oscillation circuit. With spark or damped wave transmissions, the key is placed in the primary battery circuit of the spark coil or the power line of the sending transformer. The key then controls the length of time that the current flows in the primary and, as a result, the duration of the sparks occurring in the spark gap.

PRODUCING CONTINUOUS WAVE SIGNALS. When using a continuous wave transmitter (undamped waves) the oscillation circuit is tuned and detuned by the key which is placed *across* a few turns of wire of the antenna inductance transformer. As undamped waves are very sharp when the receiving set is in resonance, it is easy to see that any slight *detuning* at the sending end will prevent the signals from being heard without retuning the receiver. When the key is pressed so that it short circuits only two or three turns of the antenna transformer the wave length sent out is changed slightly. It is possible, therefore, to make the necessary dots and dashes with the key. However, *two* waves are sent out, the signal wave, to which the receiver should be tuned, and the detuned *compensation* wave which is unreadable.

Continuous Wave Signal Modulation. A continuous wave is often modulated or broken up into wave trains by placing in the grid circuit a transformer, the primary of which has a key and *buzzer* in its circuit. The modulator on the oscillation tube is produced by the buzzer vibrations at an audible frequency. The note or frequency of the transmitted wave trains will have the tone of the buzzer. Such signals may be received by a crystal or any damped wave receiver that will not pick up straight continuous waves. In place of the buzzer, a motor driven circuit breaking device called a *chopper* is often used. This will break the continuous wave up into wave trains of a given number. The number of times per second will determine the frequency of the audible sound wave. The key then breaks this modulated wave into the necessary dot and dash groups of trains to form the code signals.

Radio Time Signals. *Time signals* are now sent out daily from a number of stations throughout the world and, in many instances, are rebroadcast by radiophone stations on lower wave lengths. Practically everyone is familiar with the time signals which for many years have been furnishing ships at sea with the correct time. The time signals begin at 11.55 a.m. and 9.55 p.m., eastern standard time. A dot is sent each second until the first 29 seconds have been sent, the next or 30th second is skipped, and the signals begin again with the 31st second. They continue until the 55th second has been given and the following 5 seconds are skipped. A second, third and fourth minute are signaled in precisely the same manner; as is the first half of the fifth minute. Beginning with the thirty-first second of the fifth minute, a tick is made for each succeeding second up to and including the fiftieth. At the end of the fiftieth second the signals cease for 10 seconds and exactly at 12 noon or 10.00 p.m., a long dash is given which announces the time. This system provides a very accurate method of checking chronometers and clocks.

Aircraft Radio. Aircraft communication involves new problems. No connection can be made to the ground and this necessary connection is furnished by the metal framework, stay wires or engine of the airship, utilized as a counterpoise. The antenna proper is usually a trailing wire that can be reeled in or out by the radio operator, and is prevented from fouling with the craft by a lead weight. While such antennas are below their grounds or counterpoise, their actions are not different from ordinary antennas. As it is possible to obatin but limited power for the operation of an aircraft transmitter, the range will not be very great. Since the motor speed fluctuates, the power generator may not be driven by the motor, but is often driven by a small wind propeller set in motion as the craft travels through the air. But while transmitting facilities are limited, receiving operations may be nearly as satisfactory as on the ground, except that noise interferes greatly.

SHORT WAVES. Phenomenal results have been obtained from the use of very *short wave* (high frequency) transmissions. In fact, one of the most important recent developments in radio is the ability to communicate over great distances during daylight using low power and very high frequencies. Since the field of experiment and research in high frequency transmission and reception has been so widely opened, it has been found, however, that the theories previously established for long wave propagation do not always hold good. Because of these peculiar characteristics of short wave transmission, it is impracticable, at this time, owing to lack of available data, to give sound definite rules and circuit arrangements which will always be satisfactory for reliable transmission and reception.

SHORT WAVE ADVANTAGES. Short wave receptions in the past few years have been such that world wide interest has been aroused and many daily intercontinental communications are now carried on. Arctic expeditions, tropic expeditions, U. S. Naval operations, etc., have provided notable short wave radio experiments. Compelled by the law, thousands of radio amateurs have used short waves so successfully that radio engineers the world over have begun to realize that short waves have more value than the long waves of the commercial corporations. The comparative values of low and high frequencies for use in radio work has been discussed in a previous chapter. However, this constant communication proves that short waves and low power will eventually provide reliable and consistent service at any time of the day or year.

SHORT WAVE DISADVANTAGES. High frequency transmission and reception have disadvantages due to the difficulty of controlling these extremely high radio frequencies. They have a tendency to leak over insulating surfaces and through all capacity or condenser surfaces, no matter how slight, and are very difficult to bring into resonance as the tuning is so sharp. The sets have very small inductance, capacity arrangements such as skin effect must be reduced to a minimum, and the natural frequency of the parts must be low. Body capacity, which affects so many radio receivers, must be eliminated as far as possible, as the effects of the operator's body near the apparatus of a short wave receiver is more marked than at higher wave lengths. This is because the inductances and capacities are small in value. To reduce body capacity, the parts should be placed at some distance back of the panel and dials. The presence of the operator's hand within a short distance of a high potential conductor or capacity will change that capacity, through induction, and completely detune the circuits as soon as the position of the hand is changed.

A SHORT WAVE DRY CELL TRANSMITTER. The demand for a transmitter to operate on low power without being bulky, dates back from the beginning of radio, and during recent months, the possibilities of such transmitters have greatly increased. Since the development of the dry cell tube for receiving radio signals, it has been found that such a tube will oscillate and act as a transmitting tube. As high frequency waves will travel much farther than low frequency with the use of much less power, it has been possible to construct transmitters using dry cell tubes, and nothing but dry cells for power purposes.

RADIATION FROM OSCILLATING RECEIVERS. Elsewhere is explained the *radiation* principles of regenerative receivers. Every radio set owner is familiar with this annoying type of interference from receivers. The radiation may be powerful enough to carry several miles to sensitive receivers, and in most cases, several city blocks. In fact, ship operators have reported that they have noticed this form of interference when over 25 miles at sea. When a receiver is radiating and sending out a signal, it is, in reality operating as a transmitter on a very small scale, and obtaining its power from the "A" and "B" batteries of the set. However, if the circuit arrangements are slightly modified and the "B" battery voltage increased it would be reasonable to expect it to cover much greater distances than it would when operating as a radiating receiver.

SHORT WAVE TELEGRAPH TRANSMITTER. It is remarkable that efficiencies as high as 2,000 miles per *watt* of input have been obtained by experienced radiotelegraph amateurs, and such a set, developed by the *Burgess Battery Laboratories*, is described in the following text. The sets, both transmitter and receiver, are operated by the type *299* dry cell tubes. About the tubes is built a very compact transmitter, assembled from two variable radio receiving condensers, two small inductances, and a small fixed condenser. These form a radio frequency generating circuit to which "A" and "B" battery current is fed from ordinary dry cell batteries. Radio frequency choke coils are connected in series with the "B" battery and the grid leak resistance to prevent losses of the generated radio frequency current through these circuits. A

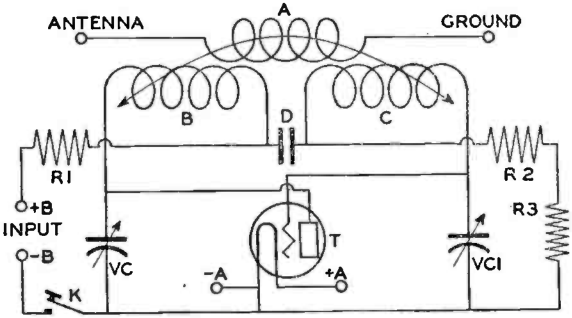


FIG. 87. A SHORT WAVE TELEGRAPH TRANSMITTER

third small inductance coil is placed between the first two, which couples the energy of the tube to the antenna circuit. This circuit is shown in Figure 87.

A SHORT WAVE ANTENNA. The oscillating radio frequency circuit is similar to standard transmitter circuits using tubes as a source of energy, but certain modifications have been made to bring it into a high state of efficiency and stability. It will be noted that the battery circuits are points having little or no radio frequency potential, so there are minimum losses at these points.

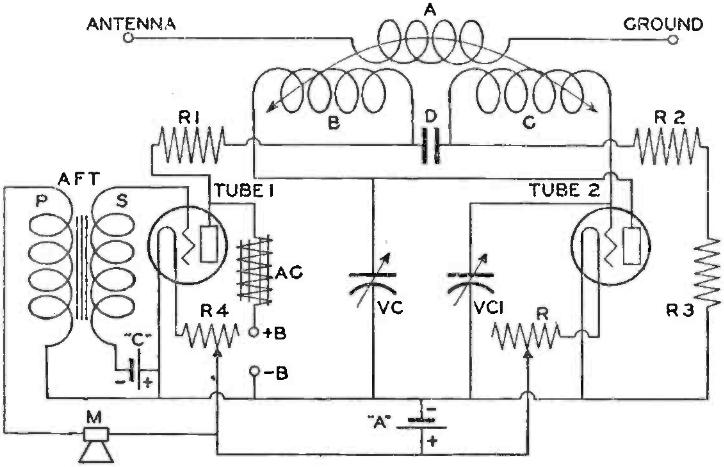


FIG. 88. A SHORT WAVE TELEPHONE TRANSMITTER

The antenna used is small with a low natural frequency, and should be a vertical wire about 30 feet long. In some cases a self-supporting vertical copper tube or rod is used as an antenna. If a counterpoise is used instead of a ground it should be of about the same dimensions as the antenna. A small series condenser may be used between the counterpoise or ground and the antenna inductance coil. A loop antenna may be used for short distance communications.

ARRANGEMENT OF THE TRANSMITTER. The coil *A*, shown in

Figure 87, of the Burgess transmitter, is the antenna coupling coil, and consists of about 6 turns of heavy bare copper wire wound self-supporting. The coils *B* and *C* are similarily made except that they have about 7 turns and are 3 inches in diameter. The fixed condenser *D* has a capacity of .001 microfarad. The radio frequency choke coils *R1* and *R2* have about 40 turns of No. 22 wire, wound basket-weave style on 7 arms having about a two inch diameter. Two variable receiving condensers of about 0.00025 microfarad capacity are used at *VC* and *VC1* for tuning the circuit. The grid leak resistance *R3* has about 5,000 ohms resistance. The telegraph key is shown at *K*. Sufficient "B" battery is used to supply from 90 to 140 volts to the plate.

SHORT WAVE TELEPHONE TRANSMITTER. The *Burgess* dry battery transmitter has a very pure direct current note which cannot be obtained from a generator source of "B" current, and this makes it possible to change the set so that telephone transmission may be obtained. The rewired set is shown in Figure 88. The set is the same as that described for telegraph operation except that an audio choke coil *AC* is added in the "B" battery circuit. An additional tube *1* is added and with its plate connected to the plate circuit of the transmitting tube. The grid is connected through the secondary *S* of an audiofrequency transformer *AFT*, which is used as a microphone transformer. This should have a high step up ratio. A small spark coil may be used to advantage. The "C" battery is used to give a negative bias to the modulating tube *1*. The primary of the transformer has a microphone or telephone transmitter connected in series with it and the "A" battery. Speaking into the microphone modulates the plate current of the oscillator tube *2*, as has been explained elsewhere.

OBTAINING MAXIMUM EMISSION. In operating either one of these transmitters an equal number of turns should be connected in both inductance coils *B* and *C* by means of a variable connector, and the two variable condensers set in approximately equal positions. When the tubes are lighted and the key closed, or the microphone spoken into, the set begins to oscillate, and resonance with the antenna circuit is obtained. At this point the *maximum* power is being emitted. A small meter, placed in series with the antenna, will indicate when the maximum energy is being radiated. Antenna meters are explained elsewhere. The above transmitter has been designed to operate on a wave band of approximately 40 meters, but to increase it to the amateur telephone band, its inductance and capacity values should be increased approximately three times.

A SHORT WAVE RECEIVER. The receiver to operate on a short wave length is shown in Figure 89. It is quite simple, using the *autodyne* principle. This method uses an oscillating detector which combines with the incoming signals in such a manner that audible signals can be obtained in the detector output circuit. The advantages of this short wave receiver are that its antenna coupling is adjustable, it has a minimum of body capacity, no choke coils are required, and the oscillation control of the detector causes a very slight wave length change. This circuit has also been designed by the Burgess Laboratories and has been highly successful in its operation.

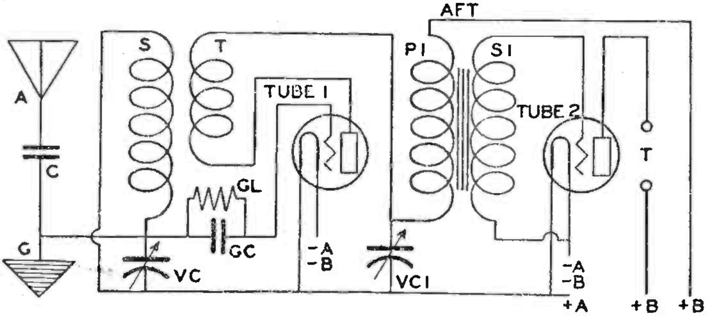


FIG. 89. A SHORT WAVE RECEIVER

THE RECEIVER CIRCUIT. In Figure 89 the antenna is connected to the circuit through a condenser C made from two small discs about one inch in diameter and set in two adjustable holders so that the dielectric distance between their two surfaces may be varied. This serves to couple the antenna to the secondary S

of the grid coil, and permits the use of various sizes of antennas. The antenna is aperiodic and eliminates the necessity of any antenna tuning device, and the small capacitive coupling equals that obtained by small coils which might otherwise be used. The coil *S* is the grid secondary with a diameter of about 3 inches, and wound with number 16 insulated wire in the usual basket-weave style. About 17 turns are used for 55 to 100 meters, and 8 turns for wave lengths of 25 to 55 meters. The coil *T* is the tickler primary coil of the same size as *S*, except that the number of turns should be 9½ and 5, respectively. The grid secondary coil with its proper primary are mounted together, using two or three small glass rods with a separation of an inch or less, determined by experiment, and made permanent to the glass rods with a few drops of collodion. The units are then interchangeable, depending upon the band of wave lengths to be covered.

VALUES OF THE PARTS. A standard grid condenser *GC* of .00025 microfarad capacity with a leak *GL* of about 6 megohms resistance is used in the grid circuit. The tuning condenser *VC* has a low capacity, just slightly more than .0001 microfarad, and consists of 3 rotating and 4 stationary plates. The regeneration control condenser *VC1* has a capacity of about .00025 microfarads. *1* is the detector tube and *2* the audio amplifier tube. The amplifying transformer *AFT* has a step-up ratio of about 1 to 6.

ADJUSTING THE RECEIVER. After the tube filaments are lighted the regeneration condenser *VC1* should be adjusted to bring the tube *1* into oscillation. The tuning condenser *VC* is then *slowly* adjusted until signals are heard. The lower the wave length, the sharper will be the tuning, and the final adjustment of the autodyne action may be most easily found by changing the setting of *VC* a few degrees one way or another. For very weak signals the setting of *VC1* should be kept very close to the point where oscillations cease. Care must be taken to prevent the close proximity of antenna systems or tuned circuits, as sufficient energy may be drawn out of the receiver to make the control poor, and prevent proper oscillation.

A SIMPLE LONG WAVE RECEIVER. A simple *long wave* receiver that will respond to various waves is shown in Figure 90. It uses a single honeycomb coil having proper inductance, and wired into the usual single circuit plan. For wave lengths around 600 meters a honeycomb coil of from 100 to 150 turns should be used; for 1,000 to 2,500 meters, a coil of from 300 to 400 turns; for 2,500 to 5,000 meters, a 750 turn coil, and for 5,000 to 15,000 meters, a coil of 1,500 turns. The variable condenser should be of considerable capacity, at least .001 microfarad.

BEAM TRANSMISSION SYSTEMS. By *concentrating* the radiation of waves sent from a radio station into one channel by means of suitable reflection, *beam transmission* is obtained. Instead of using long wave lengths, and sending them out in *all* directions, low wave lengths are used and *directed toward* the place for which they are intended. This radio beam is directed like a beam of light projected from a reflector. The system so intensifies the signals that they are received with greater strength and regularity. The first beam transmission on a commercial scale took place late in 1926 between Canada and England. Automatic transmitters and receivers enable the stations to handle over 250 words a minute.

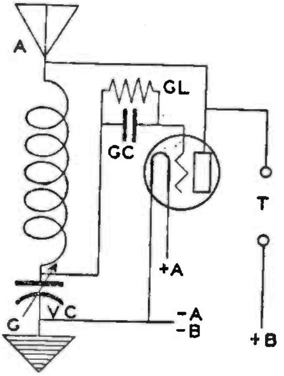


FIG. 90. A SIMPLE LONG WAVE RECEIVER

THE BEAM TRANSMITTER. The principles of beam transmission depend entirely upon the peculiar type of *reflecting* antenna used; otherwise the remaining apparatus is essentially the same as in any commercial radio-telegraph transmitting station. Similar systems of antennas and reflecting wires are used at both the sending and receiving stations. The antenna consists of a row of vertical wires parallel to another row of reflector wires. There are two vertical reflector wires to each vertical antenna wire. The two parallel rows are erected in a straight line at *right angles* to a line passing through both sending and receiving points. The reflector wires are placed on that side of the antenna wires which is farther-est from the receiving station. The signal strength is greatly increased and the *entire* wave is projected out in a narrow beam and is caught at the receiving station by a similar reflector which concentrates the energy upon the receiving antenna wires. Figure 23 shows such an antenna.

RADIO TELEPHOTOGRAPHY. The transmission of pictures, still and moving, now engages the attention of the scientist, and remarkable progress has been made within the past year. Photographs are transmitted across the seas, and before long, motion scenes of events as they happen in other lands, will be sent by radio the instant they occur. The transmission of black and white drawings or photographs with only two contrasting shades, is quite a simple undertaking. On the other hand *television* by radio, the event in motion, is an extremely complicated matter. To C. Francis Jenkins and Dr. Alexanderson in the United States, and Baird in Europe, is due credit for the progress made in this new radio development.

THE RADIO TRANSMISSION OF PICTURES. The transmission of photographs and pen and ink drawings of solid blacks and pure whites is simple and easily explained. The system used by Jenkins in 1927 will be described. It consists of a glass cylinder about which is wrapped the photographic negative of the drawing or picture. This negative is made by contact photography. The cylinder is revolved at a constant speed by an electric motor. Within the cylinder is a small but powerful electric light. Outside is a *light-sensitive* photo-electric cell that is arranged so as to

PLATE 5

Upper: WEAF's studio at 195 Broadway, New York—courtesy Foto Topics, New York. *Lower:* National Broadcasting Company's transmitter at Bellmore, Long Island. Thirty-two high power tubes in a row—courtesy National Broadcasting Company.

move along in front of the cylinder at the rate of one-fiftieth of an inch for one complete revolution of the cylinder. This cell has a very small aperture, and the light from within the glass cylinder passes through and affects the sensitivity and electrical conductivity of the cell. The electric light within the cylinder advances with the cell as to be always opposite the aperture.

LIGHT CHANGES CAUSE ELECTRICAL VARIATIONS. Now as the black and white portions of the film (the whites being transparent and the darks opaque) rotate before the aperture of the cell, the light passing through from within is *intermittently* cut on and off, and the conductivity of the cell is varied accordingly. But, as the cell is advancing along the cylinder from one end to the other at the rate of one-fiftieth of an inch to each revolution, and the diameter of the aperture is the same, it will be seen that the same transparent place on the negative film never passes before the cell opening more than once. As the light is broken up into impulses of various durations by the white lines on the negative, it causes corresponding variations in the electrical resistance of the cell. These resistance changes cause sharp fluctuations in the flow of current through the cell.

AMPLIFYING THE CURRENT VARIATIONS. In order to strengthen this weak current so that it will operate the relays of the radio transmitting station, it must be passed through a number of alternating current transformers and amplifying electron tubes. A *pulsating* current through the cell is obtained by breaking up the light waves by means of a chopper wheel rotating in front of the electric light within the cylinder. This pulsating current can be transformed into alternating current to pass through any number of amplifying units necessary. The signals sent out by the radio station are similar to code signals except that they are a meaningless mixture of buzzes, and may be confusing to operators until they know what the signals represent.

RECEIVING THE PICTURE BY RADIO. These pictures may be received over any type of radio set capable of tuning to the wave length used and, after being suitably amplified, are passed to the *picture reproducer*. A sheet of white paper is wrapped about a rotating cylinder of the same size as the one on the transmitter. Both cylinders operate at the same speed and, as the radio impulses come in, a magnetic pen traces lines on the rotating paper to correspond with the transparent whites of the negative. The pen advances at the same rate as the electric cell before the rotating receiving cylinder and the picture is reproduced by a large number of fine lines marked in their proper positions and drawn in a very flat *spiral* around the paper on the cylinder. If the speeds of the two machines vary, the ink marks will not be properly located and the picture will be greatly distorted or entirely meaningless.

SYNCHRONIZING THE SENDER AND RECEIVER. The speed of both transmitter and receiver should be constant, but as this is almost mechanically impossible, it has been found necessary to synchronize the cylinders at each revolution. A special synchronizing signal is transmitted at the end of each revolution of the sending machine so as to *check* and hold the receiving cylinder from revolving until the end of this signal comes. In this way each new revolution begins in synchronism with that of the transmitter. The hesitation is very slight, but sufficient to keep any number of receiving machines in perfect step with the transmitting machine at the radio station.

RADIO TRANSMISSION OF PHOTOGRAPHS. A photograph has more than two contrasting *shades* of white and black. It is made up of fine shading and variations in intensity of many tones. It is comparatively simple to send these shades as variations in current strength over a wire, but in radio it is difficult to obtain perfect results. In radio the signal strength may change from time to time due to causes over which the operator has no control, and these changes will affect the receiving machine in the same manner as a change in film intensity. However, such satisfactory results have been obtained from experimental work that it is possible to transmit very good photographs. At the receiving end the process is reversed, the incoming signal causing current variations which vary the intensity of a *light* which is focused upon a photographic film wrapped around a rotating cylinder. This film becomes covered with fine lines, on a flat spiral, of varying intensity or density, which, when developed in the usual manner, makes up the complete picture.

RADIO TELEVISION. *Television* apparatus is that which is capable of transmitting *instantaneously* to a distance, images of views, or objects in motion, by telegraphy or radio. An image of the object to be transmitted is caused to traverse a light-sensitive cell, and modulates the electric current. This controls the radio carrier wave which in turn, affects a source of light traversing a screen in exact synchronism with the transmitter. This receiving process is carried out at a great speed, and the image is built up on the screen almost instantaneously by small portions which are *retained* on the eye in a way similar to the changes in motion picture projection. Television by radio is subject to distortion, interference and static, the same as any radio signal reception or transmission. This produces a serious form of trouble which will be difficult to overcome.

THE RADIO PATENT SITUATION. Familiarity with *patent procedure* will be of benefit to individuals who believe they have produced a patentable invention. A general knowledge of the patent laws is not difficult to acquire, yet, unfortunately, many do not know the fundamental principles of determining whether or not a device may be patentable, or whether one infringes another's rights. No doubt many radio experimenters have discovered valuable constructions and methods, but failed to secure the protection they were entitled to under the patent laws. Often those who discover improvements injure themselves by not obtaining patents, besides depriving the public of the benefits.

REQUIREMENTS FOR OBTAINING A PATENT. The rules of the Patent Office, as quoted below, state in brief, the conditions under which a patent may be obtained:

> "A patent may be obtained by any person who has invented or discovered any new or useful art, machine, manufacture, or composition of matter, or any new and useful improvement thereof, not known or used by others in this country or described in any printed publication in this or any foreign country before his invention or discovery thereof, or more than two years prior to his application, and not patented in a country foreign to the

> United States, or an application filed by him or his legal representatives or assigns more than twelve months before his application and not in public use or on sale in the United States for more than two years prior to his application, unless the same is proved to have been abandoned, upon payment of the fees required by law and other due proceedings had."

An invention is usually some new article, combination, machine, or an improvement on an existing device. As such it may be patented. The skill or superior workmanship shown in making an article or some general principle upon which a device operates, cannot be patented. However, a scheme for utilizing certain things and principles in order to carry out the general principle might be patented. The device or method in all cases must be *novel* and, in a general way, not known *prior* to the application for a patent. The patent might be upset by someone who can claim and prove prior conception, publication, public use or sale, even if steps were not taken for prior application for a patent.

THE VALUE OF A PATENT. The granting of a patent does not imply that the inventor may proceed unrestrained in the sale for profit of the patented device, and that the protection of the Government will be given. There may be earlier similar inventions and the matter of infringement of earlier patents may be brought up. The issuing of a patent indicates that the device is presumably something new in its field, but that is as far as the Government goes. The rest depends upon the individuals and the courts. A patent never permits the holder to infringe the rights of someone else holding a similar patent. And a patent gives no protection against infringement of some earlier patent. It is of value for *offensive* purposes only and, as such, will prevent copying of the invention by others. Its *defensive* value is slight and does not in any way justify the copying of some prior invention. A patent gives to the inventor a monopoly on his invention for a period of seventeen years, and provides him with an instrument of offensive value for court action against infringers.

THE RADIO PATENT ATTORNEY. The first step in securing a patent is to consult a reliable *patent attorney*. In many cases the attorney may know little about radio as a science, but he will listen to the description of the method or apparatus and encourage the inventor to take out a patent. Consequently, in selecting an attorney, it is necessary to use caution, as a valuable and remunerative patent can be carelessly obtained, and the inventor will discover too late that his patent may not be valid, if there is a court decision growing out of a suit to prevent infringement. Many patent attorneys are in the business to obtain as many patents as possible, regardless of whether or not they are familiar with the subject of radio. Others are capable and enjoy good reputations after long years of experience. The latter class of patent attorney should always be selected and, with the radio patent situation now existing, it is quite imperative to do so.

PRIORITY RIGHTS. As soon as a patent application has been officially filed with the Unites States Patent Office—not merely placed in the hands of the patent attorney—it establishes a prior claim in case another patent application for a similar invention is filed by someone else. If an inventor has not taken steps to protect the invention and secure a patent, the right to it may be lost by abandonment. The fact must be shown that the invention was diligently developed from the time of its inception, and the patent law permits the inventor to have two years in which to apply for a patent. It is important that anyone working on a radio invention keep a record of dates and of the progress of the experiments. A public disclosure of the invention should not be made until the application is filed with the Patent Office. However, there is such a thing as carrying secrecy too far as it may happen that two or more persons will think of an idea at the same time. Do not fail, then, to tell at least two persons who can be trusted, what the invention is, and how it operates. Put in writing the facts which have been told them, and have them sign and date the statement. Keep this safe so that if a question should arise at any time as to who was the first to conceive the idea, there will be evidence to prove the claims. In this way the inventor is assured of proper claims because of priority rights.

THE PRELIMINARY SEARCH AS TO PATENTABILITY. After the idea has been conceived and recorded as *proof of conception* it should then be developed for its practicability. This latter test will indicate whether it is worth patenting and, if so, a working model or practical mechanical drawing must be furnished the patent attorney for his use in the preparation of the application. The attorney will now undertake a *preliminary search* of the files of the Patent Office. He examines all patents of the same classification as that of the invention and, if none of them show the same or a similar device, he will prepare the application for filing in the Patent Office. The fee charged for this preliminary search should vary from ten to twenty dollars, according to the complexity of the invention and extent of field of search.

PREPARING THE APPLICATION. A skillful and experienced attorney can often prepare the *application* with sufficient scope so that the value and field of usefulness of the patent will be greatly increased. The preparation of the patent application consists of the drawing up of specifications and claims which set forth in simple and concise language the purposes of the invention, and what may be accomplished by its use. Clear and simple drawings are prepared so that anyone versed in the particular art should be able to understand and duplicate the device. When the patent attorney files this application at the Patent Office a fee of twenty dollars is required. If the application is rejected the fee is not returned.

PATENT OFFICE PROCEDURE. Applications for radio patents have almost overwhelmed the Patent Office and, in spite of the fact that the force of examiners has been increased greatly, the number of applications continues to gain ground. The Patent Office does not rush an application through but, in each case, conducts a long and diligent search before it arrives at a definite decision. Usually the original application is rejected on the ground that it does not fully distinguish the new invention from devices or methods which are already known. Upon rejection of an application by the Patent Office, *amendments* are ordinarily made to cover the objections raised. The claims are frequently revised to describe the invention more clearly. The importance of proper claims in a patent application cannot be too strongly emphasized, nor can the necessity for *extended prosecution* of the amended application. A number of successive rejections and amendments may be necessary before the patent is finally granted.

ALLOWING THE APPLICATION. When the Patent Office passes on the application and notice of its *allowance* is given, an additional fee of twenty dollars is required which must be paid within *six months* after date of notice, or the application will *lapse*. When this fee is paid the patent is granted, and is effective for *seventeen years* from the date of issuance. In some cases the inventor permits most of the six months payment period to pass before claiming the patent by paying the last fee, as this extends the life of the patent by that length of time. This period is of some value if the inventor is not prepared to exploit the invention as soon as the patent is allowed. The Patent Office then publishes a number of copies of the patent which are sold to anyone interested at a nominal sum of ten cents each.

THE PATENT ATTORNEY'S SERVICES. The total charges are met by the patent attorney who is reimbursed by the inventor plus a fee for his services in the preparation of the application and drawings. This total fee should be about $125 to $200. However, there are times when this fee will not apply as the case may be involved and require much time in preparing and presenting all angles before the patent examiners. Expenses are increased by appeals and interferences with other inventors to determine priority. These are special cases, however, and the fees are not set by any arbitrary methods. The patent attorney nearly always demands a deposit when the case is given him, while others call for the full payment to guarantee the costs and fees, and still others expect no payment unless they obtain a patent. There are a good many patent attorneys who make the claim that they will obtain a patent and sell or see that it is financed. Few actually make good their claims, although for these services additional fees are charged. Before entering into any such contract with the attorney or broker, it will be wise to consider the proposal with care.

LIFE OF A PATENT. The *life* of a patent is seventeen years.

After its expiration it becomes public property and the device may be manufactured and sold by anyone without special license. But care should be taken to ascertain whether or not any patents for improvements on the original device have been granted to others since the issuance of the first patent.

ASSIGNMENTS AND LICENSES. Patents may be *assigned* to a person or manufacturer outright, or the inventor may become a partner in the ownership. A license to manufacture may be granted without actual assignment of rights in the patent. Anyone is liable for infringement of a patent if he *makes*, *uses* or *sells* an article coming within the scope of any claim of a patent. This applies irrespective of any later patents, or licenses under such patent.

PATENT MARKING. Manufacture and sale may commence with the filing of the application, and many devices are marketed with the inscription "Patent Applied For" or "Patent Pending." When the patent has been issued the patented device should be marked with the date and patent number.

THE COPYING OF PATENTED DEVICES. A patented device *cannot* be made by an individual (or firm) for his own use or sale, directly or indirectly. Such an action constitutes an infringement. In such cases inventors may use their patents as offensive weapons in prosecution of such infringements in the courts. However, in cases where patented articles are copied for private use, the holders of the patents seldom take action to prevent the practice because of the considerable expense and time involved.

RADIO PATENT INFRINGEMENTS. There is an uncertainty as to the validity of many valuable patents and therefore complex conditions bring about a maze of patent litigation. The prospective inventor of radio methods and devices must bear in mind that in nearly all patent cases, he is likely to infringe upon a previous patent and thereby violate someone else's rights under the law. The radio art is so tied up that a new invention will, in all probability, immediately be found to infringe existing earlier patents in some way. But there is always the possibility of an entirely new invention of great importance to the radio world, and the best legal advice possible to the inventor is recommended.

FEW SUCCESSFUL RADIO PATENTS. Before the inventor attempts to seek a patent on a new idea, it will be well to question it from the angles which might be considered in case a purchaser desired to market the invention. Without satisfactory answers to these queries it will be better not to patent. It should be considered whether the invention will appeal to a large number of radio users and manufacturers. Will these users pay a reasonable price for it in the market so as to yield *actual* profits to *all* concerned? Is the service a new one, economical, efficient, satisfactory and lasting? Will the device be simple in operation or will it require the services of an expert to keep it in perfect operation? And last, but not least, can it be made cheaply in quantities, and sold without excessive advertising and other costly organization? In other words, will the device sell itself because of an obvious demand for it?

RESEARCH LABORATORY INVENTORS. The small inventor can hardly expect to have any influence on the radio situation unless he has an invention that is revolutionary. The control of the radio situation by big corporations is such that independent manufacture is more or less hopeless. These large corporations have developed radio and they spend millions in research work with corps of trained inventors on their investigative staffs. As soon as an improvement is made or a new device deemed satisfactory, the corporations' patent departments attend to the securing of patents. The inventor has little to do with the obtaining of the patent and holds no interest in the profits if the patent becomes the sole property of the corporation. However, there are cases where the inventor has just claims to the patent although it was developed while he was in the employ of someone else. As the development of radio is now in a course of refinement rather than in the stage of basic inventions, the small inventor, working under the handicaps of a lack of research facilities, is not in a situation comparable to the constituent members of the large corporation groups and their great research laboratories. Consequently, in all but exceptional cases, the patenting of useless and meaningless radio inventions mean little to the science of radio as a whole.

CHAPTER XII

CAUSES AND PREVENTION OF RADIO INTERFERENCE

RADIO INTERFERENCE. *Interference* is an important problem both in theory and practice, since it has now become so widespread and critical in its effects. In the early days of wireless the simple detectors and circuits which were in use responded to static and local electrical fields, and a state of resonance was never critical in tuning. As the number of wireless stations increased, interference became marked and regulations were passed to prevent as much of it as possible. Today interference has reached such a stage that more legislation has been required (1927) providing for a radio committee appointed by the President to allot and enforce noninterfering wave lengths. With radio regulation at its best, not all interferences can be eliminated, but close study and the application of certain remedies will do much to prevent them.

SOURCES OF RADIO INTERFERENCE. It should not be inferred that *all* interference comes from radio stations close to one another in transmitting frequencies, though such stations do cause an interference condition that has become serious. Interference from many other sources is common. Taken in the order of importance, they are: broadcasting stations with interfering wave lengths; commercial and naval spark telegraph stations using damped waves; harmonics from arc and other relatively nearby stations; amateur spark and CW stations; regenerative receivers which are not neutralized to prevent radiation; X-ray and violet-ray electrical machines; electric cars; electric elevators; telegraph transmitters; leaking power lines; electric power line hum; poorly insulated electric lines; telephone and other electric communication or signalling systems; sparking electric motors and other machines; vacuum cleaners; electric light and other switches; some automobile ignition systems; tube battery chargers (electron emission); and practically all instruments and machines using electricity and producing frictional electricity. Much interference is due to inherent faults of the receiver itself. Atmospheric electrical disturbances which produce the greatest static interferences known are discussed in another chapter. While it is common practice to refer to all foreign interfering noises as *static,* there is really but one static condition, and that is the kind produced by atmospheric electricity. The types enumerated above may be better classed as *man-made* static.

STATIC. The classification of static now seems to embrace *all* kinds of electric oscillations and waves set up when an electric spark is produced. Man-made static can often be located and remedied, but the natural static of the atmosphere cannot be eliminated. *Leaking insulators* on high-voltage power lines, especially during wet weather, produce interference. *Brush discharges* over the wet insulators will cause loud hissing sounds in nearby radio receivers. Electric light circuits sometimes give off an annoying *hum* and switching off the lights produces sparks which cause loud clicks in the radio set. Street car and some automobile ignition systems may produce bad interference. The street car is especially bothersome if the equipment is in a run down condition, or when the rails and trolley wires are covered with ice and sleet in winter. Telephone and door bells often cause annoyance.

INTERNAL NOISES. Much interference is blamed on outside sources when the radio receiver is faulty. However, if the interfering noises do not persist when the antenna and ground are disconnected, it is quite certain that the noises are produced elsewhere.

INTERFERENCE ELIMINATION. It is possible to provide filters, chokes, shields, etc., if the *sources* of disturbing electrical influences can be located. The trouble lies in locating the source, and in convincing the managements of the organizations controlling the apparatus that remedial action should be taken.

THE NOISE LEVEL. Much radio interference is inevitable and must be regarded as a part of the inherent limitations of radio reception. This is especially true of atmospheric electric disturbances. The *limit* of radio reception is fixed not only by the broadcasting distance and power of the transmitting station, but by electrical disturbances which drown out signals as soon as their intensity falls below a certain degree. This *noise level* or background is the reason why local broadcast reception is invariably far superior to distant reception. Only under exceptional conditions will the latter approach perfection.

EXPLORING FOR INTERFERENCE TROUBLES. In locating and measuring local disturbances, the use of an *exploring loop* and a portable but sensitive receiving set may prove essential. The person making the explorations must be able to discriminate between the effects produced by various sources, such as those having a surge or change in potential, and those having a continuous cycle due to induction.

SPARK STATION INTERFERENCE. The interference resulting from the use of damped wave transmitters presents a serious problem. It has been decided, however, that such interference is not inevitable, as improvements may be made to reduce the decrement and the interference resulting from it. Reduction of the number of damped wave transmitters, and gradual improvement in the emission of the few remaining is gradually eliminating this source of interference. The installation and use of spark sets is almost inevitable. But since many of the stations are remote from population centers, they give little trouble. The difficulty lies, not with the few remaining efficient spark stations in this country, but with foreign ships equipped with spark transmitters, which operate as they move along our coasts. Fortunately, radio regulations prevent their transmitting while in American ports; otherwise the interference from this source would be extremely serious in coastal vicinities.

ARC STATION INTERFERENCE. Arc transmitting sets are very productive of interference by reason of the two different wave emissions employed (signal and compensation waves), and their many *harmonics*. The elimination of harmonics and a careful adjustment of frequency to keep the spacing waves sharply tuned, may remove such sources of interference. Total elimination of the two waves will automatically do away with this interference. These transmission interferences would have no effect on radio telephone reception if it were not for the harmonics which are set up and broadcast with reduced energy.

HARMONIC INTERFERENCE. Interference from *harmonics* results from the emission of radio waves on several frequencies *higher* than the fundamental frequency, but with much less intensity. Nearly all transmitters are subject to this fault if oscillating directly into the antenna circuit. The trouble may be practically overcome by the use of oscillator-power amplifier systems; and the situation is improved when loose coupling between the oscillating and the radiating systems is employed. It is also suggested that, as a station is licensed to use only *one* wave length, stations radiating harmonics are actually radiating appreciable energy on frequencies other than that for which they are licensed, and are violators of the law.

HARMONIC FREQUENCIES. The fundamental frequency of a transmitting circuit is the lowest frequency at which the radiated current attains its maximum value. In the same circuit there are *other* frequencies of lesser resonance and which are known as *harmonic frequencies*, and while the maximum current is being radiated on its fundamental frequency, smaller amounts of energy are radiated at the harmonic frequencies. These radio frequencies are 3, 5, 7, etc., times the fundamental frequency. Or, to state it another way, they are 1/3, 1/5, 1/7, etc., of the fundamental wave length. For instance: A station transmitting on 1050 meters wave length will emit harmonics of 350, 210 and 150 meters, which are known as the first, second and third harmonics, respectively. The first two harmonics seriously interfere with nearby radio telephone reception as they are within the broadcast band. But since stations can be equipped to suppress harmonics, it is only a matter of time until this type of interference will be done away with.

INTERFERENCE DUE TO FREQUENCY CHANGES. Variations from the authorized wave length or frequency is a common occurrence, and a cause of interference with other operating stations. These variations may come about because a station shifts to an unauthorized frequency, owing to transmitting trouble on the assigned frequency. In such cases the offending station causes interference to others, although its own transmitting efficiency may be improved. Accidental variations are infrequent as the wave meter and frequency control crystal systems soon show the operator that a variation has taken place, and the trouble is immediately remedied.

Beat Interference. A serious type of interference is caused when two stations of nearly identical frequencies operate at the same time. The two stations cannot be tuned out separately, and the two frequencies produce a *beat* note having a frequency equal to the difference between the frequencies of the two stations. This produces a swelling, throbbing, hissing or whistling sound, due to the frequency of the beat, which prevents clear reception of either station. The harmonic from one station may interfere with the fundamental wave of another station and produce beats in the receiver. Thus we not only have the possibility of obtaining interfering beat notes from true waves, but from harmonics as well. This interference between wave lengths is known as *heterodyning.*

High Power Station Interference. Commercial stations often cause unnecessary interference by using greater power than is needed, and by much useless and careless testing. The higher power produces harmonics having greater amplitude, and prolonged testing or tuning augments the useless dissemination of audible interfering signals. It is well known that nearly all commercial stations use *more power* than is necessary, because they desire to maintain communication even under unfavorable conditions, and to get every signal through clearly without repetition. Much testing can be conducted without radiating much energy as it is possible to secure a proportional maximum of energy at a reduced power. Testing should also be confined to certain hours of the day when few listeners are using radio sets.

Super Power and Interference. From time to time broadcasting stations increase their output to appreciably higher power. Such stations have been called *super-power stations.* Their installation gives rise to the fear that there will be an appreciable increase in interference from this source. But the radio public has much to gain from such power increases, and this warrants the construction of super-power stations. It would be unwise to limit the increase of power for radiophone broadcasting, but *suitable variations* of power should be made with the seasons, the hours of the day, and changing weather conditions which tend to affect reception ranges. It does seem essential, however, to locate these stations at some point distant from the centers of population to prevent interference to all but relatively few listeners. This type of interference is caused by the intensity of the signals, as the great amplitude forces out beyond the assigned wave band, and gives the wave the appearance of a very high decrement.

INTERFERENCE FROM REGENERATIVE RECEIVERS. Regenerative receivers belonging to neighbors usually cause considerable annoyance. In regenerative radio receivers a controllable coupling is provided between the output and input circuits of the amplifying or detector tubes, so that some of the amplified voltage may be fed back into the tubes and reamplified. These sets, when the feedback coupling is poorly adjusted, will generate continuous radio frequency oscillations which cause weak radio waves to be sent out from the receiving antenna in much the same manner as from a broadcasting station. For this reason, the use of simple regenerative receivers should be discontinued. The operation of the receiver circuit too near an unstable condition will frequently distort the detector action and give rise to radiations. Such receivers have been termed *bloopers,* due to their characteristic whine. While it is commonly thought that such receivers give rise to interference only when nearby, it must be remembered that sensitive receivers can detect the radiations many miles away. In fact, ship station operators thirty miles at sea have reported consistent interference from bloopers. The problem is to *eradicate* the interference from this type of receiver *without* injuring the reputation of the receiving apparatus and causing a radical change in circuit design. To bring about such a change would eliminate the desirable qualities of the regenerative circuit.

RADIATING CIRCUIT CONTROL. The worst offender is the simple single circuit type of regenerative receiver as shown in Figure 65.

When the circuit consists of three separate windings (three circuit tuner) it does not radiate quite as much energy as the single circuit type. See Figure 66. The former type has the oscillating tube connected directly into the antenna, while the three circuit tuner couples through an inductance. Thus the circuit shown in Figure 66 will not radiate as much as that shown in Figure 65. When a radio frequency amplifier is used ahead of the detector and regenerative circuit, there will be a less radiation. In such cases a small degree of radiation may exist even if regeneration is not used. Such a circuit is shown in Figures 70 and 71. The surest method is to *prevent all* radiation by *neutralizing* the tube capacities. As we have previously seen, regeneration is accomplished by feeding back a part of the energy from the plate circuit of a vacuum tube into the grid circuit. We must be able to determine when *sufficient* energy is fed back without bringing the tube into a state of oscillation. The various methods of control whereby a tube reaches its maximum of regeneration without breaking into oscillation are given in the following text. If regeneration is properly controlled there should be little or no interference from radiation and no necessity to replace regenerative receivers with some other type of circuit. The good qualities of regeneration may be adhered to by providing better regeneration control.

Capacity Control of Radiation. The best method of eliminating receiver oscillation is the *capacity neutralization* system, by means of which the variations in plate potential, which are caused by variations in grid charge, do not *react* upon the grid circuit, and cause feed-back in the radio frequency amplifier. Any subsequent feed back at the detector will not cause oscillation of the circuit, and its interfering radiations. This is shown in Figures 71, 72 and 73. Considering what causes the oscillation of the receiver, it is quite easy to see that it can be eliminated by connecting a small *capacity* in such a manner that the current passed through it will affect the grid to an extent equal and opposite to the effect of the current flowing through the grid-plate capacity. This may be accomplished by the various connections shown in Figure 91. In every case the current flowing through the neutralizing condenser *NC* to the filament does away with the effect of current flowing through the grid-plate capacity, provided the neutralizing condenser is adjusted to the correct capacity. There is no set position for the neutralizing condenser, although the connections shown in Figures 71, 72, 73 and 91, are standard practice.

THE NEUTRALIZING CONDENSER CONTROL FOR RADIATION. The condenser used is a *midget* type of low capacity. It should be adjusted until the signals either disappear entirely, or are at a decided minimum. It will be necessary to *retune* the circuit after this setting has been obtained, but with the *first* radio frequency tube turned out. When correctly set, the sound should be at a minimum with the best of tuning. After setting the midget condenser to this neutralizing position, the radio frequency tube should be turned on, and no oscillating squeals should be noted. A set properly neutralized cannot annoy radio listeners by radiating these distracting squeals and whistles.

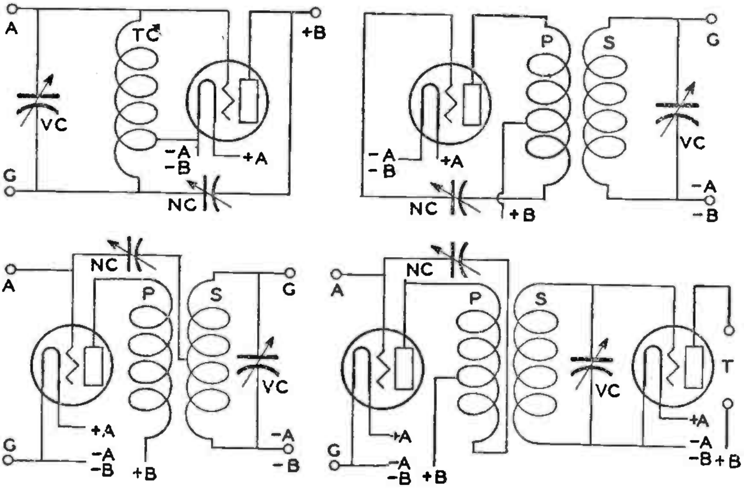


FIG. 91. METHODS OF PREVENTING RADIATION INTERFERENCE

INTERFERENCE BY LOCAL STATIONS. The concentration of the broadcasting stations in large centers and the increase to greater power bring about local interferences. With some types of receivers it is impossible to eliminate local interferences, and it is wise to use the local broadcasting when it is on the air. After all, local reception is the best, as it comes in with sufficient strength to produce the clear volume necessary for good broadcast reception. However those who have efficient radio receivers naturally desire to listen to distant programs, it is no more than fair that steps should be taken to permit them to cut through the barrage of local stations. Very often the remedy of certain inherent faults in the receiver will permit sharper tuning of the locals.

INTERNAL PICK UP IN A RECEIVER. In many cases the interference from a local station is caused by a direct *pick-up* in the coils and parts of the radio receiver itself, and the natural tuning resonance of the set will be of little avail. This usually occurs when the receiver is in close proximity to the broadcasting station and its field strength is so powerful as to induce unwanted currents in the coils and wiring of the receiver. This may be discovered by disconnecting the antenna and ground wires, and listening carefully to see if it is still possible to hear the local station. The only practicable method of preventing induction is to *shield* the parts of the receiver, and to use closed field coils. To shield the receiving set, line the inside of the cabinet with thin sheet metal or foil. The shield is soldered and connected and grounded to the negative "A" battery leads. The grounded shield excludes all external electrical currents and fields. This will not prevent interference due to inherent poor tuning qualities. Shielding methods are discussed further in another chapter.

PREVENTING LOCAL INTERFERENCE. After internal induction interferences have been eliminated, it is possible to further provide against local station interference if the set is fairly selective. When the signals induced in the antenna system are strong there is a *forced decrement* that places the signal over a rather wide band of wave lengths, thus excluding all other signals of neighboring frequencies. Very few receivers have a selectivity sharp enough to eliminate these side wave bands entirely, although when the set is used some miles distant from the transmitter, it may be perfectly satisfactory. If we can *decrease* the strength of the undesired local signal and reduce its apparent decrement, we will be able to tune around it as sharply as if it were coming from a distance of many miles.

WAVE TRAPS. For this purpose the most common device is the *wave trap.* As a rule a wave trap consists of a simple coil and a variable condenser connected in the antenna circuit. It is tuned *against* the frequency of the interfering local signal so as to present the highest possible impedance to the flow of current at that frequency. This makes it difficult for the current of the local station to pass through the coil and condenser unit, and greatly weakens that portion which does find its way into the receiver. To other frequencies the adjustment of the wave trap presents little impedance, and they pass easily into the receiver when proper adjustments are made. The efficiency at which a wave trap operates depends upon its ability to present a sudden high impedance to the passage of the unwanted signal, and a very low impedance on either side of that adjustment. We have seen elsewhere that when a circuit is at resonance it presents no impedance to the flow of the radio frequency current, and that is the principle upon which the wave trap works.

USING THE WAVE TRAP. Figure 92 shows several methods of using wave traps. At *A* is shown a simple but effective trap that consists of a coil *L* and a shunting condenser *VC*, both made up as a unit, and connected in series with the antenna just ahead of the receiving set. *P* and *S* are the primary and secondary coils, respectively, of the aperiodic antenna coupling of the radio set. At *B* a slightly different type of wave trap is shown. The trap is coupled to the antenna circuit inductively through an aperiodic circuit. The coil *P* consists of but few turns of wire, but the coil *S* should be of the same size and value as the coil *S1* of the antenna circuit of the set. Somewhat sharper tuning will be obtained with this arrangement than with that shown at *A*. No set rules can be given for the use of a wave trap as it must be made to fit in with the particular type of receiving set used. Any aperiodic antenna system, such as is used on the three circuit regenerative tuner, the super-heterodyne, the neutrodyne, and similar circuits, may be greatly aided by the use of a suitable wave trap. A properly designed trap should not affect the tuning of the set to any great degree except on waves to which the trap is not tuned. In most cases the values of the windings and condensers should nearly equal those used in the antenna tuning circuit of the receiving set.

Natural Interferences. In addition to the kinds of interference outlined above, produced by other radio stations and associated phenomena, there are natural electrical disturbances occurring in the atmosphere, and which cause serious interferences with perfect radio reception. These disturbances set up electromagnetic waves which strike the antenna or parts of the receiver. While there does not seem to be any real remedy for these natural types of interference, static, fading, and wave interference, they are discussed further in another chapter.

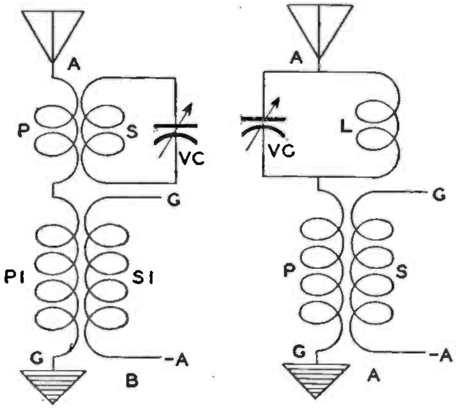


Fig. 92. Types of Wave Traps

Static Elimination. The most satisfactory results in static elimination have been obtained through the use of various kinds of directional receiving antennas, as well as experimental underground antennas. The latter, however, have not reached the stage of practicability. In all cases, it is desirable that the antenna receive most strongly the desired signals, and this can be accomplished only by selective tuning and filtering. The possibility of procuring readable signals depends upon the *ratio* of the strength of the signal to the strength of the noise level of static. Static can be reduced with directional loop antennas only when the broadcasting station is at right angles to a line joining the distant storm or static producing region and the receiving station. This is only practicable when the static area is many miles removed, and will not procure the desired results if the static is local. It must be acknowledged at the outset that it is practically impossible to bring about the alleviation of static. Investigators have worked on the problem for years without finding any means of doing so. When static signals are reduced in intensity, radio signals are reduced in proportion, and the ratio between signal and noise level strength remains constant. Perhaps the use of short, indoor, loop antennas will do more toward reducing static strength than any other known means.

POOR CONNECTIONS. All so-called static is produced by some sort of electric wave set up by tiny electric sparks, and by oscillations resulting therefrom. Within the radio receiver itself there is a strong possibility of static sounds. *Loose connections* will cause loud sounds. Some of these will seem to be sharp contacts and breaks of current, while others will be hissings and sputterings produced by the high resistance and temperature effects at the point of loose contact. If the antenna and ground are disconnected, real outside static will stop, but a bad internal connection will continue to cause trouble.

AUTOMOBILES AND STATIC. The ignition systems of some automobiles produce static interferences, especially if the receiver is located in the proximity to passing automobiles. Signals as distinct as those from a real telegraph station may be broadcast by the sparking ignition systems of certain automobiles, while most makes cause some interference. A sensitive receiver can detect this form of static several hundred feet away, and the spark discharges occurring along a crowded traffic avenue may be quite serious to radio sets located along the right of way.

POWER LINE INTERFERENCE. Power lines may have *leaky* insulators, and in wet weather these poorly insulated currents leak across broken and defective insulators, sending out static waves that sound as a steady buzzing or hissing in the set. This may vary in intensity as the degree of leakage changes. In such cases it is quite likely that high tension power lines are in the immediate neighborhood and search should be made for transformers and contact junctions located on nearby poles. If such a place is carefully watched on a wet dark night, a faint blue glow is seen where the leakage takes place. Relief may be obtained by getting the power company to replace defective insulators with new ones. Power companies are glad to receive such reports, since repair means a saving in electrical current.

STATIC IN THE HOME. About the home there are many causes of static interferences. The electric washing machine, especially if splashed with water over the motor, the sewing machine, electric refrigerator, and all other devices using electric current and depending upon a motor for power, are potential sources of static noises. Dirty and worn commutators and brushes will cause heavy sparking which will transmit electric impulses to the radio receiving set. The remedy is obvious and, with the elimination of commutator sparking, this interference can be greatly reduced. Other sources are the telephone, electric lighting and doorbell circuits.

X-RAY INTERFERENCE. The presence of a physician or individual using an *X-ray, violet ray,* or any kind of *cathode ray machine* for treatments or examination purposes, will always cause serious static interference. It is difficult to locate and eliminate this source of trouble, yet the intensity of such disturbances will prevent radio reception during the period that the machine is in use. The obvious remedy is to refrain from using such machines during the popular radio reception hours, say from 7 to 11 p.m. The electron emission from the cathodes of these tubes set up powerful oscillations, and tend to paralyze all reception within a short distance.

ELECTRIC CAR STATIC. Passing *trolley cars* send forth strong static waves, due to the contact breaks of the powerful currents in use; also the sparking of the motors, trolleys and wheels. Between the noise of the car itself as it passes along the track, and the powerful electric impulses, there is little to commend the electric railway to the broadcast listener. During wet and icy weather the cars play havoc with radio reception, as the sparking on the rails and trolley wires is intense. Underground circuit and trolley feed systems are better than overhead wires or the third-rail system of the elevated lines. Underground sparking along feed rails is absorbed to some extent by the earth and metal surroundings, but there is little remedy for the car evil.

DOOR-BELL STATIC. Door-bell and buzzer systems are strong sources of static oscillations, due to the sparking at the buzzer contacts, and the fact that the source is always located in the same building as the radio set. While this source is troublesome, it only occurs at times. It may be remedied by the use of iron box bells grounded to their metal frames. The buzzers in passing street cars and busses have been known to give rise to waves which interfere with sensitive receivers.

STATIC FROM COMMERCIAL SOURCES. There are many sources of static from commercial power plants, switch boards, telephone central stations, flashing electric signs, elevators, etc. Such sources are a part of the general scheme of business, and are practically impossible to overcome. They affect the listeners who may reside nearby, while the great majority is free from the noise.

INTERFERENCE FROM FADING. *Fading* is a variation in intensity of received signals from the same transmitting station while the receiver remains unchanged in its tuning. The phenomenon is seldom noticed at short distances from the transmitter. Because of the strength of the signal, slight variations cannot be detected. What the listener observes is that, without any change in the adjustments, the signal becomes louder and then rapidly fainter and fainter until it is too weak to be heard; then it quickly resumes its original intensity, and fades away again. This variation may continue at regular intervals, or it may occur at occasional indefinite periods. It is brought about by several causes. Those outside of the transmitter and receiver are not fully understood. Mechanical fading is due to variations in the wave length and intensity of the transmitted wave. Fluctuations of this kind are caused by a swinging antenna which moves with the wind and varies the capacity and the fundamental wave length. To avoid such wave length changes it is necessary that the antenna be kept taut. Other causes are inherent difficulties within the transmitter, and can be overcome only by redesign and careful manipulation.

DISTORTION INTERFERENCE. *Distortion* may be caused by several reasons, the principal ones being interference from other stations, nearby objects, and poor circuit design. The use of a loop antenna in congested districts or in iron supported apartments and hotels, will prevent accurate directional reception, as the wave tends to follow the metal lines of least resistance near the set. This produces a form of wave deformity, a natural cause of distortion. Other objects should be removed as far as possible from the antenna as they may distort the wave front, and there may be some slight distortion of direction as well as wave characteristic.

WAVE DEFORMITY. *Wave deformity*, static, poor modulation at the broadcasting station, inefficient loud speakers, microphonic tubes and contacts, and poor battery action, are some of the factors which contribute to produce distortion outside of that generally caused by unequal amplification. Wave deformity is caused by poor design at the transmitting station, and through the contributing causes outlined in the previous paragraph. A slight deviation from true wave form is hardly noticeable; greater deviation or deformity produces serious distortion. Local wave deformity is often produced by oscillation of both the radio and audio frequency circuits; by too great regeneration; by incorrect grid bias on the grids of the audio amplifying tubes; by audio tubes that do not have sufficient capacity of amplification constant; by poor rectification by detector tube as well as partial rectification by audio tubes; by poor grid leak and condenser or insufficient values on the detector tube; by beats or heterodyne action produced by interfering waves; and by poor audio transformers. The last-named are the most common causes of distortion.

BLASTING SOUNDS. The correction of distortion consists of the removal of the cause. This remedy can usually be applied, except in the case of wave deformity through external causes. In the case of poor audio frequency transformers, the remedy is obvious. Whenever poor quality is received from an audio amplifier, no matter whether transformer, resistance or impedance coupled, it is well to see that the *last* tube has sufficient value to carry the voltage impressed upon it without danger of becoming overloaded. The overloading produces *blasting*, as well as distorted sounds. It is quite easy to overload small tubes but larger tubes will carry greater grid voltage changes as the amplifying constant (*mu*) is higher. A surprisingly large percentage of distortion in the audio amplifier is due to tubes of too small a capacity in the last stage. If the tubes have been carefully selected and the trouble is not remedied, the transformers should be examined.

TRANSFORMER DISTORTION. The purpose of the transformer, as explained elsewhere, is to receive an input and *deliver* it to the grids of the following tube in exactly the *same wave form* as the original modulation but as an alternating current at a higher potential. If the exact characteristics of the wave are not preserved, distortion is to be expected. Most transformers amplify well within certain frequencies, but either above or below that range there will be poor or uneven amplification. The result is a form of wave distortion. For the selection of the proper transformer, study the characteristics of transformers, as given previously.

CHAPTER XIII

SOME ESSENTIAL RADIO APPARATUS AND INFORMATION

ELECTRIC METERS. A radio receiving set will operate well without the use of *electric meters* or indicating apparatus, but a careful operator will always want to know the condition of the set. When a complete set of meters is installed on a radio receiving set, there is at *all* times a visual indication that the set is operating under favorable conditions. The meters give warning of a lowered battery potential, too high a drain on batteries, or any other condition adverse to satisfactory radio reception. Not only should meters be used on receiving sets of large size, but they are necessary on all kinds of transmitters. In the following paragraphs all electrical meters used in radio operations are described. The magnetic effect brought about by the force induced between a permanent magnet and a wire carrying a current made into a rotating coil, is utilized to operate these electrical measuring devices.

THE VOLTMETER. In all electrical installations the *voltmeter* is of the highest importance. It is used to measure the difference of potential, in volts, between two terminals of a battery or circuit. Voltmeters are made for use on potentials of less than one volt, and as high as many thousands of volts. A pointer or hand is carried by a moving or rotating coil that is permitted to turn about in a magnetic field, in proportion to the voltage applied to the rotating coil. The degree of voltage is indicated on a graduated scale by the pointer. As the resistance of the meter is known, and is quite high, the current flowing is controlled by Ohm's Law, and any change in voltage will cause a *proportional* change in the current. When the voltages to be measured are very low, the resistance of the meter should be low. When high potentials are to be measured, the resistance may be many thousands of ohms. Voltmeters are wound with many turns of very fine wire, as the current passing through is extremely small, seldom over 0.01 ampere.

USING THE VOLTMETER. A voltmeter should never be connected between points of higher potential than that indicated by the scale, and its positive terminal should be always connected to the positive side of the circuit. The voltmeter is always connected *across* the circuit so that it may indicate the real potential difference existing between the two terminals. When a load is thrown on a circuit, such as the lighting of the tubes in a radio set, the voltage *drops* slightly. Now is the time to read the voltmeter and to adjust the circuit rheostats to compensate for this *voltage drop*. In radio reception the voltmeter is used to measure the voltage of the batteries, the proper filament operation of the tubes, and the plate potential.

THE FILAMENT VOLTMETER. The most important consideration is the filament circuit, and a voltmeter will show the proper setting of the filament rheostats for best operation. It is far more desirable to operate a tube at a constant voltage than at a constant current. The voltmeter is connected directly across the socket terminals of the tube, which places the rheostat outside of the circuit, as otherwise only the battery voltage would be indicated instead of the actual voltage that is being applied to the filament of the tube. The rheostat should be adjusted to show the correct number of volts called for by the manufacturer of the tube. As a small increase in voltage may harm an electron tube, the importance of control of the filament voltage will be seen. One meter may be used to measure the voltage of any number of tubes by means of a multi-point switch.

THE AMMETER. Meters which measure the correct current flowing in a circuit are known as *ammeters*. They can measure minute portions of an ampere, or currents of many hundreds. The ammeter is similar to the voltmeter except that it consists of a very few turns of heavy wire of large current carrying capacity. Unlike the voltmeter, the ammeter is placed in *series* with the circuit, and *all* the current passing through the circuit must also pass the ammeter. However, the amount of current being consumed by the apparatus controls the amount flowing in the circuit and through the ammeter. If the meter were to be connected in shunt, similar to a voltmeter, the instrument would be instantly destroyed as it would be a dead short circuit across the circuit. In radio circuits the ammeter is not so important except to indicate the consumption of current from the battery. It provides a check on the filament consumption, and should be inserted in the "A" battery circuit just before the rheostats are reached.

THE MILLIAMMETER. One of the most important meters used in radio is the *milliammeter*. This instrument is a sensitive ammeter, but the scale is graduated to read in milliamperes, or thousandths of an ampere. It is delicate of construction, and quite accurate in operation. Like the ammeter, it must never be connected directly across a current source, but in series. It is necessary only that the meter be inserted so that the polarity is correct, and that it be located so as to indicate the plate current flow of the tube. It may remain permanently in the circuit; unlike the voltmeter, it is not a drain on the battery. Although it does not consume an appreciable amount of current, it indicates at all times the amperage flowing in the plate circuit.

USING THE MILLIAMMETER. The reading in milliamperes *indicates* the rate of drain on the "B" batteries. When the tubes are lighted an electron flow begins in the plate circuit which is indicated by the milliammeter. As soon as signals begin to come in, the hand or pointer of the meter begins to swing or fluctuate to a greater reading, showing that the signals cause a still greater increase in the plate current and "B" battery consumption. The application of a "C" battery to the grid of the tube (in audio amplification) gives a negative grid bias to the tube, and the reading of the milliammeter falls off. When the pointer goes back to zero it indicates that the proper negative bias has been applied to the tube grid, thus checking the flow of plate current when no signals are being received. This alone is a great saving in "B" battery consumption, as well as the production of better amplification without distortion.

THE GALVANOMETER. When very delicate measurements are made, as in experimental work, even the milliammeter is not sufficiently sensitive to measure the current, and a *galvanometer* is

PLATE 6

Top, center: A. F. Choke Coil—courtesy National Company. *Top, left and right:* A. F. Transformer and speaker filter coil—courtesy General Radio Company. *Second row, left:* Tone filter—courtesy National Company. *Second row, center:* Lightning arrester—courtesy L. S. Brach Company. *Second row, right:* Carborundum detector unit—courtesy the Carborundum Company. *Lower left:* Milliammeter. *Lower right:* Voltmeter—courtesy Jewell Electrical Instrument Company.

used. The rotating coil is suspended by a wire that conducts the current and also opposes the turning of the coil. Small amounts such as a millionth of an ampere may be measured. In many cases a tiny mirror attached to the coil is used to change the direction of a *reflected* ray of light that passes over a darkened scale, as the coil is very slightly moved. Such an instrument is highly sensitive to slight currents, but is sluggish in action and cannot be used to indicate the rapid modulations of the radio current.

MEASURING RADIATED CURRENTS. While magnetic effects of audio frequency and direct currents are used to indicate their energy, it is necessary to use the *heating effect* of the current for measurements at radio frequencies. The amount of current flowing in the antenna circuit indicates the degree of efficiency of the set. Meters which are used in electrical work operate on low frequency and direct currents, and they cannot be used to measure the rapidly oscillating high potential current flowing through the antenna circuit. Special types of meters, therefore, are used to measure these currents.

THE HOT WIRE AMMETER. The oldest and best known type used principally in spark transmitters is called a *hot wire ammeter.* It consists of two wires stretched taut between two supports, and connected in series with the antenna so that a definite proportion of the antenna current passes through it. This broadcasting current heats the wire to a certain degree and causes it to expand. This expansion or slack is taken up by another wire attached to the center and which in turn rotates a small spindle or shaft carrying the indicating hand or pointer. A small coil spring holds this shaft at a tension and zero position. When the position of the wires is changed by the expansion due to the passing current, the spring tension changes and the pointer is moved a distance over the scale. The greater the amount of current passing, the greater will be the heat expansion, and as a result the hand will move farther over the scale.

THE THERMO-COUPLE AMMETER. Another type of meter is the *thermo-couple ammeter* that makes use of the fact that two *dissimilar* metals in contact will generate a small current when heated. Two wires, for example, of bismuth and antimony are joined, and a sensitive voltmeter is shunted across this juncture. The radio frequency currents passing through the joint causes it to heat slightly. This produces a slight difference in potential which is measured by the voltmeter. Because of the high reactance of the meter windings, it will not by-pass any of the antenna current from the thermo-couple unit. But the voltmeter is graduated in amperes instead of volts, as it is necessary to indicate only the amount of current generated by the thermo-couple, which is directly proportional to the current flowing in the antenna. Its action is very quick, and is usually more responsive than the hot wire type.

THE DECREMETER. The antenna ammeter used to indicate the maximum energy being radiated from a transmitting station antenna is one form of meter used; another form, the *decremeter*, is used to measure the logarithmic decrement of the current of the antenna. It is a form of wave meter, or simple receiving set. As we have already learned, the decrement or damping of the antenna current will affect the sharpness of tuning in the receiving set. Therefore if we can measure the *sharpness* of this tuning in a receiver, we can obtain the decrement of the transmitted wave trains. When the receiver is in resonance, the pointer of an indicating meter will reach its greatest deflection. A decrease or increase of tuning, or a change in impedance, so that the set is not in resonance with the transmitter, will reduce the deflection of the pointer to a certain degree. If the decrement is great, the tuning is *broad* and the pointer little affected, but if the decrement is slight the tuning is sharp and the pointer may fail to register. Thus, the amount of decrease of current through the sensitive meter for a given amount of *detuning* will indicate the degree of decrement. The more quickly the signal strength drops off on either side of the peak of resonance when the receiving decremeter is detuned from the transmitting station's tuning, the more easily will interference from the station be prevented, and a true indication of the station's sharpness of tune is provided. The decremeter is used close to the transmitting apparatus without any antenna or ground connection.

THE WAVE METER. That a transmitting station may operate on its specified wave length, it is adjusted to its wave length by the use of a *wave meter*. This device is an oscillating circuit having inductance and variable capacity, and a sensitive current measuring device or meter. The state of resonance in the circuit is indicated by the maximum strength of current in the meter, or the greatest response in the telephone receivers if a detector is used.

USING THE WAVE METER. A wave meter is calibrated so that certain places on the variable condenser dial will correspond to standard wave lengths. By placing the wave meter near an oscillating transmitter, the wave length of that circuit may be obtained by reading the scale when the tuning produces *maximum* signal strength. Or the transmitter may be brought to its proper wave length by setting the wave meter dial at the desired wave length, and adjusting the transmitter until the wave meter is in resonance with the greatest response. As we know the wave length of the calibrated meter, we also know that the wave length of the transmitted wave must correspond when the wave meter is in absolute resonance.

THE AUDIBILITY METER. The audibility or comparative strength of a received signal may be indicated by an *audibility meter*. The careful comparison of two or more signals requires delicate instruments. Although the current received can be measured with very sensitive galvanometers, the method requires careful manipulation and is not satisfactory. A simple method of obtaining good results is roughly to *compare* the signal strength when the telephone receivers are shunted with a known resistance. By reducing the resistance of this shunt until the signal can be just heard, we may calibrate the variable resistance so that comparisons with other signals may be made. The ratio of impedance of the telephones and the impedance of the shunt resistance can be expressed in units of current if properly calibrated, and may be taken as the degree of audibility of the signal. Another method of determining signal strength is to compare its intensity with another signal of known intensity produced by an oscillating electron tube or a high pitch electric buzzer.

PIEZO ELECTRIC CRYSTALS. Many crystals are *piezo electric;* that is, they have the property of giving rise to an electric voltage when they are mechanically *squeezed.* This action also works in reverse; that is, when a voltage is applied to the crystal, it changes its dimensions in certain directions. A flat disc cut from quartz crystal in the correct plane, and containing no flaws, is used to procure this *piezo effect.*

THE PIEZO ELECTRIC OSCILLATOR. Radio broadcasting stations can be held absolutely on their assigned wave lengths if the transmitter is placed under the control of this tiny piece of crystal apparatus. When the quartz plate or disc is placed between two metal plates it can be made to maintain a fixed value of frequency in the oscillating transmitter. Quartz has been found to be more satisfactory for this purpose than any other crystal. The fundamental frequency of the piezo crystal is determined by the dimensions of the quartz plate and it is not affected by changes in inductance and capacity in the circuit. Therefore the crystal will give its fixed frequency, or will fail to function at all. Because of this action, the transmitting circuit instantly shows when its adjustments are off the assigned frequency. As long as the crystal oscillates freely, it is known that the circuit remains in

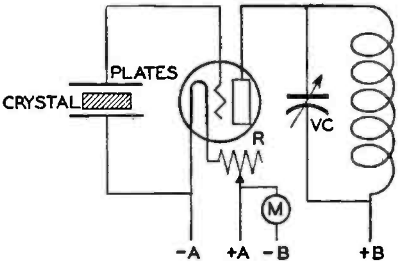


FIG. 93. A PIEZO-ELECTRIC OSCILLATOR

perfect adjustment. Figure 93 shows a piezo oscillator circuit. The quartz crystal is in the circuit of a vacuum tube oscillator for generating radio frequency oscillations on a standard frequency, and will act to maintain that frequency.

THE INTERNATIONAL RADIO CODE. The average radio receiver controls wave lengths between 200 and 550 meters. As one goes above the limits of the dial, he will begin to pick up a myriad of whistlings which are broken up into the long and short sounds—dots and dashes—of the radio telegraph code. These are the sounds of radio commercial life—ship and land telegraph stations. As one goes to the lower limits of the dials, 200 meters and below, the calls and signals of the low wave length stations will be heard. These are mostly amateurs, of which there are many thousands. The code used throughout the civilized world is the same, and is shown in the table in Figure 94.

A	· —	S	· · ·
B	— · · ·	T	—
C	— · — ·	U	· · —
D	— · ·	V	· · · —
E	·	W	· — —
F	· · — ·	X	— · · —
G	— — ·	Y	— · — —
H	· · · ·	Z	— — · ·
I	· ·	1	· — — — —
J	· — — —	2	· · — — —
K	— · —	3	· · · — —
L	· — · ·	4	· · · · —
M	— —	5	· · · · ·
N	— ·	6	— · · · ·
O	— — —	7	— — · · ·
P	· — — ·	8	— — — · ·
Q	— — · —	9	— — — — ·
R	· — ·	0	— — — — —

FIG. 94. THE INTERNATIONAL RADIO TELEGRAPH CODE

LEARNING THE RADIO CODE. Learning the code is greatly facilitated by a natural aptitude for remembering a succession of sounds. The first step is to memorize the *sounds* representing the letters of the alphabet. This process is aided by grouping letters and becoming thoroughly familiar with one group at a time. It is a mistake to memorize the alphabet *visually*, by attempting to call the letter *A*—a *dot* and a *dash*. The beginner should form an impression of the sound of a letter and not a *sight* picture of it. In the latter case there is a tendency to visualize the sound and then refer back to its corresponding letter or figure through a mental picture of the code table shown in Figure 94. Going back to the letter *A*, the sound of the dot and dash symbols are short and long buzzes, which should immediately bring to mind the letter *A*, and not a picture of a dot and a dash with its associated letter.

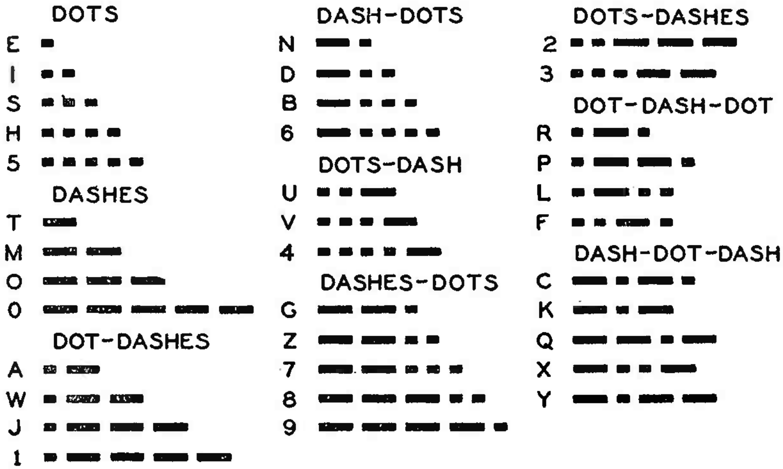


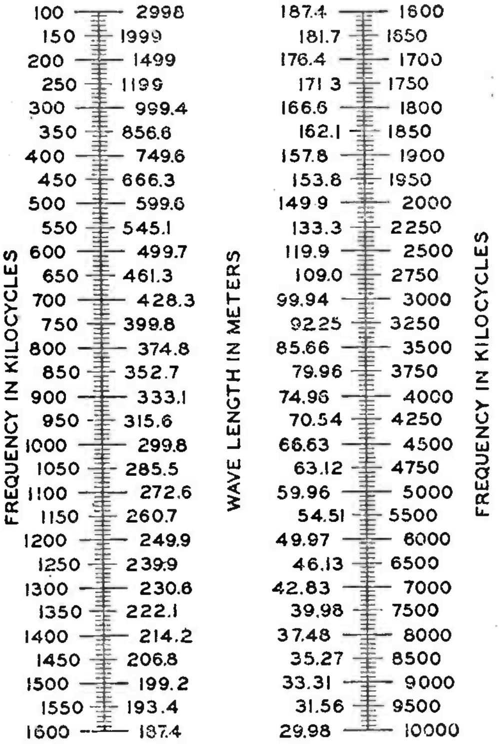
FIG. 95. CODE SOUND GROUPINGS

DOTS AND DASHES. The *dot* is exactly what its name implies—a dot of sound; practically the shortest distinguishable buzz that can be made. The *dash* is a longer buzz; three times the length of a dot. Some operators make their dots and dashes very short, while others draw them out. The dot, however, should always be long enough so that it can be recognized as a buzz of dot length, and not a mere click of sound. The dash, on the other hand, should not be unnecessarily long, but just sufficient to enable the listener to know that it is a dash. In any case, the lengths of the sound buzzes distinguishing dots and dashes should be definite, regular and easily determined.

Sound Groups. The radio code should be divided into groups of dots, dashes, and combinations of dots and dashes. Such a grouping is shown in the table in Figure 95. The methodic arrangement is clearly shown, and such a grouping will greatly aid the beginner in learning the code. It will be best to use a telegraph key and small electric buzzer so as to become familiar with the groupings and their characteristic sounds. After the sounds have become firmly established in the mind, practice in receiving may commence.

Amateur Radio Station Requirements. It is necessary to obtain an amateur station and operator's license from the Government before an amateur radio transmitting station can be operated. The United Sates Radio Supervisor of the proper district should be requested to supply the necessary forms. These are filled out and sent to the Supervisor who will then set a date for a technical and code test and examination. The examinations are not difficult, and consist of a series of questions on installation and operation of transmitters, and a demonstration of the ability to send and receive code signals at the low rate of about ten words a minute.

Frequency and Wave Length Conversion Tables. We know that the lengths and frequencies of radio waves are directly related. This *reciprocal* relation means that high frequencies correspond to short wave lengths, and low frequencies to long wave lengths. However a change between frequencies in regular or fixed amounts, will not bring about wave length changes of equal amounts. Wave lengths between 500 and 600 meters are more nearly equal to their frequencies, as the reciprocal figures are very close. The range of frequencies in broadcasting, as established by the United States Government, fixes the station frequencies as having an equal separation of 10,000 cycles, or 10 kilocycles. This arbitrary system may be changed from time to time, but there does not seem to be any system that can equal or better the allocation of wave lengths to radio stations. In the chart shown in Figure 96, the radio frequencies between 100 and 10,000 kilocycles are given in the outside columns and the corresponding wave lengths between 2,998 and 29.9 meters, in the center columns.



FREQUENCY IN KILOCYCLES	WAVE LENGTH IN METERS		FREQUENCY IN KILOCYCLES
100	2998	187.4	1600
150	1999	181.7	1650
200	1499	176.4	1700
250	1199	171.3	1750
300	999.4	166.6	1800
350	856.6	162.1	1850
400	749.6	157.8	1900
450	666.3	153.8	1950
500	599.6	149.9	2000
550	545.1	133.3	2250
600	499.7	119.9	2500
650	461.3	109.0	2750
700	428.3	99.94	3000
750	399.8	92.25	3250
800	374.8	85.66	3500
850	352.7	79.96	3750
900	333.1	74.96	4000
950	315.6	70.54	4250
1000	299.8	66.63	4500
1050	285.5	63.12	4750
1100	272.6	59.96	5000
1150	260.7	54.51	5500
1200	249.9	49.97	6000
1250	239.9	46.13	6500
1300	230.6	42.83	7000
1350	222.1	39.98	7500
1400	214.2	37.48	8000
1450	206.8	35.27	8500
1500	199.2	33.31	9000
1550	193.4	31.56	9500
1600	187.4	29.98	10000

FIG. 96. CONVERSION TABLE FOR WAVE LENGTHS AND FREQUENCIES

RHEOSTATS IN RADIO RECEIVERS. The rheostat is a *variable* resistance and functions as a current-voltage regulator. Technically speaking, a rheostat may be of any maximum resistance value; but in radio practice other names are employed for variable *high resistances*, and the word rheostat is limited to low value variable resistances of less than 500 ohms. A rheostat very seldom serves any other purpose than to control the filament current to one or many vacuum tubes. But the *maximum* resistance value of a rheostat is important, as one value would not be suitable to all tubes or circuits.

RADIO RESISTANCES. All conductors do not have the same electrical resistance. A piece of copper wire does not have the same resistance as a similar piece of german silver wire. Silver wire has less resistance than any other conducting material of similar cross sectional area. Some conductors heat more readily than others when an electric current is passing, and this is an important consideration in the determination of materials to be used in rheostats and resistance units. German silver wire, iron wire, chromium-nickel (nichrome) wire, and carbon discs, are used in various kinds of rheostats.

AUTOMATIC FILAMENT CONTROLS. In addition to rheostats, which we may say are manually adjusted, there are self-adjusting rheostats or *automatic filament controls*. They take the form of a ballast resistance and are composed of a piece of iron resistance wire sealed in an evacuated glass tube, similar to an electric light. They operate on the principle that wire, composed of iron or other metals of electrical resistance, increases in resistance value as it becomes heated. Since the amount of current flowing through the wire determines the amount of heat generated, the resistance is self-regulating. If, for any reason, more current attempts to pass, the wire becomes hotter and its resistance increases. If the "A" battery is run down a trifle, less current actually flows through a given value of resistance; but in the case of the automatic filament control unit, the resistance of the wire adjusts itself to allow the correct current to pass. The same amount of current will pass when the battery is new or fully charged.

THE POTENTIOMETER. *Potentiometers* are actually variable rheostats, but may be better used as voltage dividers and polarity regulators. A potentiometer has three connections, two to the ends of the resistance wire, and the third to the movable contact arm. Since potentiometers are seldom called upon to handle heavy currents, they are usually wound with very small high resistance wire. A potentiometer may be put to a number of uses, but it is generally employed for obtaining a variable negative grid-bias for radio frequency amplifying tubes. The resistance wire is connected directly *across* the terminals of the "A" battery, and the contact arm to the grid return circuit of the radio frequency tube. Since the resistance is connected directly in the "A" battery circuit, there is a drop of potential across it; this becomes greater and greater as we move away from the positive side of the potentiometer resistance coil. If we move the arm towards the negative side we impress a negative potential or voltage on the grid of the tube. The amount of negative potential obtained depends upon the position of the contact arm; also of course, on the total voltage of the "A" battery. Since the usual battery is 6 volts, it is possible to get a negative variation from zero to 3 volts. A potentiometer employed in this manner is functioning as a *stabilizer*. A potentiometer having a much higher resistance (25,000 ohms) may be used as a *regeneration control*, by connecting the resistance across the tickler coil and the arm to the positive "B" battery lead for the detector tube.

FIXED RESISTANCES OR RESISTORS. In radio work, fixed resistances or *resistors*, ranging in value up to more than ten million ohms, or ten megohms, are employed. There is hardly a radio circuit known that does not require at least one resistor unit. All of the electron tube circuits shown in this book require one or more of these fixed resistances. Even in the single tube circuit using a rheostat for controlling the current to the tube filament, it is necessary to use a very high fixed resistance, often as much as 7 megohms, as a grid leak. More complicated circuits utilize a great number of resistances of different values for definite functions. Resistors have fixed values ranging from 25,000 ohms to 10 million ohms. Those ranging between 25,000 and 1,000,000 ohms are used in connection with resistance coupled amplification, and are of special construction. Metallic or graphite substances are used as resistance elements, and are either coated on glass, fused into the glass, or pressed into strips or rods under great pressure. These resistors are far superior to the older types of carbon impregnated material. Some resistors are of the heavy duty type and carry heavy currents. They are used as voltage regulators in "B" battery eliminators, for obtaining "C" voltage and as current by-pass and shunt units, wherever a fixed value of resistance is satisfactory.

GRID LEAK RESISTORS. Resistors having values over one million ohms are employed as grid leaks in the grid circuits of electron tube detectors, as has been previously explained. They are made in various values for the reason that different types of tubes and circuits require different grid leak values, and different makes of receivers operate most efficiently with different particular values of grid resistance, even though the value of the grid resistance may be the same as that in another type of receiver which uses similar tubes. The action of the grid leak has been described elsewhere. Variable grid leaks having a range of approximately 250,000 to 10,000,000 ohms are often of the carbon disc compression type, or of a mixture impregnated surface with a non-frictional contact. These variable grid leaks can be relied upon to hold the adjustment indefinitely.

TYPE OF TUBES	NUMBER OF TUBES		
	1	2	3
All six-volt tubes	4	2	1.5
199–299—with 4.5 volts	25	13	9
199–299—with 6 volts	50	25	17
11–12—with 1.5 volts	1.6	0.8	0.6
11–12—with 2 volts	4	2	1.5
112–312—with 6 volts	2	1	0.7
120–320—with 4.5 volts	12	6	4
120–320—with 6 volts	24	12	8

FIG. 97. TABLE OF RESISTANCE VALUES

VARIABLE HIGH POWER RESISTANCE. Variable *high power resistances* are in extensive use today in modern radio circuits. While their range is about the same as low power resistances—25,000, 50,000, 100,000, 250,000 or 500,000 ohms—they have a much greater current carrying capacity. They are employed primarily as voltage regulators in alternating and direct current "B" battery eliminators, but can also be used to obtain "C" battery voltage from a "B" eliminator, and as current by-pass and current shunt units in connection with low-current operating relays, voltmeters, ammeters and milliammeters.

RHEOSTAT VALUES. The values of resistances given in the table shown in Figure 97, are just sufficient to reduce the battery potential by the necessary amount, for the voltage electron tubes indicated.

SHIELDING IN RADIO RECEIVERS. *Shielding* has become popular with the radio set builders, and by the intelligent use of shielding, receivers can be made many times more sensitive than is otherwise possible. If a charged object is suspended above the ground, there is an electric field between the object and the ground. Consequently, if a second and uncharged object is placed in the field between the charged object and the ground, the second object will assume a voltage corresponding to its place in the electric field. One method of preventing this is to interpose the ground between the two suspended objects. Then the field between the first charged object and the ground does not pass through the second object, and therefore does not affect it. A similar result may be achieved by *interposing* a grounded conducting plate between the objects. Now the lines of force terminate on the plate and are conducted away to the earth. In this manner the second object is shielded from the influence of the first object.

BENEFITS OF RADIO SHIELDING. Primarily, the advantage of shielding is to reduce the feed back or to advance the point of self oscillation, so that *increased* amplification may be obtained. In this way it is possible to make amplifiers far more sensitive, and capable of receiving over much greater distances, than is at all possible without shielding. At present shielding is the only reliable method of definitely limiting the extent of the external electromagnetic and electrostatic fields between coils. By using thorough shielding, and thus advancing the point of self oscillation, it is possible to use a greater number of radio frequency amplifier tubes without undue difficulty in preventing or controlling self oscillation.

BODY CAPACITY EFFECTS. Grounded rotor variable condensers have made most receivers free from *body capacity effects;* but, in some sets, and particularly at the short wave lengths, this annoying action is still evident. Thorough shielding absolutely eliminates this trouble. The action is the same as explained above; the grounded conducting plate prevents changes in the field on one side of the plate from affecting objects in the circuit on the other side. Therefore, changes in the field between the body and the interior of the receiver, which might be caused by the moving of the hand or body toward or away from the panel, do not influence tuning.

SHIELDING MATERIALS. A good conductor will dissipate stray charges and currents more easily than a poor one. It follows that copper, because if its low resistivity, is a very efficient shielding material. Experiments have shown that strong magnetic fields will pass through very thin sheet metal. The efficiency of perfect shielding has been shown by inclosing radio receivers in copper boxes and testing them in the vicinity of transmitting stations. It has been found that the *smallest* crack in the shielding is enough to ruin entirely the effect of the shielding material. Several years ago it was thought that copper screening would give sufficient shielding effect, but experiments have shown that screening is not to be compared with solid sheet metal. Present day broadcasting, with its numerous and powerful stations in a limited area, requires perfect magnetic insulation. In many cases simple aluminum plates have been used between adjacent radio frequency stages, and while they serve the purpose fairly well, they do not provide the full insulation that *complete* boxed-in shields do.

CHAPTER XIV

NATURAL PHENOMENA AND THEIR EFFECT ON RADIO OPERATIONS

ATMOSPHERIC ELECTRICITY. About one hundred and seventy-five years ago Benjamin Franklin demonstrated that the lightning in the atmosphere is similar to the electricity produced in the laboratory. This theory was later definitely accepted and it is now known that there is such a thing as *atmospheric electricity.* This electricity manifests itself in many ways and, while it is always present in the atmosphere there are times when it becomes excessive. We are not greatly concerned with the natural presence of atmospheric electricity, but we are concerned with those excesses which affect our radio receivers. With radio receiving sets in nearly every home, listeners have become convinced that there must be a *correlation* between the phenomena of radio transmission and reception and the electric conditions which exist throughout our atmosphere. In the following text we see how these electric excesses are produced and their effect on radio operations.

THE EARTH'S ELECTRIC FIELD. The earth is a great conductor and is negatively charged. In the immediate space surrounding the earth there is an electric condition called potential. It is the *earth's electric field*, and we can use the volt to measure its intensity just as we measure the potential difference existing between two terminals of an electric battery. In measuring the electric field of the earth, we have no positive and negative terminals to which to attach our measuring device, and instead it is customary to refer to the field as having so many volts per foot of change in height above the surface of the earth.

ATMOSPHERIC POTENTIAL DIFFERENCE. It has been determined that the potential strength of the earth's field under normal conditions is such that at six feet above the surface the potential may be several hundred volts greater than at the ground. As the distance between the earth and the measuring point above is increased, this potential difference in the atmosphere also increases. If the earth were a perfect sphere we could draw imaginary concentric lines about it, each line at a higher elevation and representing an increase in potential difference. If we assume each line to be an increase of a thousand volts, or some other regular unit, the lines would then be known as *equi-potential surfaces.* However the earth's contour greatly varies and these surfaces are subject to considerable distortion and strain. The general effect is to warp the surfaces upward and to bring them closer together. The potential difference over the earth will vary therefore, and the electric strain in places where the equipotential surfaces are brought closer together will become greater. The potential of the atmosphere is greatly affected by the changes in the weather. Because of this evident correlation it is wholly probable that weather influences radio reception conditions to a very great extent. A storm may easily increase the atmospheric potential difference by many hundred per cent.

THE EARTH'S ELECTRIC CHARGE. The origin of the earth's charge and electric field is not known, but it is safe to assume that, in order to explain it, the sun as well as the earth must be taken into consideration. The presence of sun-spots and their relation to the earth's electricity has done much to substantiate this theory. One may wonder why we are not subject to an electric shock because there would seem to be a potential difference between the head and the feet. This is true, but it must be remembered that the earth is negatively charged and, while standing upon it we are a portion of it, like a bird that sits on a highly charged wire without receiving any shock. The body forms part of the earth just as much as a hill or building and the potential surfaces are not *cut* by the body, but are distorted and curved about it so that the head and feet never get in two potential differences.

EARTH CURRENTS. Since there are changes in the atmospheric potential values over different portions of the earth there must be currents of electricity to the earth from the atmosphere. For instance, precipitation brings down quantities of electricity to various places on the earth, and there ought to be *earth currents* flowing between these places to neutralize the discrepancies due to the descending electric currents. It is known that these earth currents exist, and their presence in long telephone and telegraph lines at times causes considerable inconvenience and trouble. The effect on radio may not be so pronounced.

ATMOSPHERIC CONDUCTIVITY. A matter of great importance to radio engineering is the ability of the atmosphere or any gas to conduct an electric current. This is called the electrical *conductivity* of the atmosphere. Strangely enough, air is also the best insulator known. We have seen previously how gases may become ionized when the normally neutral molecules and atoms take on negative or positive electrical charges and become ions. Positive and negative ions attract each other, and whenever they come into contact their charges neutralize. This circumstance causes the ions of the atmosphere constantly to seek each other and neutralize their charges. Within a certain time this neutralization would cease if it were not for the fact that new ions are being created. In fact, some scientists state that a cubic inch of air will contain at all times over 15,000 free ions having either electrical charge.

FLOW OF IONS. The positive ions are believed to *flow* toward the earth because of the latter's action, and the negative ions flow upward for the same reason. As a result, there is a flow of electric current from the air into the earth but, while we may speak in terms of millions of volts, the amperage is so small that it is impossible to measure it at any one point. In fact, considering the surface of the earth as a whole, the *total* flow of current to it may be less than a thousand amperes. The source of replenishment of ions to the earth's atmosphere is a question. Many believe it comes in the form of energy from the sun, but there is no proof that electricity from the sun actually reaches the earth. Internal actions, of course, cause ionization. This is not a form of replenishment, but a reagitation of neutralized atoms of gas. From certain theoretical reasonings, some scientists and investigators have arrived at the conclusion that the atmosphere at some very high region is heavily ionized and has a great electrical conductivity. Actual observations at high points have proved that the air is a better conductor there.

THE HEAVISIDE LAYER. As early as 1900, *Sir Oliver Heaviside* pointed out that in the higher regions of the atmosphere there probably exists a *permanently ionized layer*, which, being a good conductor of electricity, acts as a guide for the radio waves. Because of the originator of the theory, which has been generally accepted, although based upon postulations, the region is known as the *Heaviside Layer*. Independent investigations by *Kennelly* also suggested the possibility of a region of upper atmosphere rich in electrons and ions and, for that reason the region is often called the *Kennelly-Heaviside Layer*. Unfortunately, we have no means of exploring this region. Radio engineers feel that a knowledge of the electric conditions there would be of the utmost importance toward an improvement of radio communication. Indirectly, however, much has been done to correlate these theories and the still greater tasks ahead will do much to show how atmospheric electricity and weather affect radio communication. The *Heaviside Layer* is now accepted as the reason why radio waves follow around the curvature of the earth and do not pass off into space in a straight line.

REFLECTION OF RADIO WAVES. Let us assume that the space through which radio signals are sent is bounded below by the earth's surface, and above by another conducting surface—the Heaviside Layer. This upper region is a good conductor and is permanently ionized, while the region between is a fairly good dielectric. Part of a radio wave is guided along the earth's surface while another part goes off as a *space wave*. By reflections and refractions from the upper guiding surface the space wave is sent back to recombine with the guided *earth wave*. The lower levels of the atmosphere are usually relatively free of permanent ionization, except under certain conditions, to be explained later. The lower surface of the upper conducting layer has a great electron density and is rather sharply defined. When a radio space wave is radiated it travels in a straight line until it meets the Heaviside Layer and, after reflection from this layer, returns in a straight line to the earth. In this description we may think of optical *reflection* as a sensible example.

HEIGHT OF THE HEAVISIDE REGION. The *height* of the Heaviside Layer is indicated as that region or distance above the earth where the rate of increase in electron density with height suddenly ceases. This is, therefore, the region of maximum electron and ionic density. The height has been set by investigators as not less than 75 miles, and may be as much as 200 miles. That it varies with the seasons and the time of day, as well as from other causes, is quite evident.

SHORT WAVE SKIP DISTANCES. One interesting phase of radio wave transmission through the atmosphere in connection with the outer conducting layer, is the behavior of short and long waves. It has been demonstrated that short waves are decreased in intensity as the distance from the transmitter is increased, until a certain point is reached. At greater distances the received signal rapidly increases in strength to a maximum. Beyond that the strength gradually decreases by true attenuation. The distance between the transmitter to the beginning of the rise in signal strength is called the *skip distance.* This zone is not sharply defined and is found to be longer at night than in the day, and longer in winter than in summer. This means that the skip zone is *greater* at times when radio transmission conditions are favorable for distant communication. The correlation is, therefore, quite obvious. In most cases the skip zone is a region where signals are entirely absent. The shorter the wave lengths used the greater the zone distances will be. Long waves do not have such skip zones as true attenuation begins at the transmitting antenna. This partly accounts for the greater distances covered by short waves even during day-light. Figure 98 shows a curve that indicates the ranges of a uniform power transmitter under equal daylight conditions.

DAY AND NIGHT TRANSMISSIONS. At night, due to variations in the atmospheric conditions that affect the upper conductivity, the losses of energy in transmission decrease and the attenuation of the wave is less. As we have seen, transmission at night is more effective than during the daytime, and the range of reception is *increased* many times. During the day the lower atmosphere is greatly ionized by the action of the sun's rays, and the upper conducting level is less defined. Thus the *absorption* of the transmitted waves will be greater. At night the cause of this ionization of the lower atmosphere is removed, the upper boundary becomes more sharply defined, and there is a greater reflection of the waves. The signals received at night therefore are of greater intensity than those received during the day over similar distances and in the same direction.

Sunset Effect. During the period of transition from daylight to darkness we may observe the *sunset effect*. About an hour before sunset there will be a rise in the intensity of the radio signal and it will drop just about sunset, after which it will rise until a maximum is reached about an hour later. During the night a further gradual rise in signal strength will go forward until several hours before sunrise. A sunrise effect, similar to the sunset effect except that the phenomenom is *reversed*, will then be noticed.

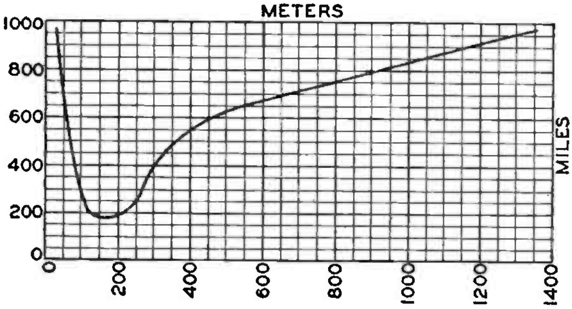


Fig. 98. Short Wave Daylight Ranges

Weather Effects. Belief that a correlation exists between radio and the phenomena of the weather is quite generally established in the minds of the radio public. The laws which control radio communication are so little known and understood that few, if any, can really speak intelligently as to what occurs, except to use the terms of general and fundamental theories. Radio reception is limited in its general usefulness to relatively small areas of the surface of the earth. Atmospheric disturbances, often of such magnitude as to seriously affect an area equal to that covered by the average radio broadcast, frequently occur. The effects produced by changes in the weather on radio reception will be briefly explained in the following text.

THE ATMOSPHERE. The *atmosphere* has weight and volume and it may be made to expand or contract. Due to its total height it has a greater density toward the bottom than at the top. At sea-level, the weight of the air is about 15 pounds to the square inch, but we cannot feel it because the pressure is equal on all sides. This normal weight of the atmosphere at sea-level will *balance* a column of mercury about 30 inches high. As the weight of the air overhead changes, the height to the top of the mercury column will also change. Such a device used to measure the weight of the air is called a *barometer*.

THE BAROMETER. When the barometer rises above the sea-level standard of pressure, it is said to be *rising*, and indicates that the air is becoming more dense with greater weight to the square inch. When it falls below the standard, it is an indication that the air is less dense and has less weight. It is then said to be *falling*. Such changes in the weight of the atmosphere are called *pressure changes*, and are accurate indicators of coming changes in the existing weather. They have also been used extensively by investigators as indicators of changes in static interferences and radio reception in general.

LOW AND HIGH AIR PRESSURE. When the barometer is falling it means that an area of lighter air is approaching, and this area is known as a *low*. When the barometer is rising it indicates that a heavier air pressure area is passing over, and this is known as a *high*. It does not mean that the air has actually changed in weight, but that the air is rising or descending, thus changing the volume overhead and decreasing or increasing the pressure at the surface of the earth. Warm air rises while cool air descends; thus warm air is always associated with a falling barometer, and cold air with a rising barometer. The temperature of the air near the earth is warmer due to convection. Here the air is more dense and radiation is better from objects warmed because of the sun's influence. At the higher levels, such as mountain tops, the air is rare and of considerably less density. Convection is poor and heat waves are, therefore, conducted with little effect. When the air at the surface is warm it must rise until it reaches a point of equilibrium. But under some conditions, and when the air has absorbed considerable moisture, certain things happen as it rises.

HUMIDITY OF THE ATMOSPHERE. The moisture in the air is known as *humidity*, and is mentioned in terms of the percentage of water absorbed in the air, without falling as rain. The rising of warm air carrying moisture or water vapor will produce clouds as soon as it comes into contact with the colder air overhead. The condensation of the moisture produces *fog* which may be prevented from falling by the continued rise of more warm air from beneath. Thus clouds are built up, and as they become greater and greater, they gradually descend until, no longer able to support their moisture, they give it up as rain, snow or hail. When the heated atmosphere ceases to rise and clouds have given up their moisture the cold air above begins to descend. The pressure is increased because of this action and the chilling of the air causes it to condense somewhat, thus producing a greater density.

AIR TEMPERATURE AND WINDS. *Temperature* is a measure of the degree of heat or cold in the atmosphere. As the air at the higher levels is always cold, it is easy to see that when it descends we experience *lower* temperatures with an *increase* in the air pressure. Also, if there is a difference in air pressure between a low area and a nearby high pressure there is considerable air movement toward the low area. This causes *winds*, and the greater the pressure difference, the stronger the wind movement will be, and the more decided the temperature change. With high pressure we usually have clear weather while with low pressures we get cloudy and stormy weather; rain in summer or snow in winter.

STATIC AND THE TROPOSPHERE. Static is believed to be directly associated with meteorological conditions existing in the lower part of the atmosphere. This is the *troposphere;* it extends upwards to a height of about seven miles over the poles and to a greater height over the equatorial regions. Atmospheric gases are kept continuously mixed by winds and convection. Here storms occur, clouds exist, rain or snow falls, and temperatures change. The intensity of static varies at different portions of the earth's surface, increasing from the polar toward the equatorial regions; also with the advent of the summer season and with immediate weather changes. It must also be remembered that as we progress southward the *depth* of the troposphere *increases* and more static bearing atmosphere is piled up overhead. The continuous changes in the electricity of the atmosphere occuring in the troposphere with weather changes are accompanied by natural electric disturbances which produce *static outbursts.* Since these static waves are so similar to radio waves in their nature no way has yet been found entirely to eliminate them, and without knowing definitely their origin, it seems safe to assume that meteorological events, associated with the atmospheric electricity in the troposphere, are responsible for them.

THE STRATOSPHERE. The outer atmospheric zone, called the *stratosphere,* exists above the troposphere level, and extends upward to a height of perhaps 200 miles. Water vapor is not present, temperatures remain constant, and convection ceases. No clouds or weather variations are known. In this case there is little likelihood that static disturbances occur and, with the exception of the great auroral electromagnetic storms at infrequent intervals, but little interference with radio communication will occur.

POTENTIAL CHANGES DUE TO WEATHER. The irregularities of the earth's surface and the movements of storms through the atmosphere tend to *distort* the concentricity of the electrical surfaces, and increase or decrease the potential difference. The continuity of the conductivity of the atmosphere is undoubtedly influenced by changes in air pressure and related weather phenomena. Storm areas, and even small areas comprised of highly ionized atmosphere, are surrounded by electrostatic fields, the size of which depends upon the extent of the disturbances. We can have an electromagnetic field concentric about a conductor of electricity, which in turn is surrounded by an electrostatic field.

If this conductor is moved with respect to the earth's surface its electrical fields also move. Fluctuations and changes set up in the conductor will set up corresponding changes in the two fields. This analogy may be made to apply to the atmospheric electricity of a storm area. It is a well known fact that the southeastern side of a storm area shows pronounced electric tendencies, such as thunderstorms and associated static. In such areas we may expect to find extreme distortion of the electric fields and potential surfaces. The static disturbances in this southeastern area will be much greater than in other portions of the general storm area.

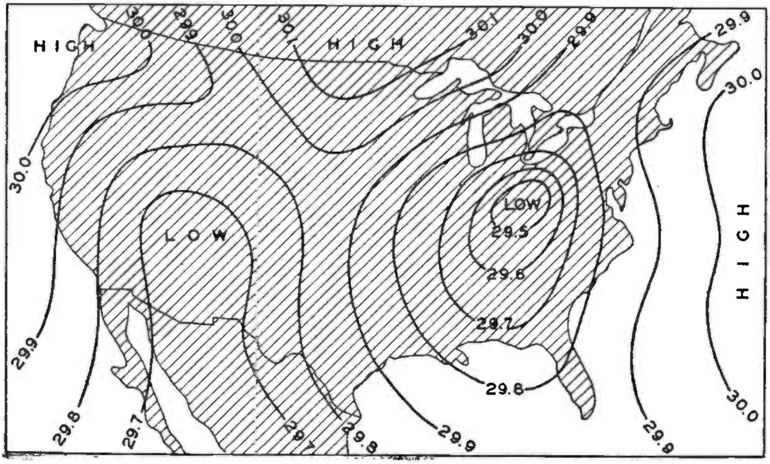


FIG. 99. A TYPICAL WEATHER MAP

STORM ELECTRICITY. It is within the electrostatic field of a storm, and especially the thunderstorm side, that atmospheric electricity becomes bothersome. The degree of electric induction will become so great that the atmosphere is subjected to severe *strains* and *stresses*, and electromagnetic waves are set up from every discharged mass of ionized gas. These are heard as static. As far as static is concerned it appears that the electrostatic field about a storm is not wholly concentric; it may reach out 24 hours in advance, is seldom in the rear, and the greatest static activity is toward the southeastern side of the storm area.

Isobars on Weather Maps. The troposphere, in which our meteorological disturbances take place, is constantly in a state of agitation due to the unending succession of areas of high and low air pressure which constantly pass from the west toward the east over the north American continent. Generally speaking a *low* is associated with inclement weather and rising temperatures, while a *high* is associated with falling temperatures and clear weather. Weather maps have all points of *equal* air pressure observed at the same hour joined together by lines which are called *isobars*. See Figure 99. They are somewhat concentric, but never cross each other as the air flows in smooth semi-parallel paths. The greater the difference in air pressure between the centers of adjoining highs and lows, the greater is the intensity of the disturbance. Air movements (winds) are stronger and temperature changes more decided. The isobars will then be closer together and a *gradient* of certain steepness will exist. These conditions have a decided influence on radio reception and static.

Static Distribution. The ions of the atmosphere, those produced through *impact* and *friction* rather than by the action of the rays of the sun, may be rather evenly distributed through areas of equalized air pressure. With such a distribution the presence of static is at a minimum, especially during clear and cold weather when the moisture content of the atmosphere is low. Dry, clear air is always quite free from local static and the nose level is so reduced at this time that distant reception is always likely. However, the movement of a low pressure area is accompanied and preceded with much humid air. The production of ions is great within the disturbance and, when this area passes, gives rise to much local static. This comparatively heavy ionization, moving with the disturbance, tends to *blanket* the regular transmission of radio waves from stations within the area. It creates heavy static charges along with a tremendous increase in the potential differences of the atmosphere and a distortion or compression of the equipotential surfaces. The ultimate result of this compression is an increase in static interference and, in certain types of storms, the stresses and strains in the atmosphere become so great that the excess charges are discharged in the form of *lightning*.

THUNDERSTORMS. The *thunderstorm* is well known to everyone, for there are very few inhabited portions of the earth which are free from this phenomenon. The approach of the thunderstorm is heralded by several events which usually follow a fairly well defined order of succession. There is a very close and definite association between these storms and radio static conditions. In fact, by the use of a radio compass the thunderstorm area of a general storm area (the southeast side) many hundred miles away may be detected. Thunderstorms occur in nearly all parts of the world, but the number decreases rapidly as we pass from the equator toward the pole. This is proportionate also to the depth of the troposphere overhead and to the distribution of static. In the tropics there are many places which average one or more thunderstorms for each day of the year, while in the far north no storm may occur for many years. Fewer storms occur over the ocean than over land, and mountainous regions have far more than the level plains. In the United States, the largest number occur over the east Gulf states. Cold weather storm areas passing out to sea on the Atlantic coast encounter the warm Gulf Stream, and, even if no static or electrical storms have been previously developed, they may rapidly occur at sea, thus creating heavy static disturbances over the Atlantic and eastern states.

MECHANICS OF THE THUNDERSTORM. Thunderstorms have their origin in masses of warm and moist air. This air rises because of convection, cools because of expansion and therefore reaches a vapor point, resulting in the formation of a *cloud*. But a cloud may become overgrown, and the condensation of moisture is sufficient to cause precipitation. Strong descending air currents now form beneath the clouds, which push forward as they reach the earth and displace the warm air that is ascending and being condensed into more clouds. In the region *between* the descending cool air and the rising warm air, a vigorous *eddy* forms which can be seen as a turbulent squall cloud rolling along in advance of the thunderhead clouds. See Figure 100. The air pressure rises and the temperature falls when this squall cloud passes. This action is due to the descending cool air of greater density in the rear of the turbulence. Rain now falls and lightning flashes follow in close succession. Storms of this character occur with greatest vigor when large masses of warm and moist air are present, during the hottest time of the day and the hottest season of the year, as all natural requirements are then in accord. These storms also nearly always occur on the southeast side of a low or storm area, and while many miles away, may give out considerable static interference in all directions.

Production of Rain Drops. In order that *condensation* may form and *rain-drops* begin to fall, it is necessary that some sort of particles be in the air to form *nuclei* upon which the moisture can collect. These nuclei are very minute, but as they pass slowly through the clouds, they collect and attract moisture, and become larger, until, overcoming the upward air currents because of the attraction of gravity, they fall as rain. Dust particles, as well as simple ions, serve as nuclei. When moisture is condensed on the various types of nuclei and rain drops form, they are constantly broken up or combined before they fall upon the earth beneath, an action that divides or increases their individual charges until the atmosphere becomes highly charged.

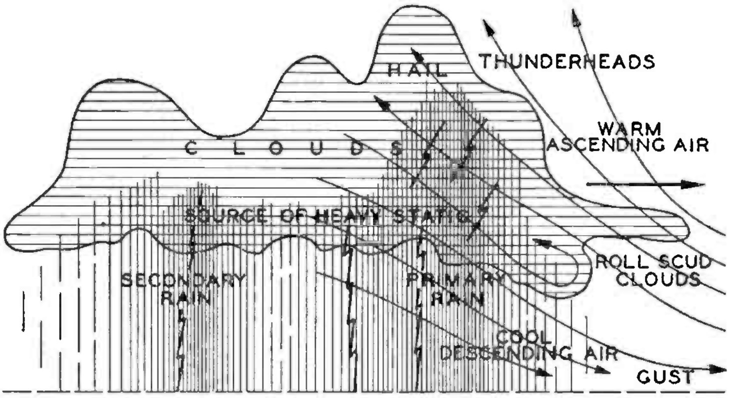


Fig. 100. Cross-Section of a Thunderstorm

ELECTRIC CHARGES OF RAINDROPS. When these raindrops, as well as the air molecules, are broken up through impact and friction, both positive and negative ions are given off. But whenever a negative ion is given off, the raindrop retains a positive charge. The charges of the clouds are thus constantly changed. There are many detached clouds within a thunderstorm, and different charges arrange themselves over the clouds with great rapidity, and many different potentials must exist between points in the atmosphere. They may become zero through negative differences in potential, and they may attain values so large that a breakdown of the dielectric or air gap, will eventually take place.

LIGHTNING. If a cloud is a thick one, or the rainfall quite heavy, the charge may become very large, and such clouds are likely to be attended by *lightning discharges.* Eventually the potential difference between the cloud and the earth becomes sufficient to cause an electric spark to pass between the two. Again, different parts of the same cloud or different clouds may become so charged with opposite charges of electricity that *internal* lightning flashes will result. Lightning occuring between clouds probably has a greater frequency than that between clouds and earth. The air gaps are less, and there is a constant change of distance and potential, while between the clouds and earth the distance may be as much as a mile. While appearing to be a single spark, a lightning flash does not pass from cloud to earth, but travels rapidly back and forth a number of times in an interval perhaps less than a thousandth of a second.

LIGHTNING OSCILLATIONS. A lightning flash is, therefore, an *oscillatory* discharge lasting an extremely short time, and capable of generating a powerful electromagnetic wave. It has been estimated that at least 20,000 amperes of electric current are liberated in an ordinary discharge. The potential greatly varies, depending upon the length of the discharge, but is always several millions of volts. When we consider that some millions of similar flashes take place throughout the world every day, propagating electromagnetic waves with an electric power that exceeds by many hundred percent that used in the greatest radio stations, it is no wonder that static is present in sensitive radio receivers at nearly all times. Lightning is usually zig-zag in appearance; it is an electric spark on a tremendous scale. There are several causes which contribute to give it this shape. The most general of these are various layers of different temperature, density and ionization in the atmosphere. Refraction is, therefore, different and a broken line appears; the eye is blinded by the glare, and much of the finer detail is lost. The electric discharge also follows the lines of least resistance which contain the greatest continuity of conductivity.

THUNDERSTORM STATIC. Every meteorological action within the development and existence of a thunderstorm is incident to the production of atmospheric electricity. The breaking of a raindrop into two separately charged portions, gives rise to very minute electromagnetic waves. Other charges of greater value are neutralized, and set up waves which reach the radio set hours before the storm develops locally. As a rule, when the weather is such that thunderstorms will develop in the late afternoon, the mechanical production of charged atmosphere takes place throughout a period of several hours, and considerable advance static will be heard. Directional radio compass apparatus may locate the general direction of the region of static, or approaching thunderstorm area. *Local static* in the atmosphere surrounding the set will, of course, have no directional effect on the apparatus. It will constantly *induce* electric charges in the antenna which will be discharged through the radio set as static crashes. In many cases the increase of static interference will *foretell* to some extent the development of a storm within a few hours. With the passing of the storm, local atmospheric electricity is cleared away and static interferences will rapidly *diminish.*

STATIC CAUSES. Small patches or areas of ionized and charged air come into contact with the antenna and are discharged; falling rain drops add their slight electric charges to the antenna so that static discharges pass into the radio set; passing charged clouds or other masses of atmosphere induce charges in the earth or in the antenna which are discharged through the receiver; and light-

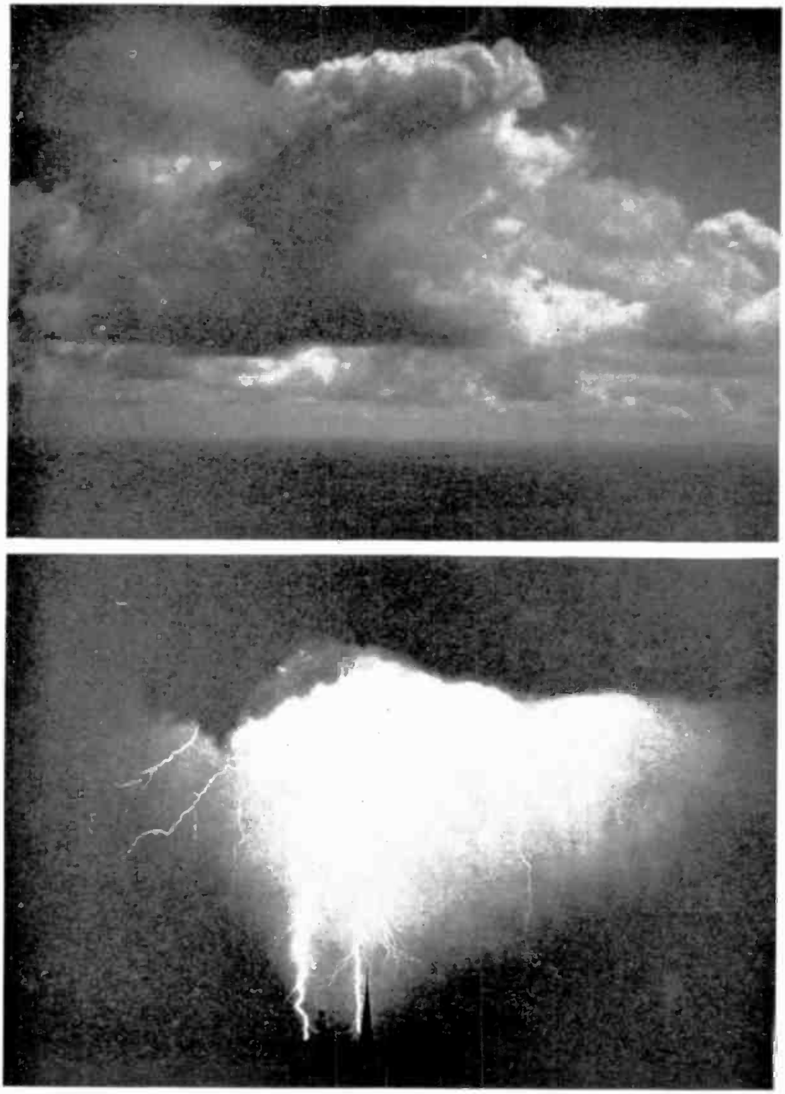


PLATE 7

Upper: A thunderstorm; and *Lower:* Lightning; serious sources of static—courtesy United States Weather Bureau.

ning discharges, nearby and many miles away, generate oscillatory waves which are picked up by the antenna. The more sensitive the receiving set, the more such static waves will be picked up. The mechanical and electrical sources of static produced through the actions of man-made instruments and apparatus, are of an entirely different nature, and were discussed elsewhere.

STATIC AND AIR PRESSURE. Cool dry air flows in the wake of a low pressure area. The air pressure rises, humidity decreases, clouds evaporate, and conditions favorable for the mechanical production of atmospheric electricity gradually pass away. With the receding of a storm area the audibility of static becomes less. When an area of high pressure covers the land, the interference from static is hardly noticeable. But static noises do not always cease with the advent of high pressure. This is because *another* low of some intensity is closely following and its approach is heralded by the continuance of the static noises.

FADING OF SIGNALS. It is not known what really causes signal *fading*, although mechanical failure is, without doubt, one of the greatest contributory causes. The radio wave travels in two sections, as it were, one by the direct horizontal path (ground wave), while the other travels by way of the atmosphere or ether. The reflecting layer (*radio ceiling*) wave reaches the receiving antenna as a reflection a very small fraction of a second *after* the ground wave. If we look upon the Heaviside Layer as a great undulating or billowed expanse that rises and falls above the surface of the earth, we can readily see that the reflection of the radio wave will vary. This variation in the under-surface will affect the quality of the reflected waves, and fading will result. Rises and falls of the Heaviside surface may produce *split* and *multiple* reflections, and cause interference or heterodyning of the various waves. Nearby reception, which uses much energy from the ground wave, is not subject to noticeable fading. Some stations will fade more than others, and some few present notable examples of consistent and fairly regular fading at all times. This may be due to some unknown local topography and associated physical condition which affects radio in some way we do not understand. It is doubtful whether meteorological disturbances in the troposphere can affect the Heaviside Layer at the top of the stratosphere, and cause it to be set in motion.

ATMOSPHERIC FADING. As the atmosphere becomes heavily ionized, it gives rise to areas or patches which act as does the Heaviside Layer in conductivity. These patches seriously interfere with the passage of the waves, either from the broadcasting station upward to the reflecting surface, or else downwards to the receiving antenna, depending upon the location of the ionized area. Such an area may reflect, deflect, absorb or distort the true passage of a wave through it, and produce a certain type of fading, or *blanketing out.* Without doubt, the inability of distant signals to reach out on certain occasions, has been due to the *smothering* effect of such areas. These present a return to daylight conditions during the night, for, during daylight, the ionized surfaces are down close to the surface of the earth, and reflections are very short. The drifting areas of ionized atmosphere may occur anywhere, but they are especially prevalent during storm periods when the ionization of the lower atmosphere is in rapid progress. It is very likely, therefore, that failure to receive from distances on certain occasions is due to the inability of the signals to get all the way through to the upper Heaviside Layer because of deflection or absorption in the lower atmosphere.

SUN SPOT EFFECTS. It is believed that *sun spots* affect radio transmissions and telegraph wire operation. Curiously enough, photographs of sun spots show a surrounding wave structure having a whirl-pool action, quite similar to the lines of force observed about a magnet. This may bring about the characteristic magnetic action of the sun spots. Whenever sun spots are plentiful there are severe electro-magnetic disturbances and strong earth currents upon the earth. Sun spots occur in approximately eleven year cycles. They are cooler than the rest of the sun, and because of the contrast in brilliancy, appear dark, while in reality they are dazzlingly bright. The electrical phenomenon in the stratosphere, perhaps in the Heaviside region, known as the *aurora,* also shows a close relationship to sun spots, and a correlation between them and magnetic storms on the earth has been almost definitely established. The aurora is nearly always associated with the higher latitudes and may be expected to interfere greatly with telegraph and radio communication. However, it must be said that interference with radio is not so severe as with telegraph lines. In the latter case, electro-magnetic induction, and corresponding earth currents, in long lines running between places having different earth potentials, will be extremely serious. Radio is not subject to this great amount of induction as there are no long lines to be considered.

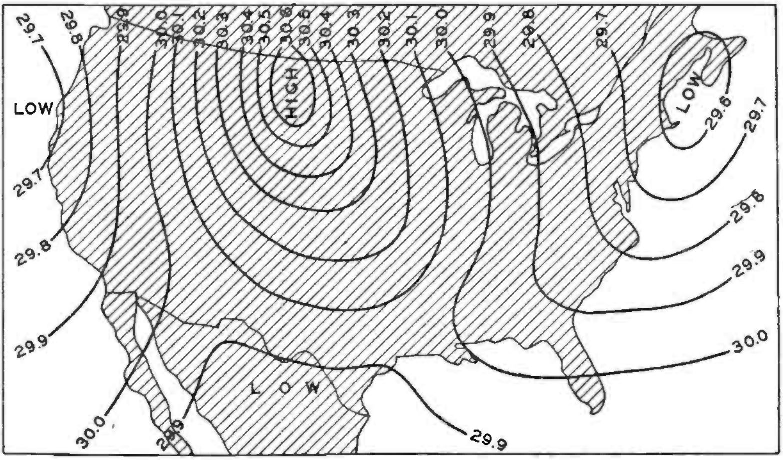


FIG. 101. HIGH PRESSURE AREA (COLD WAVE) ON WEATHER MAP

Little is known of the relationship between radio and the activities of sun spots and the aurora, and further research is handicapped because of the lack of some tangible basis of operation.

RECEPTION DURING COLD WAVES. During the fall and winter months high pressure areas of great magnitude, called *cold waves*, often cause phenomenal reception. See Figure 101. After a low area has moved off toward the east of the observer and practically no pressure difference exists between the sending and receiving stations, this phenomenal reception will slightly *diminish*, but due to the clear and cold atmosphere, static is virtually eliminated.

However, if reception is *across* (at right angles) a barometric gradient, or between two pressure areas, during a cold wave, excellent distant reception will be noted. When weather maps of these types are noted, it is safe to assume or predict excellent receiving weather for the ensuing 24 to 36 hours.

TEMPERATURE EFFECTS. Temperature alone does not affect radio transmission and reception, except for its *direct* relationship to the pressure of the atmosphere. Low temperatures, which are nearly always indicative of high air pressures and clear weather, are always accompanied with more or less freedom from static interferences. Falling temperatures indicate the arrival of a high, and a sharp *increase* in good reception may be expected. Rising temperatures indicate a fall in air pressure, as a rule, with high percentages of humidity content, and a *decrease* in good reception due to static increases. *Distant reception* may be satisfactory during high temperatures, but as the noise level of static will be increased, the advantages of loud distant signals is overcome, and reception will be poor. The temperature correlation may be summed up as follows: Reception will be consistently good and static will be mostly eliminated when the temperatures are low. This condition is reached during the winter in clear weather, or at other seasons in northern regions. In either case the air pressure is increased; and the depth of the troposphere overhead is decreased. Reception will not be good, and static interference will be serious in summer, or when the temperatures are high or when the weather is cloudy and stormy. If in winter, it is when storms occur and the temperatures rise, and toward the southern regions. In any case the air pressure is decreased, and the depth of the troposphere is increased, as over the equatorial regions.

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