CHAPTER TWO

FUNDAMENTAL PRINCIPLES OF RADIO

Electric Current—Electric Energy and Power—Batteries—Direct and Alternating Current—Magnetic Effect of Current—Production of Radio Waves—Nature of Radio Waves—Frequency and Wavelength—Wave Reception—Transmission Formulas—Comparison of Radio with Wire Telegraphy and Telephony—Tuning—Modulation—Summary.

It is a mistake to suppose that radio must remain a mystery because it operates through invisible electrical actions. It is easily possible to obtain an insight into the underlying processes. They are much less complicated than the mechanism of an automobile. The reader who is interested in the explanation of radio is advised to peruse this chapter, not omitting the early sections giving an introduction to electrical principles in general.

The thing about radio that seems mysterious and complicated is, of course, the lack of connecting wires between the place from which the message is transmitted and where it is received. This mystery begins to disappear when we think of some similar happenings. Sounding a certain note in a room will sometimes cause a string in a piano on the other side of the room to resound. Consider another case. Suppose you are watching a chip floating near the edge of a quiet pond. If someone drops a stone in the middle of the pond, the water ripples spread out in rings and soon the chip is bounding up and down. This is very much indeed like radio. The stone corresponds to the transmitting station, the chip is the receiving station, and the ripples correspond to the electric waves which constitute radio.

As will be explained later, the radio waves are produced by electric current in the transmitting station, and at the receiving station they are converted into electric current again. So we have to deal with electric current, both at the transmitting and the receiving end. Understanding of radio and ability to work with it boils down to understanding of electric current.

Electric Current.—When a battery is connected to a metal wire, a something called an electric current flows in the wire. Like anything else, the electric current is useful because of the effects it produces. The two principal effects produced by electric current, through which it serves mankind, are (1) the heating effect and (2) the magnetic effect. Whenever current flows in a wire it heats it somewhat; this is the basis of electric heating devices and the incandescent lights in our homes. If a very small magnet is brought near a wire in which a current flows, the magnet will be deflected; that is, there is a magnetic effect produced near the wire. This is the basis of action of all dynamos and motors, of most electrical machinery, and (as we shall see later) of radio.

In order to have an electric current there must always be a closed "circuit," or path which returns into itself. A useful illustration of the electric circuit is a closed circuit of pipe (Fig. 1) completely filled with water, and provided with a pump to circulate the water. Electricity behaves in the electric circuit much like an incompressible liquid in a pipe line. We are very sure that electricity is not like any material substance which we know, but the common practice among students and shop men of calling it "juice" shows that they think of it as like a liquid. It is convenient to consider the electric current to be a stream of electricity flowing through the wires. Current is measured

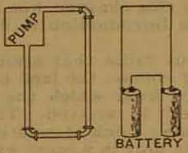


Fig. 1—An electric circuit is like a pipe circuit full of water.

by an instrument called an ammeter, which shows at each moment just how strong the current is, in somewhat the same manner as we may estimate the swiftness of a stream by watching a chip on the surface. The ammeter measures the current in a unit called the ampere.

The water will not flow in the pipe line, Fig. 1, unless there is some force pushing it along, such as the pump, and it cannot be kept flowing without keeping up the pressure. Electricity will not flow in a circuit unless there is a battery or other source of electricity in the circuit. The battery is for the purpose of providing an electric pressure. This electric sort of pressure is called voltage. The larger the number of cells which are joined in the circuit the greater the electric pressure and the larger the current produced, just as the rapidity of flow of the water in the pipe line may be increased by increasing the pump pressure. The unit of voltage is the volt, and voltages are measured by an instrument called a voltmeter. The usual city lighting circuits have a voltage of 110 volts. One cell of a lead storage battery gives two volts and a dry cell about 1.5 volts.

There is always some friction or resistance in a pipe whatever its size or material, and this hinders the flow of the water to some extent. Similarly, there is something like friction in an electric circuit, which is called resistance. The greater the resistance the smaller the current which can be produced in the circuit by a given battery.

The unit of resistance is called the "ohm." The current in amperes is equal to the voltage in volts divided by the resistance in ohms.

Electric Energy and Power.—The flow of an electric current is accompanied by the flow of a certain amount of power. The capacity of anything to do work is called energy, and power is the rate at which energy is produced or the number of units of energy produced per second. The purpose of electrical apparatus is the transformation of the power of the current into other forms of power, heat, light and motion. The electric current is the means by which we transmit energy from the power-house to the consumer, and we are not, for practical purposes, concerned with the method of carrying the energy any more than we need to inquire into the nature of the belt by which mechanical energy is carried from one wheel to another, or into the chemical nature of the water which is furnishing the power in a hydraulic plant.

The electric current itself cannot be seen, felt, smelt, heard or tasted. Its presence can be detected only by its effects—that is, by what happens when it gives up some of its power, as, for example, causing a motor to turn. Electrical power is given up, and mechanical power takes its place. Similarly, electric power may be used up and heat or light may appear in its place. The electric lamp has an effect on the eye. We do not see the electric current in the lamp, but the effect on the eye is due to the light waves sent off by the hot filament. The power of the current has been changed over into heat in the lamp. When we hear a buzzing in the telephone, it is not the electric current we hear, but merely the vibration of the receiver diaphragm. The electric current has used some of the power in moving the diaphragm.

The power which is furnished by the electric current to any electrical apparatus depends both on the amount of the current and the voltage (electric pressure). The power is the product of the two. The product of current in amperes by voltage in volts gives power in watts. For example, an electric flatiron takes about 5 amperes at 110 volts, so the power which it uses is 550 watts. Another unit of power that is commonly used is the kilowatt, which is simply 1000 watts. Thus

750 watts is three-quarters of a kilowatt; that is, about one horsepower.

A little study of the following table may assist the reader to understand the units in which electric power and energy are expressed. The way electric current furnishes power is similar to the flow of water through a pipe system, at some point at which a water motor is placed. The power supplied to make this water motor turn and perform work would depend both on the flow of water through it and the pressure acting between the inlet and the outlet of the water motor.

	Water	Electricity
Rate of flow is measured in	Gallons per sec.	amperes
Pressure is measured in. . .	Lbs. per sq. in. . .	volts
Power is measured in	Horsepower . . .	watts or kilowatts
Energy is measured in	Horsepower-hrs.	kilowatt-hours

Batteries.—A battery consists of a number of units called voltaic cells, or simply cells. A cell is a combination of chemicals with two metal terminals. When the terminals are connected by a wire, a current flows in the wire, the electrical energy coming from the chemical energy inside the cell. Batteries are used to light the filaments of electron tubes and to supply plate voltage.

Among the most commonly used batteries are so-called dry batteries. These are not really dry, but are filled with a material which is moistened with the active solution and then sealed. One terminal is a carbon rod, while sheet zinc forms the containing vessel. This type of cell is made in a variety of shapes and sizes, and is now used in large quantities for use in flashlights, vehicles and all sorts of portable devices as well as radio receiving sets. Attempts are sometimes made to increase the life of dry cells by making a hole in the top and adding water, and also by recharging them electrically, like storage cells; but the gain is very slight and is seldom worth the trouble.

Dry batteries depend for their operation entirely upon the chemical energy contained in the materials of which they are constructed, and when the cells are exhausted, the materials have to be replenished or new cells purchased. In distinction from such cells are storage cells. These do not contain any available energy to start out with, but this energy is supplied by passing an electric current through them. This operation is called charging. After being so treated, current can be drawn from them. The process of drawing a current from the battery is called discharging.

The energy which is stored in the cell by the charging process is stated in watt-hours or kilowatt hours, like any electrical energy. As already explained, electrical energy in watt-hours is the product of the voltage in volts, the current in amperes, and the time in hours. The last two of these factors taken together, *i. e.*, the current multiplied by the time, gives the quantity of electricity that is put into the cell in the process of charging or converting electrical energy into chemical energy in the cell. The quantity is expressed in ampere-hours. Battery manufacturers have gotten into the habit of rating storage batteries by the number of ampere-hours used in charging.

Only two types of storage cells have proved to be commercially successful. The more common type, called the "lead" storage cell, consists of lead plates, the surface of which have been specially treated with lead oxides, immersed in a dilute solution of sulphuric acid. It gives a voltage varying from 2.0 down to 1.75 when discharged. The Edison storage cell has nickel and nickel-iron for the plates, and the solution is an alkali. It gives a voltage varying from 1.4 down to 1.0 volt when discharged.

Direct and Alternating Current.—When a water pump keeps up a steady pressure, the water in the pipe line flows steadily and continuously in the same direction. Just so electric batteries and certain dynamo machines cause a current which flows always in the same direction around the circuit. This kind of current is called direct current. Certain other kinds of dynamo machines produce current which alternates in direction at some definite frequency; this is called alternating current. The usual frequency of lighting current is 60 per second; that is, the current flows first in one direction and then the other, repeating this 60 times each second. Radio makes use of currents alternating millions of times a second.

It is easy to tell whether an electric current is direct or alternating by using it to light a carbon-filament incandescent lamp and holding the lamp near a permanent magnet. If the hot filament is drawn to one side of the bulb and remains there, it is direct current. If the filament vibrates so that it seems to widen out into a bright band, the current is alternating.

Electric devices which depend for their operation on the heat produced by the electric current operate equally well on direct and alternating current. Devices, however, which make use of the magnetic effect of the current may behave very differently with direct and alternating current.

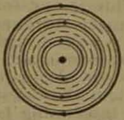
Magnetic Effect of Current.—One of the principal reasons why electricity has revolutionized the everyday life of mankind is that it may be utilized to produce motion. This simple principle makes possible the operation of telegraph and telephone, electric bells, electric motors, elevators and street-cars. The electric motor is also the backbone of many labor-saving devices used in the home, such as the vacuum cleaner, washing machine, electric fan, pump and sewing machine.

The reason that an electric current can cause motion is that every electric current is surrounded by a magnetic field. This is simply shown by the fact that any iron which is near an electric current becomes magnetized and tends to move. The motion of the iron may be back and forth, as in the telegraph, telephone, or electric bell, or it may be round and round as, in a motor.

In an electric bell, the electric current produces a magnetic action which causes motion of an iron piece; then the current is interrupted and the iron piece allowed to fall back to its former position, and then the whole process is repeated over and over.

Besides causing iron to move, the magnetic field which every electric current produces is responsible for many other important effects. Whenever a magnetic field changes, it tends to produce an electric current in any conductor nearby. Thus a changing electric current causes a changing magnetic field, and this in turn causes another electric current in a different conductor. The changing magnetic fields produced by varying electric currents are what make radio possible.

Production of Radio Waves.—Wherever there is an electric circuit in which alternating current is flowing, a magnetic field around the wire is constantly being produced and varied as the current in the wire varies. This magnetic field spreads farther and farther out, giving rise to an electric wave, just as a sound wave starts out from a vibrating bell or tuning fork. A powerful sound can be produced by using a very large tuning fork, and similarly a powerful electric wave is produced by making some part of the electric circuit large in dimensions. This enlarged part of the circuit is called the antenna. The antennas used in radio work, as is well known, often consist of long conductors supported on very high towers. The mechanism for producing a radio wave, therefore, is simply an enlarged or extended portion of an electric circuit in which an alternating current is made to flow. In the space near the antenna, alternations of electric pressure and of magnetic field are produced, just as alternations of air pressure are produced around a tuning fork. At any instant the electrical condition of the space around an antenna which is sending out radio waves could be shown by a diagram such as Fig. 2. The arrow on the line extending between the antenna and ground indicates that the electric pressure at a particular moment is in the direction indicated. When the current changes in direction, the direction of this electric pressure will be reversed and the electric pressure already mentioned will have handed on its effect to the surrounding space. Thus the effect of an electric pressure is handed on and spreads out through space, the direction of this pressure at any point is constantly alternating as the direction of the current in the antenna producing it alternates. The frequency of this alternation of the wave is the same as the frequency of alternation of the current in the antenna.



VIEWED FROM ABOVE

VIEWED FROM SIDE

Fig. 2—Production of Waves Around an Antenna.

Lines of electric pressure alternating in direction are thus constantly spreading out from the antenna just as the ripples spread out on a pond after a stone has been thrown into it. Something very similar to the ripples would be seen if, in some way, the alternations of electric pressure could be made visible and a person were to look down from above upon the antenna and the space around it. The waves of electric pressure spreading out and successively alternating in direction would look something like the lines shown in the upper part of Fig. 2. The waves spread out in all directions and go to great distances.

It at once suggests itself that the waves will produce an effect at a point far distant from the source if a means is provided at that point for converting the wave action into electric current in a circuit. In this way electric communication without connecting wires is established.

Nature of Radio Waves.—We cannot see electric waves as we see ripples or the waves on a pond, but there is nothing especially mysterious about them. We cannot see sound waves. If a tuning fork is struck, it gives off sound waves which, starting at the tuning fork, travel out into the air in all directions, like the ripples referred to. Sound waves are produced by the motion of the metal prong of the tuning fork. As the prong moves back and forth it causes the air next to it to move back and forth. This motion is handed on to the surrounding air and so moves out to a great distance in the air just as the ripple on the pond spreads out. The slight to-and-fro motion of the air spreading out in this manner is called a sound wave.

Electric waves also consist of a certain kind of to-and-fro motion. Just as the motion of the tuning fork causes alternating pressure in the surrounding air, similarly, whenever an alternating electric current flows in an electric circuit, the to-and-fro motion of the current causes alternating electric pressure in the space next to the wire. This to-and-fro or alternating electric pressure in the space surrounding the wire affects the surrounding space and spreads out in exactly the same way as a sound wave in air.

The electric waves are also called radio waves, and it is by means of them that radio communication is carried on. It is an interesting fact that radio waves are really of the same kind as light waves. We are all familiar with light waves, and it should help to make radio waves less mysterious to know that they are both electric waves. The difference between light and radio waves is the frequency of alternation. Thus electric waves are much more common things than is sometimes supposed. Electric waves are used for many purposes, their use depending on the frequency of the waves. This is shown by the following table.

Waves Produced by	Cycles per Second
Commercial Alternating Currents	25 to 500
Ordinary Telephone Currents	16 to 3,000
Radio	12,000 to 20,000,000
Heat and Light	3,000,000,000,000 to 3,000,000,000,000,000
X-Rays	3,000,000,000,000,000,000

Frequency and Wave Length.—Frequency is the number of cycles per second, or the number of to-and-fro alternations of the electric pressure as the wave travels out through space. Wave length is the distance from the crest of a wave to the crest of the next adjacent wave. Since all electric waves travel at the same velocity (186,000 miles per second, or 300,000,000 meters per second), the shorter the length of the waves the larger the number of them which will pass by a given point during a second. The length of the waves is numerically equal to their velocity divided by their frequency (number of cycles per second). That is,

$$\text{wave length in meters} = \frac{300,000,000}{\text{frequency}}$$

$$\text{or, more exactly,} = \frac{299,820}{\text{frequency in kilocycles}}$$

For example, a radio wave 600 meters long is caused by a current in a transmitting antenna having a frequency of 500,000 cycles per second, or 500 kilocycles per second, the term "kilocycle" designating 1000 cycles.

All of these waves travel at the same speed. These electric waves are of an entirely different nature from sound waves. Sound waves are not at all electrical; they consist of actual to-and-fro motions of the air particles and travel with a speed of about 1,000 feet per second. The speed at which electric waves travel is much greater than this; it is so great that the passage of any kind of electric wave is practically instantaneous. The various kinds of electric waves shown in the table are much alike in many ways, but they have some characteristic differences. Thus, radio waves are different from light waves in that they go through ordinary walls of buildings and other obstacles which are opaque to light.

The waves are radiated and spread out more effectively the higher the frequency. The ordinary low frequencies used in the alternating currents which light our houses alternate very slowly. Such waves travel readily along wires. In order to get a wave which will travel effectively through space, higher frequencies must be used; that is why the waves used in radio communication make a large number of vibrations per second.

It is to be noted that these frequencies are not, however, as high as the frequencies of light waves. Light waves travel in straight lines, which is one of their characteristic differences from low-frequency waves of alternating current power which follow along wires. Radio waves are intermediate in character between the two, and can travel in straight lines and also travel along conducting wires.

The fact that radio waves, which are able to travel out into space without conducting wires, are of high frequency, is one of the important characteristics of radio communication.

Wave Reception.—Now think of what is happening at a distance from an antenna which is sending out waves. As the wave passes any point there is an alternation of electric pressure going on continuously at that point. The alternating electric pressure or

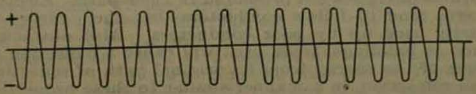


Fig. 3—Continuous Wave.

wave action at that point could be illustrated by the wavy line of Fig. 3. The portions of the wave above the horizontal line correspond to the electric pressure in one direction, and the portions below correspond to the electric pressure in the other direction. This can be understood by thinking of a sound wave. As the sound wave passes out through the air, it will set in vibration any object which is capable of taking up the motion. Suppose, for instance, that a sound wave produced by a tuning fork passes a second tuning fork which is in tune with it, that is, having the same natural pitch or frequency of vibration as the first tuning fork. The to-and-fro motion of the air will start the second tuning fork into motion. This can be readily shown with two tuning forks, striking one of the forks, thus producing a sound wave. It can be proved that the second tuning fork is set into vibration by grasping the first with the hand so as to prevent its further motion. A sound from the second one can then be heard.

A radio wave can produce an effect at a distance in just the same manner. In any electric circuit the moving wave of electric pressure produces an electric current alternating with the same frequency as the wave. The moving wave is accompanied by a magnetic field, just as a current is. This moving magnetic field produces an electromotive force in any conductor across which it cuts, just as an electromotive force is produced by any other relative motion between a conductor and a magnetic field. The electromotive force thus produced is what causes a current in the receiving antenna.

Transmission Formulas.—Formulas expressing the relation between the current received in an antenna expressed in terms of the current in the transmitting antenna and the constants of the two antennas are presented in Chapter Seven. The magnitude of etheric disturbances depends upon the current in the transmitting antenna, and the magnitude of the current in the receiving antenna depends upon this disturbance. The effects are different for the different types of antennas, so the equations were worked out for different combinations of the two most used types—flat-top and coil antennas.

As the waves travel through space they are subject to absorption of energy as the distance increases and various obstacles are presented in their path. Electric waves tend to follow conductors, but their energy is partly used up by poor conductors. Also obstacles, such as buildings, trees, etc., will cause a deflection of some of the energy from its original path of reflection and refraction, in a manner similar to these properties of light waves. By absorption of the waves we simply mean the diminishing of the wave through loss of energy in obstacles, etc.

This decrease in intensity, expressed in terms of the intensity at the transmitting antenna, is called the absorption or correction factor. To determine the value of the current received in the antenna, the proper formula must be used, and then multiplied by the correction factor to take into account the absorption.

From the formulas certain general conclusions can be drawn. Thus, since λ appears in the denominator, it follows that, for given heights of antenna, sending current, receiver resistance, and distance apart, there will be more current in the receiver, the shorter the wave length used. On the other hand, there is more absorption of short waves than of long ones. This effect is taken account of in the correction factor to be used for long distances. In this factor, λ enters in such a way as to make the received current less when the wavelength is short than when it is long. Hence, in general, we conclude that to get the greatest possible received current, we should use short waves for short distances and long waves for long distances.

It may be seen from the formulas that, for simple antennas, the received current (for a given wave length, sending current, receiver resistance, and distance apart) is greater, the greater the heights of the antennas. In the case of coil antennas under the same conditions, the received current is greater, the larger the areas and the number of turns of the coils. For the dimensions actually used, antennas are much more effective radiators and receivers than closed coils. In order to secure the same radiation or received current with a closed coil as with an antenna, other conditions being the same, its dimensions must be nearly as great as the antenna height. However, it is often possible to put more current into a transmitting coil than into the corresponding antenna, and also the resistance of a receiving coil is usually smaller; hence the coil can be a smaller structure than the antenna.

The coil has some other advantages over the ordinary type. For a given power input in the transmitter a larger fraction of the radiation is sent out in the direction desired. As a receiver, the directional property is a great advantage.

Comparison of Radio with Wire Telegraphy and Telephony.—In the preceding sections the mechanism by which an electrical action can be made to affect a distant point without wire connection has been explained. The ether which fills all space can be considered to replace the wire connection. Thus, in wire communication there is a system as represented in Fig. 4, which shows a conducting wire line containing a source of varied current at one end and a detecting device (D) at the other end. In radio communication the wires are eliminated, so that the corresponding simplified system would be as represented in Fig. 5, which shows the similar source of varied current and detecting device (D), each of these, however, being placed in a simple electrical circuit and the conducting wires between being eliminated. Both of these diagrams have been so greatly simplified that neither of them is really just like an actual telegraph or telephone system. Certain additional features must be used beyond what is shown in either Fig. 4 or Fig. 5 to carry on telegraphy or telephony. A species of telegraphy is possible by merely adding a key in either Fig. 4 or Fig. 5. Wire communication of this kind

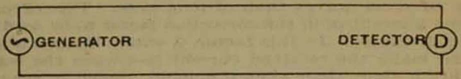


Fig. 4—Wire Communication.

would thus be the use of an alternating-current generator as the source of power and a telephone receiver as the detector (D). The corresponding radio system would be the use of an alternating-current generator of high but still audible frequency together with the use of a telephone receiver in place of detector D. As a

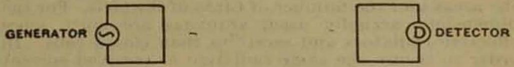


Fig. 5—Radio Communication.

matter of fact, simple systems of just this kind are not used because great advantages are secured by the addition of certain features which will now be discussed. Furthermore, these additional features not only improve radio-telegraphy but are necessary for radio telephony.

Tuning.—The extremely simple system of radio communication indicated in Fig. 5 is not effective unless the alternating current used is of high frequency. Even then the current produced in the receiving circuit would be very small indeed unless the receiving circuit is in tune with the wave; that is, it must be arranged to respond to the frequency of alternation possessed by the first circuit and the wave which it sends out. This is just like what happens with the two tuning-forks and the sound wave. The second tuning-fork does not respond to the wave from the first unless the two are in tune. This can be shown by placing a bit of wax on one of the prongs of the second tuning-fork, changing the pitch of that fork. When the first tuning-fork is struck under these conditions it can readily be demonstrated that the second fork does not respond. In the same way the electrical arrangements in the receiving circuit which are used to receive radio waves must be such that the receiving circuit is electrically in tune with the radio wave. By this means the radio receiving circuit can pick out the particular wave which it is desired to receive and not be affected by other waves. This is fortunate, because otherwise the interference between different radio messages would be hopeless. It would be just as though every sound wave which passed through the air set absolutely everything which it touched into vibration.

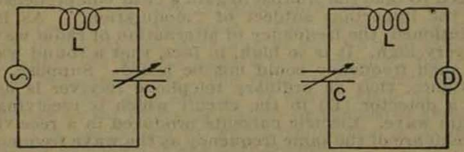


Fig. 6—Tuned Radio Circuits.

Just as the frequency to which a tuning fork responds depends upon its inertia or mass and its springiness or elasticity, the frequency to which the electrical circuit responds depends upon two corresponding electrical properties called inductance and capacity, respectively. The "inductance" is the electrical quality that corresponds to the inertia or mass of the tuning-fork, and the "capacity" corresponds to its elasticity.

A condenser may be thought of as similar to a gas tank used for the storage of gas. The amount of gas a tank will hold is not a constant fixed amount; it depends on the pressure. If the pressure is doubled, twice the amount of gas is forced into the tank. If the pressure is released and an opening is left in the tank, the gas rushes forth. Similarly, the amount of electricity that can be put into a condenser depends on the electrical pressure, called voltage. When the voltage is increased, more electricity flows into the condenser, and when the voltage is diminished, the electricity flows out again. By alternately increasing and diminishing the voltage, an alternating electric current flows in the condenser. Thus a condenser allows an alternating current to flow, although it contains an insulating partition which prevents the steady flow of direct current.

The greatest current is produced in a receiving circuit when both the transmitting and receiving circuits are tuned—that is, arranged so that the product of the capacity and inductance is the same in each. The elements of a typical radio circuit are thus rather more complicated than shown in Fig. 5, which should be replaced by Fig. 6. The symbols C and L indicate the conventional diagrams for capacity and inductance. The device used to introduce capacity into a circuit is called a condenser, this usually consists of a pair, or two sets, of metal plates separated by air or by some solid non-conductor. The device used to introduce inductance into a circuit is called an inductor, or an inductance coil, or simply a coil; it is a coil of wire, as suggested by the usual diagram for an inductance.

Modulation.—We come now to a feature of radio which is often not understood. The reader is especially urged to take the trouble to gain a clear comprehension of the important subject of "modulation." As just mentioned, the frequency of alternation of radio waves is very high. It is so high, in fact, that a sound wave of such frequency could not be heard. Suppose, for instance, that an ordinary telephone receiver is used as a detector (D) in the circuit which is receiving a radio wave. Electric currents produced in a receiving circuit are of the same frequency as the wave frequency and tend to cause motions of the telephone receiver diaphragm. These motions are, however, of such great frequency that the diaphragm produces no audible sound. In order to permit the radio wave to be received and transformed into a sound, it is therefore necessary to break up the radio wave in some manner. This is done in radio telegraphy by interrupting the wave

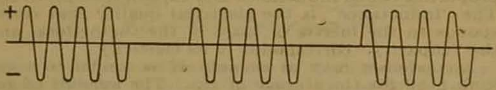


Fig. 7—Interrupted Wave.

completely, so that it consists not of a single regular series of alternations but of a succession of groups of such alternations; that is, instead of the continuous wave shown in Fig. 3, it consists of the interrupted wave or group of waves illustrated in Fig. 7. The frequency of the interruptions or of the groups of waves is a frequency which is low enough to be heard. One of the ways of breaking the waves up into groups is by use of a "chopper," which is simply a rapidly rotating disc with contacts on it so as to alternately open and close the circuit.

This process of varying the high-frequency wave so that it is no longer a single, regular series of alternations is called modulation.

Instead of breaking the wave up into simple groups of alternations, it is possible to modulate it (*i. e.*, cause it to vary) in a manner which follows the sound variations produced by the human voice. It is thus possible to make a radio wave carry a voice wave. This is the process of radio-telephony.

A voice wave may be represented as in Fig. 8. The variations in the voice wave are much slower than the alternations used in radio and it is possible to so impress the slower alternations on the high-frequency wave that a suitable detecting device will reproduce the voice wave in a telephone receiver. The voice will be heard just as radio telegraph signals are heard. The way in which the voice wave is superimposed upon the radio wave is shown in Fig. 8. The alternations of the radio wave are shown by the full lines, and the dotted boundary lines show that the intensity of the wave has been made to vary in accordance with the sound wave produced by the voice. This wave can be received in exactly the same way as any wave in radiotelegraphy—no special apparatus is required for receiving radio-telephony. The voice at the transmitting station is heard very clearly. It can be made as loud as desired at the receiving station by the use of amplifiers. The mechanism by which modulation is accomplished is explained in the next chapter.

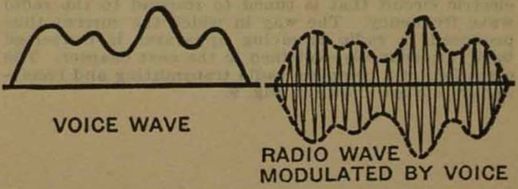


Fig. 8—Voice-modulated Radio Wave.

Besides the reason given in a preceding section for the use of high frequency in radio, there is another very powerful reason, which is connected with modulation. When it is desired to carry on telephony, it is necessary that the alternating current which produces the waves be of a frequency to which the sense of hearing does not respond. This is necessary because if the waves were of an audible frequency, the current which they produce in the receiving circuit would produce a sound that would be heard and would interfere with the voice or other sound which it was desired to hear. The wave frequency must therefore be so high that a sound wave of such frequency could not be heard.

Summary.—The principles of radio have been briefly explained in this chapter. They are few and simple. An electric wave is sent out into the air by means of electric current flowing in the transmitting antenna the current being an alternating current of very high frequency. The high-frequency current (and consequently the wave it produces) is varied in accordance with the sound variations of the speech or other sound

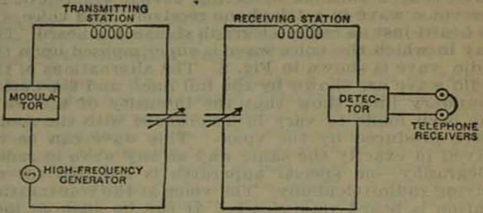


Fig. 9—Complete Radio Transmitting and Receiving System.

or signal which is to be transmitted, this process being called modulation. The radio wave spreads out in all directions, and can produce electric current in any electric circuit that is tuned to respond to the radio wave frequency. The way in which the current thus produced in radio receiving apparatus is converted back into sound is explained in the next chapter. The essentials of a complete radio transmitting and receiving system are shown in Fig. 9.