FIG. 1. CIRCUIT PRODUCING RADIO WAVES (AT RIGHT) AND (AT LEFT) CIRCUIT IN RESONANCE THEREWITH

Radio Communication

Elementary Explanation of the Principles of Radio Telegraphy and Telephony

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MESSAGES are now sent without wires between any points on the earth's surface, in the air, or under the ocean. It is possible to sit down to the telephone in your house and talk to persons not only in distant cities but to persons sailing on the ocean or flying in airplanes. The principles which make wireless or radio telephony possible are really not difficult to grasp. While a great deal of mystery has been made of radio, as a matter of fact everything about it is simply a part of principles and ideas well known to science.

Since the results achieved in wireless communication are somewhat striking, the newspapers lose no opportunity to use them to incite the wonder of people.

The radio telephone is not a particular instrument; that is, when you talk into a radio telephone you do not necessarily talk into anything different from the ordinary telephone on your desk. Sometimes people talk of a radio telegraph or even of a radio, indicating an idea that some particular, wonderful kind of apparatus accomplishes the feat of communicating from one place to another without wires. As a matter of fact, radio is a system or method involving a great many instruments and appliances. Some of the instruments are very interesting indeed, among them being the electron tube of which more will be said later.

The history of radio is all comprised within our own lifetime, and has been a steady conquest of distance. The rising line in Fig. 2 shows for any year since 1897 the greatest distance which had then been obtained by radio commu-

Despite the fact that radio telegraphy and telephony is now an old story and although countless youthful experimenters throughout this land are familiar with the principles underlying these forms of communication, there are many men to whom the transmission of messages through space is still a deep mystery. For this reason we believe that the following paper by J. H. Dellinger of the staff of the U. S. Bureau of Standards, which was recently delivered as a popular lecture and which gives a very elementary explanation of radio communication will be welcomed by many of our readers.—EDITOR.

nication. It increased from three-fourths of a mile the first year, when Marconi performed his startling first experiment, to thirty-four miles the next year across the English channel, and so the distance has steadily risen. Last year the distance finally rose to 12,000 miles. This is the limit, since 12,000 miles is half way round the earth. We cannot communicate any further than this unless we exchange signals with other planets. To be sure the newspapers had us communicating with Mars in April, 1920, but this must be discounted.

The word "radio" suggests its own explanation. It means to radiate. Radio communication is carried on by means of waves which are radiated from one place and received at another. These radiated waves are electric waves but they have all the characteristics of wave motion possessed by other kinds of waves, such as sound waves or even the simple waves produced in water when a pebble is thrown into a pond. Much can be learned about the way radio waves act by watching the spreading out in circular rings of ripples on water. Other simple types of waves are also produced by ordinary mechanical means. One can easily produce waves on a rope by shaking the free end. This illustrates that a wave always consists of some sort of to-and-fro motion. Waves can be slow or fast and of different wave length. We cannot see electric waves, as we see ripples or the waves on a rope, but there is nothing special or 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. Fig. 1 shows a simple electric circuit (rectangle of wire) arranged so that an alternating current is produced in the wire. When the key is pressed a spark occurs at the spark gap, which lets one know that an electric current is flowing. It is to be noted that this apparatus produces at the same time sound waves, light waves, and electric waves. 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 showing the frequencies of the various kinds of electric waves. By frequency is meant the number of vibrations per second or the number of to-and-fro alternations of the electric pressure as the wave travels out through space.

Waves Produced by	Vibrations per Second
Commercial Alternating currents	25 to 500
Telephone Currents	16 to 3,000
Radio	10,000 to 30,000,000
Heat and Light	3,000,000,000,000 to 3,000,000,000,000,000
X-Ray	3,000,000,000,000,000,000

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.

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 frequencies shown in the table for 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 the 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.

Radio waves are different from light waves also in that they go through ordinary walls of buildings and other obstacles which are opaque to light.

We are now ready to consider how an electric wave may be produced.

Whenever there is an electric circuit in which alternating current is flowing an electric wave starts out just as a sound wave starts out from a vibrating 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. The antennas used in radio work, as is well known, often consist of long conductors supported on very high towers. A 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 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. 5. 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

FIG. 2. PROGRESS OF LONG DISTANCE RADIO TRANSMISSION

FIG. 3. CONTINUOUS WAVES

FIG. 4. INTERRUPTED WAVES

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 constantly alternating as the direction of the current in the antenna producing it alternates. Lines of electric pressure alternating in direction are thus constantly spreading out from the antenna just as the ripples spread out on a pond. 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. 5. The waves spread out in all directions and go to great distances.

Now think of what is happening at a distance from the antenna. As the wave passes any point there is an alternation of electric pressure going on continuously at that point. The alternating electric pressure or 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 again of the ripple on the water. Suppose there is a cork or other floating object on the surface of the water at a distance from the place where the ripple starts. As the ripple takes place, the cork rises and falls, partaking of the to-and-fro motion of the surface of the water. Or consider the 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. The same thing is sometimes illustrated in a room. If a note is sung or produced on some instrument, a response may be heard from one of the strings of the piano or from a loose portion of a chandelier or other resonant object in the room.

FIG. 5. PRODUCTION OF WAVES AROUND AN ANTENNA

An electric wave can produce an effect at a distance in just the same manner. In any electric circuit the moving wave of electric pressure can produce an electric current alternating with the same frequency as the wave. This is also readily illustrated just as the effect of one tuning fork on another was illustrated. Taking the same electric circuit with its spark gap, which was shown before, and allowing an alternating current to flow in it, it sends out an electric wave which can act on another electric circuit entirely disconnected from the first. In Fig. 1 the response in the second circuit when a current flows in the first circuit is shown by the fact that the indicating tube in the second circuit lights up when a current flows in the first circuit.

In order that this may take place, the second circuit must be in tune with the first. 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.

As has been mentioned the frequency of alternation of radio waves is very high, so high, in fact, that a sound wave of such frequencies could not be heard. Suppose, for instance, that an ordinary telephone receiver was placed in the circuit which is receiving a radio wave. The electric currents of the same frequency as the wave frequency tend to cause motions of the telephone receiver diaphragm. These motions are, however, of such great frequency that no audible sound is produced. In order to permit the radio wave to be received and transformed into a sound it is therefore neces-

FIG. 6. USING ELECTRON FLOW FROM HOT FILAMENT

FIG. 7. USE OF ELECTRON FLOW APPARATUS AS AN ELECTRIC VALVE

FIG. 8. ELECTRON TUBE FITTED WITH A GRID BETWEEN THE FILAMENT AND PLATE

sary to break up the radio wave in some manner. This is done in radio telegraphy by interrupting the 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 we use the interrupted wave or group of waves illustrated in Fig. 4. The frequency of the interruptions or of the groups of waves is the frequency which can be heard.

There is another thing that is to be taken into account before it becomes possible to translate the received radio current into a sound that can be heard. When one of the groups of alternations shown in Fig. 8 acts on the telephone receiver it causes no motion of the diaphragm because each variation of the current in one direction is immediately followed by the current in the opposite direction so that the resulting effect of the group of waves upon the telephone receiver diaphragm is no motion at all. It is therefore necessary, in order to convert the current into a sound, to use something else with the telephone receiver. This something else must be such as to make the current flow through the telephone receiver in only one direction. It must allow the electric current to flow through it in one direction and stop current which tries to flow through it in the opposite direction; that is, it must be some sort of electric valve. The effect of such an electric valve may perhaps be understood more clearly by taking a sheet of paper and placing it upon Fig. 4 so as to block out the lower half of the waves shown. This leaves only the upper halves of the little groups of waves and this is exactly what the electric valve does. It results that successive impulses of current flow through the telephone receiver and all of these tiny impulses in any one group add their effects together and produce a motion out of the telephone diaphragm. The interval between one group and the next permits the motion of the telephone diaphragm to subside and this intermittent motion causes what is heard as a note in the receiver.

A number of devices are used to perform the electric valve action which has been mentioned. The most interesting and most effective device of this kind is the elec-

FIG. 9. VARIOUS TYPES OF ELECTRON TUBES

tron tube. The electron tube is a very simple device which looks more like an ordinary incandescent lamp bulb than anything else. Your attention is particularly invited to the principles upon which it operates since this is the most important of the apparatus used in radio. While experimenting in the development of the incandescent lamp Edison made the discovery that an electric current could be made to flow in the empty space inside the bulb near the hot filament. If a middle plate is placed inside of an incandescent lamp

bulb near the filament (Fig. 6) and if by means of a wire through the glass this middle plate is connected by wire through a battery and an indicating instrument to the filament, a current will flow as indicated by the instrument. A current is flowing in the wire and also flowing across the empty space between the filament and the plate. By much patient scientific research, scientists have found out that this current taking place in the lamp consists of the flow of a stream of very small electric particles called electrons. These electrons are shot out into the surrounding space in all directions by the hot filament. The electrons may be said to fill the bulb like a vapor. They move at random in all directions unless there is an electric force to make them move in some particular direction. The battery connected in the circuit outside the bulb supplies an electric force which acts between the filament and plate and makes the electrons move from the filament to the plate. If the battery is disconnected, there is no current, and as many electrons as strike the plate fall off again into the bulb. The current depends on the number and speed of the electrons. The battery is what gives them their speed in the direction filament to plate.

The battery performs much the same action as a steam pump would if the bulb were a room into and out of which steam pipes were connected. If the pump were disconnected, there would be no flow of steam and when the pump is connected, steam is made to flow into and out of the room and through the pipe.

The point of all this is that the electron flow in the bulb has a valve action. The electrons are emitted by the very hot filament and can be

FIG. 10. VOICE WAVE CARRIED BY RADIO WAVES

FIG. 11. THE PRINCIPLE OF THE AMPLIFIER

made to flow toward the plate by connecting a battery in the proper direction. If the connections of the battery are reversed, however, no current will flow because there is no such emission of electrons from the plate, which is cold, the electric force produced by the battery in this case has nothing to work on and can do nothing except prevent the flow of electrons out of the filament to the plate. It

should be clearly understood before going further that the action of the electron tube thus depends upon the fact that an electric force can be applied in one direction which causes an electric current from the filament to the plate, but that if this electric force is reversed no current flows. The device gives exactly the electric valve action needed in order to make the incoming radio signals produce sound in a telephone receiver. Suppose that the bulb shown in Fig. 6 is connected up to a radio receiving circuit in place of the battery. Suppose also that the indicating instrument is replaced by a telephone receiver. This is shown in Fig. 7. The pulses of current in the radio receiving circuit similar to those of Fig. 4 produce electric force inside the bulb between the filament and plate which alternates in direction just as the pulses of current do. On account of the valve action, current can flow through the bulb only in one direction and consequently the pulses of electric force in one direction only are effective. As a result, pulses of current flow through the telephone receiver in groups, the pulses being all in one direction. This causes a note in the telephone receiver, as already explained.

It might seem that these small electric particles, called electrons, are very remote from any practical use. The study of electrons has in fact been advanced by purely scientific re-

search not at all connected with any applications. By means of the electron tube, however, very practicable use indeed is made of electrons and their importance is recognized commercially. Scientific research work which has been done in this connection has revolutionized radio and provided a means for great improvements in ordinary wire telephony and also in other uses of electricity.

An improvement in this electron device can be made which very greatly extends its power and usefulness. As shown in Fig. 8 a grid of very fine wire can be placed in the tube between the filament and the plate. The grid is placed closer to the filament than to the plate. The electrons which are emitted by the filament can move freely between the grid wires. If by means of a battery or something else an electric force is established between the filament and the grid, this electric force causes electrons to move away from the filament toward the plate and since the grid is placed much closer to the filament the electric force makes the electrons move much faster than the same electric force between the filament and plate would. Very few of the electrons are taken by the grid, and a very small current thus goes through the wire connected to the grid. Thus a very small current to the grid controls the flow of a much larger current to the plate. Hence a larger current can be taken out of the tube than is put into it. A small electric force acts between grid and filament causing a large electron flow from filament to plate. There results a relatively large flow of current in the apparatus connected outside the tube between the plate and filament. This device is commonly called an electron tube. It magnifies or amplifies electric currents. It accomplishes the control of a large amount of power by a small power. This is just the same

FIG. 12. PHONOGRAPH PLAYING INTO A RADIO TRANSMITTING SET

FIG. 13. PORTABLE RADIO RECEIVING OUTFIT WITH CASE OPEN

FIG. 14. LOUD-SPEAKING OUTFIT RECEIVING CALLS FROM SHIPS AT SEA

FIG. 15. RECEIVING OUTFIT IN A CASE ONE FOOT SQUARE

thing that a gun does—pressing the trigger several times in a repeating pistol is like the action of the tube with successive pulses of electric force. The grid corresponds to the trigger and the plate to the gun barrel.

A number of forms of electron tubes as used today are shown in Fig. 9. They are used to receive radio waves and make signals just as the simpler device shown in Fig. 6 does, and they amplify the signal as well as make it audible. This is suggested to the mind by the larger wave shown with the telephone receiver in Fig. 7 and Fig. 8. On account of the control of the plate current by a smaller grid current, the electron tube makes possible very wonderful feats. It is worth while to note the explanation quite carefully as it will be shown presently that this explanation contains all the most important features of radio telephony.

It is perfectly possible and quite easy to take the magnified output from an electron tube and pass it into a second electron tube, using that to make a still further amplification of the current. Using one tube after another in this way, we obtain what is called an amplifier. Two tubes joined together in this way are shown in Fig. 11 and the process can be repeated several times using a number of tubes. The current is increased by each tube and handed on to the next without any change or distortion of the current even though it passes through several stages.

The amplifier is of the greatest importance both in radio and in long-distance wire telephony. It reduces the amount of power that must be used in a radio transmitting station because when an amplifier is used in a receiving station, signals can be received which are far too feeble to be received without an amplifier. By means of amplifiers to which were connected loud-speaking telephones, demonstrations have been given in which an airplane more than a mile in the air addressed large crowds on the streets of New York. One of President Wilson's speeches in the West was spoken into a telephone apparatus and amplifiers were used to make it fully audible to all persons in a very large crowd. The large announcers used in railway stations now make use of amplifiers. By means of amplifiers, submarine vessels can receive radio messages when entirely submerged. It is an interesting fact that an amplifier can be made so powerful that no input current at all is required. This does not mean that it is a perpetual motion machine, because the power to operate it must be supplied by the battery that is connected in the plate circuit of the tubes. It does mean, however, that the electron tube can be used to generate alternating currents as well as to receive and to amplify them.

Thus far we have discussed only signals such as are used in telegraphy. The voice can be transmitted and received by the same apparatus and principles. The human voice produces sound waves which cause air vibrations of an irregular character. Such a wave may be roughly illustrated as in Fig. 10. The variations in the wave are much slower than the alternations of current used in radio. It is possible to make a radio wave carry a voice wave, and when this voice-modulated wave is received it can be passed through a telephone receiver and the voice heard just as the radio telegraph signals are heard. The principle simply is that instead of breaking up the continuous wave of Fig. 3 by interrupting it, as in Fig. 4, it is caused to vary in accordance with the voice wave and these variations can be made audible. The way in which the voice wave is superimposed upon the radio wave is illustrated in Fig. 10. 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 ordinary radio telegraphy—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 just as radio telegraph signals can be by the use of amplifiers.

The radio wave is really modulated or molded just as a phonograph record is molded by a sound wave. The means by which this modulation is accomplished is the electron tube. If in Fig. 8 the telephone receiver is replaced by any kind of generator of radio current, then if a person speaks into a telephone transmitter connected between the grid and filament of the tube the variations caused by the sound of the person's voice are impressed upon the radio current in the plate circuit and a modulated radio wave as in Fig. 16 is produced.

A small radio telephone transmitting outfit which is used for demonstration and experimental purposes at the Bureau of Standards is shown in Fig. 12. Music is readily transmitted out into space by playing the music into a telephone transmitter. A phonograph may be used as shown in Fig. 12. The telephone transmitter is connected to the radio telephone apparatus upon which the electron tubes may be seen.

A receiving outfit usable in demonstrations is shown in Fig. 14. The receiving circuit or antenna is entirely contained within the frame shown in the picture, and electron tube used as a detector and amplifier and the loud-speaking telephone receiver are all visible. A much more compact radio receiving outfit is shown in Figs 13 and 15. The box encloses the electron tubes, the receiving antenna and all necessary apparatus connected to the horn which projects from the box. This is actually a satisfactory receiving set for demonstration and other purposes. It suggests the possibilities of the future. Radio sets of small enough size to use in any ordinary room or in moving vehicles can easily be made even now.

By means of electron tubes, radio telephone messages were successfully transmitted five years ago over a distance of 5,000 miles. Concerts are already being sent out by radio and are receivable by anyone who has an ordinary receiving set. This result has been accomplished by patient research, scientific study and progressive engineering. In Bellamy's "Looking Backward," describing conditions in the year 2,000, an arrangement is described by which people receive music in their houses any time desired by simply connecting a certain electrical instrument. In this particular the dreams of the prophet have been anticipated by eighty years.

USE OF BARBED WIRE AS A PROTECTION AGAINST SURGES

R. NAGEL, writing in *Archiv f. Elektrot.*, Jan. 8, 1920, proposes to utilize the glow discharge as a protective device against surges. A loss of energy takes place through the discharge, and this can be accentuated by providing sharp points, from which this discharge can the more easily take place.

It is the opinion of the author that commercial barbed wire might serve the purpose of providing a number of sharp points along a conductor in an easily manufactured form. He describes various tests that have been carried out with a view to determining the most convenient conditions under which the barbed wire should be installed. Various types of barbed wire are on the market, but any material serves. It would be well not to use ungalvanized iron, seeing that the spikes would be liable to rust, and in this way the tips from which the discharge takes place would eventually lose their sharpness and become ineffective. If the whole of the transmission line were made of barbed wire, this would be effective, but it is an unnecessary expense. It would be sufficient to insert lengths of barbed wire in the transmission lines for short distances in the neighborhood of every substation. If the atmospheric conditions are such that it is known that there is a danger zone over a given stretch of the line, as, for instance, over an exposed mountainous stretch, it might be well to use barbed wire in such places. The paper contains the results of tests which have been made with a view to determining the effect produced and the amount of energy that can be dissipated in this way.—*Science Abstracts.*