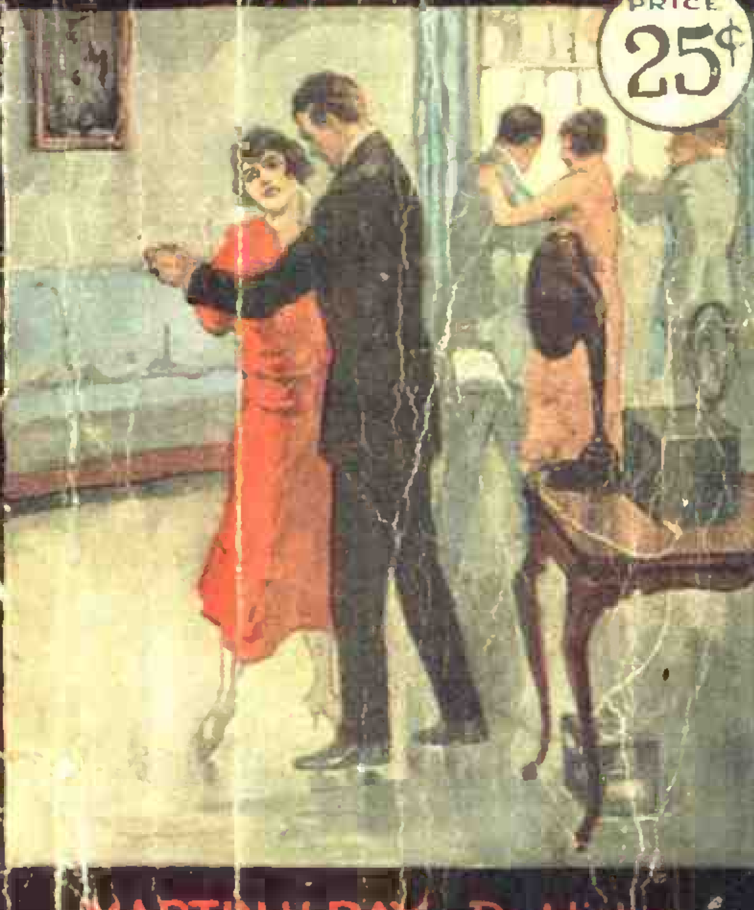
The A.B.C. of RADIO

By
WALDEMAR KAEMPFFERT

PRICE 25¢



MARTIN H. RAY Publisher
165 BROADWAY NEW YORK

The A.B.C. *of* RADIO

The underlying principles of

WIRELESS TELEPHONY

in simple language with Explanatory Drawings and Glossary

By

WALDEMAR KAEMPFFERT

First Edition *100,000*

Second Edition *150,000*

MARTIN H. RAY

Publisher

Real Literature and Live Topics

165 Broadway **New York**

The author wishes to acknowledge his great indebtedness to his friend Mr. William Dubilier, who inspired this little book and who aided in its preparation by helpful criticism and advice.

CHAPTER I.

About Waves in the Ether.

THE first question that a thinking man is sure to ask about radio is this: "How does the music reach me? The windows are closed, and yet I hear!"

It strikes everyone that the voice of the distant singer or lecturer is conveyed not by the air, but by some other medium. No one shouts into the broadcasting telephone transmitter. The man who reports the news of the day speaks in an ordinary voice. And you hear!

Long ago, when scientists began to study light scientifically, they were puzzled by a similar mystery. What transmitted light? We see the blazing sun, the twinkling stars, and yet between the sun and the earth and between the stars and the earth there is an airless abyss which measures millions of miles. Clearly, it is not air that transmits light.

So the scientists had to assume the existence of a medium much more pervasive, much more subtle than air, a medium that filled all space and even the inconceivably small intervals between the atoms and molecules of bricks, mountains, and human bodies. This medium they agreed to call the "ether." Its existence had to be assumed in order to explain not only how light reaches us from the sun and the stars and from candles and lamps, but also how heat makes itself felt through dense bodies and how certain electric effects are produced. But granting that the existence of ether must be assumed, just how does the ether transmit light?

Experiments were made which proved that light is a wave motion in the ether. Atoms vibrate in the sun, in the stars, in blazing bonfires, in burning lamps, and as they vibrate they generate waves in the ether. The waves are just like those that circle out when a stone is dropped into a pool of water.

Nearly all energy reaches us in the form of waves. When a note is struck on a piano or a bow is drawn across a violin the string of the piano or the violin vibrates, sets up waves in the air that reach our ear-drums. We say that we "hear" the note. Tie a rope to a post and shake one end of it up and down. A wave travels back and forth along the rope.

It is thus that energy is usually transmitted. Waves are set up in some medium by a body that moves *alternately* back and forth. The alternations of movement, the "oscillations," or "vibrations," as they are often called, create the waves.

In radio we deal with waves in the ether —waves which must therefore resemble light waves, even though we cannot see them. The voice that comes to you from the broadcasting station is a voice which has first been transformed into ethereal waves, and then back into a voice by means of the telephone receiver.

It is a curious fact that much was known about such electric waves before they were discovered. Michael Faraday, perhaps the greatest experimenter that ever lived, found that a current of electricity in one wire can make an electric current flow in another wire some distance away. We say that one current "induces" the other. Moving magnets produce the same effect in wires. Hence we speak of "electromagnetic induction."

Faraday wondered what was the medium through which the electromagnetic effect was transmitted. It remained for James

Clerk Maxwell, a great English mathematical physicist, to substitute a plausible theory for mere wonder. He made a study of light which proved conclusively that it is an *electromagnetic* effect. But light is a wave motion in the ether. Are there any other wave motions in the ether of which we know nothing because we cannot see them or feel them? By mathematical reasoning Clerk Maxwell reached the conclusion that the medium between Faraday's two wires, the medium by which the electromagnetic effect was transmitted, must be the ether. Light can be seen, but Faraday's waves could not be seen. There was no other difference between the two. Both traveled at the same speed—186,000 miles a second. To see the elctromagnetic waves an artificial eye was needed—something that would respond to them.

It remained for Heinrich Hertz, a German professor in physics, to prove that Maxwell's theory was correct by inventing an eye which would actually see the electromagnetic waves. In the first place he had to generate waves in space, and this he did by the simple expedient of copying Nature. In other words, he created a little flash of lightning in his laboratory, and the flash generated waves in the ether just as a stone dropped into a pool generates waves in the water. The "eye" which he devised to "see" the waves was simply a metal ring which was not quite closed and the almost meeting ends of which terminated in knobs. As soon as his little flash of lightning crackled minute sparks passed between the knobs of the "eye." Millions of waves radiated each second from the spark-gap, where the miniature bolt of lightning flashed, just as millions of waves a second are sent to us from the sun or a flame. The "eye" of Hertz saw what our own eyes could not see, and thus he proved that electrical effects are transmitted by the ether.

What happened was this:

The spark leaped back and forth between the terminals of the gap. It was an alternating effect, a series of oscillations or vibrations. Each alternation or oscillation pushed the ether and set up a wave. The waves in turn dashed against the ring and caused a feeble current to alternate or oscillate back and forth. The current had so much momentum that it did not stop when it reached the knobs but leaped across. This leaping current became visible as a tiny spark—a spark which oscillated or alternated back and forth synchronously with the spark of the transmitter.

These invisible electromagnetic waves, about which Maxwell reasoned and the actual existence of which Hertz proved, transmit signals or human speech in what we popularly call "wireless" telegraphing and telephoning but what scientists prefer to term "radio" communication. Because Hertz first devised a way of seeing them these electromagnetic waves in the ether are sometimes called "Hertzian waves." Hertz called his "eye" a "resonator," because the sparks passed between its knobs in resonance with the leaping of the little lightning flash back and forth between the terminals of the transmitting spark-gap. Many different types of "eyes" were invented after Hertz devised his resonator. We call them "detectors" in radio communication.

Curiously enough none of the early experimenters realized that these invisible waves in the ether could be used to signal through space without wires and that the ether could be charged with words of love and hate. Faraday, Maxwell, Hertz, Sir Oliver Lodge, all were so engrossed with the purely scientific aspects of the waves that they did not imagine what an astounding part radiated energy was destined to play in peace and war. It was Sir William

Crookes who first boldly prophesied that men would talk to each other through the ether some day, and it was a twenty-year-old Italian boy, Guglielmo Marconi, who fulfilled the prophecy. In 1894 Marconi signalled a few hundred feet, in 1896, two miles. By 1899 he had stations operating on opposite sides of the English Channel. Now we communicate through the ether with Europe or far-off Asia and with thousands of ships on the Seven Seas.

Whenever black clouds obscure the sky and there is a blinding flash of lightning between clouds and earth or between two clouds, Nature is sending out a terrific radio signal. Lightning is but a spark which may be miles in length—a spark which oscillates between cloud and earth, and which in turn generates ether or wireless waves.

Nature is always sending these wireless signals of hers. Even when there is no thunderstorm, neighboring clouds are trying to relieve themselves of their electric charges. Electricity leaps from one to the other and back again in an oscillatory discharge, which dies away when the electric tension is relieved. Hence Nature is always sending radio signals through the ether.

These natural effects radio operators call "strays" or "static," which latter term is an abbreviation of "static electricity." In midsummer "static" proves very troublesome, particularly in the reception of telegraph messages in code. Since the receiving operator takes down code signals without knowing what their meaning in the message may be he sometimes mistakes Nature's "static" for a code letter and writes it down. In radio telephoning "static" is heard as a grinding and scraping and hissing and sputtering that occasionally drowns out all other sounds. So many engineers are studying this problem and so many improvements have been made that the problem of "static" will soon cease to puzzle as it does now.

CHAPTER II.

What We Mean By "Wave Lengths" and "Tuning In."

THE waves that follow when a stone is dropped into water radiate in all directions. All waves radiate when they are not confined. It is because the sun sends out waves in all directions that all eyes see it, and it is because the air transmits sound waves in all directions that every one in a concert-hall hears the violinist on the platform. There is nothing secret about the sun, and there is nothing secret about radio, because, like light waves, the Hertzian waves circle out in the ether in all directions. Every radio transmitting station is therefore as public as the sun at noon.

The little pebble dropped into a pool sets up water waves that are smaller than those generated by a rock. The distance from crest to crest is perhaps a few inches in the case of the little waves and fully a foot in the case of the larger wave. This distance from crest to crest is called the "wave length." It is impossible to send or receive a radio telegraph or telephone message without considering wave lengths. Wave lengths in radio are always measured in meters, because the metric system is that which scientists prefer to employ. A meter is the equivalent of 3.28 feet.

The waves used in radio may vary in length from about a hundred meters to thirty thousand meters. Ocean waves may have a length of one hundred meters—328 feet. But think of the great invisible, all-pervading ocean of ether heaving with waves that measure thirty thousand meters from crest to crest—about eighteen miles! Such is the wave length occasionally employed by the great stations that send radio messages across the Atlantic to Europe and across the Pacific Ocean to Australia.

Wave length in radio corresponds with pitch in sound and with color in light. Sounds are transmitted through the air by bodies that move back and forth or vibrate and thus create a train of waves. If the waves come through the air regularly, we hear a musical note, which may be shrill or high-pitched or deep or low-pitched. The pitch depends on how many waves reach our ears in a second, and this in turn depends on how many times the sounding body vibrates the air. When we tighten or loosen the string of a violin we raise or lower its pitch. We call this "tuning." In radio we also speak of "tuning," and when we do we mean simply that we are adjusting the radio pitch of the receiver to the pitch of the transmitting station. Pitch is a matter of wave length. The smaller the waves and the smaller their length, the more of them strike the receiver, whether it be an eye, an ear or a radio detector. Hence when we "tune in" on a wave length of three hundred meters in radio we simply adjust the receiving instrument to receive waves of that length, just as a violinist tunes his instrument to agree in pitch with the piano that his accompanist plays. Wave length can also be explained in terms of light. When we say that one color is "red" and another "blue" we mean that the pitch of the color we call red is lower than the pitch of the color we call blue. In other words, red has a greater wave length than blue. When we look at the world through a piece of red glass our eyes see with light of one wave length. When we look through a piece of blue glass, we see the world with light of another wave length. Hence we "tune in" on definite wave lengths of light when we wear red, yellow or blue spectacles. A radio broadcasting station which makes the ether ripple with Verdi's "Celeste Aida" on a wave length of three hundred and sixty meters is like a lighthouse or beacon which sends forth beams of red light only. A normal eye can detect all the colors in the rainbow; a color-blind eye cannot. Hence, a tuned receiver is color-blind, in a radio sense.

All devices or circuits by which Hertzian waves are generated have "capacity" and "inductance."

The word "capacity" almost explains itself. Every conductor, whatever its form, has a certain amount of surface. Two conductors, insulated from each other, can be charged with a definite amount of electricity, and this is called the "capacity." A device which can be thus charged with electricity is called a "condenser." Obviously it takes a longer time with the same electrical pressure to charge a large surface than a small surface. Therefore, by varying the surface to be charged we vary the time required for charging. A condenser that has a variable surface is called a variable condenser.

We have seen how Faraday discovered that a current flowing in one wire can "induce" a current in another wire nearby. A vibrating tuning fork can induce vibrations in a piano wire of the right tension and length. To tune the wire we can either regulate its tension or its length, or both. To tune a radio receiving circuit to the wave length of the sending circuit we vary either the "capacity" or the "inductance" of the receiving circuit, or both. The capacity may be compared with the tension of the piano wire which is to be tuned to vibrate in sympathy with a tuning fork, and the inductance with the length of the wire. When we cannot vary the capacity, we vary the inductance, and which of the two we vary is a question of economy and convenience.

As we have seen, every radio transmitting station is a power house. Like the power house that drives trolley cars and supplies current to our lamps it has its electric generators, which sometimes even resemble those to be found in any central station. The power generated is all distributed in the form of Hertzian waves, which, because they spread out in ever-widening circles, become feebler. A distant receiving station is a mere point on one of these circles. The farther away it is the less is the power that it can detect. A receiving station in

England must be affected by about one millionth of a millionth part of the power lavishly hurled into space by a transmitter in the United States.

A little pebble dropped into a pool produces little waves. A big rock produces bigger waves. When a pebble or a rock is thrown into a pool energy is expended, and the waves that follow are energy waves. So, in radio communication, it takes energy to create waves in the ether. A little electrical energy, the equivalent of the pebble, generates waves which cannot travel very far and which soon die out. Much electrical energy is required to send waves for hundreds of miles. To send a radio telegram across the ocean, huge electrical rocks, as it were, must be thrown into the ether, so that enormous waves will be sent billowing out into space. Instead of a single rock, a steady stream of rocks is thrown into the ether; for to telegraph through space we must have trains of waves, which can be interrupted with a Morse key to correspond with the dots and dashes of the telegraph code.

CHAPTER III.

How Waves are Generated.

WE have learned that something must alternate, vibrate, or oscillate to produce waves in the ether. Clamp a corset steel in a vise and pluck it. The steel vibrates back and forth. Each vibration is of less amplitude than that which preceded it. Gradually the vibrations die away altogether. So it is with the spark that Hertz used in his first trials and that long served Marconi and the early experimenters. Like the corset steel, the current oscillates back and forth and finally dies out. The spark oscillations occur so quickly that the eye cannot follow them or even note their gradual enfeeblement and death.

From ten thousand to thirty million vibrations per second are required to generate Hertzian waves, and the corset steel vibrates only a few hundred times per second when it is plucked. Although the vibrations that cause the Hertzian waves may number millions a second they are not as rapid as those which cause light. Something must vibrate from 3,000,000,000,000 to 3,000,000,000,000,000 times a second to generate the ether waves that we call light. Because Hertzian waves are set up by vibrations much slower than those which cause light we cannot see them; we must rely on detectors.

Sparks were once exclusively employed in telegraphing through the ether. But sparks, as we have seen, die out very quickly. They produce what are called "damped waves." What is wanted for radio telephony is a continuous vibration —an alternation that does not die away. By such a vibration what are called "continuous waves" are produced, which have greater carrying power.

Very early in radio communication inventors began to think of generating Hertzian waves by alternations or vibrations constantly maintained. Alternating currents had long been used in commercial engineering practice. Why not use them to set an arc aglow—an arc like that which we see in many streets at night. Such currents flow back and forth in a wire from twenty-five to five hundred times a second. Too slow. We must have at least 10,000 alternations a second. Millions would be better. A Danish engineer, Valdemar Poulsen, finally hit upon a way of producing the alternations so that an arc could be used instead of the old spark for radiating waves. With that discovery the radio telephone was born; for with waves that were as steady as any electric current in a wire, it became possible to modulate them, in other words to mold them so that they assume pattern-forms which conform with the inflections of the human voice, and which can be changed back into voice inflections.

Alternating currents can radiate waves in the ether from the wires through which they flow. But we must have many thousands of alternations a second, as we have seen. Ordinary alternating current dynamos or generators cannot turn fast enough to produce any such number of alternations. Special dynamos have been invented by R. Goldschmidt in Germany, and by Dr. E. Alexanderson in the United States, which meet the requirements. Although some stations are equipped with such dynamos, so that they look for all the world like ordinary power-houses, it is likely that in the future Hertzian waves will be generated by what is variously called the "vacuum tube," "electron tube," or "thermionic valve"—an invention which has had such an extraordinary effect on radio, particularly on broadcasting, that it will be discussed in the chapter entitled, "What Is Electricity?" appearing elsewhere in this book.

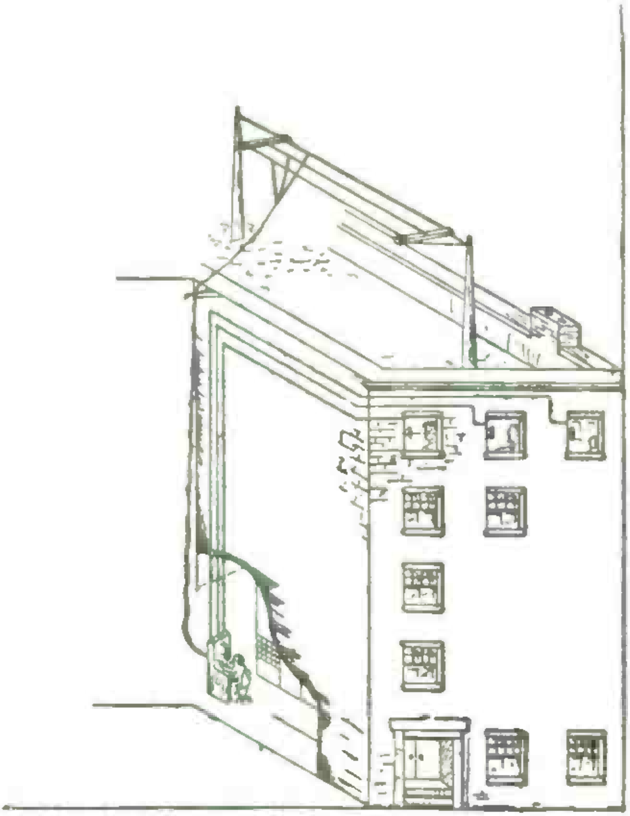
CHAPTER IV.

On Antennae and Loops.

THE best that Hertz could do in detecting his waves at a distance was a few feet. When Marconi boldly decided to invent a way of using the Hertzian waves in telegraphing, he realized that their application could never be of practical importance unless he could send them through the ether for miles and what is more, detect them at the receiving station. It was he who discovered that even Hertz's primitive apparatus could send waves several hundred feet if the current that produced the spark alternated in a conductor that was elevated. So he soon erected poles from which the conductor was suspended. He even hung the wires from kites, so desirous was he of obtaining the maximum effect. After a while it became the general practice to hang the conductors from tall masts or towers and to call them "antennae." The term was borrowed from entomolgy. It is applied to the long feelers of insects. And the tall antenna of a great radio station with wires stretched between look for all the world as if they were reaching out and trying to feel something in space. They do feel electric waves.

It has been said over and over again in preceding pages that any electric alternation which is rapid enough will produce Hertzian waves in the ether. The antenna is simply an alternating current circuit so far extended that it affects more of the ether than a short circuit, and the more of the ether that is shaken to produce waves the more pronounced is the effect at the distant detector bound to be.

Since amateur stations or broadcasting stations are not intended to send signals over distances measured by thousands of miles (although the amateurs have actually been heard in Scotland) their antennæ are not so long nor tall as those of the great stations which telegraph to Europe or Japan and which have towers several hundred feet high. It is easy to see why the big stations must have such high antennæ. They must shake a great deal of the ether in order to form tremendous billows measuring ten and twenty miles from

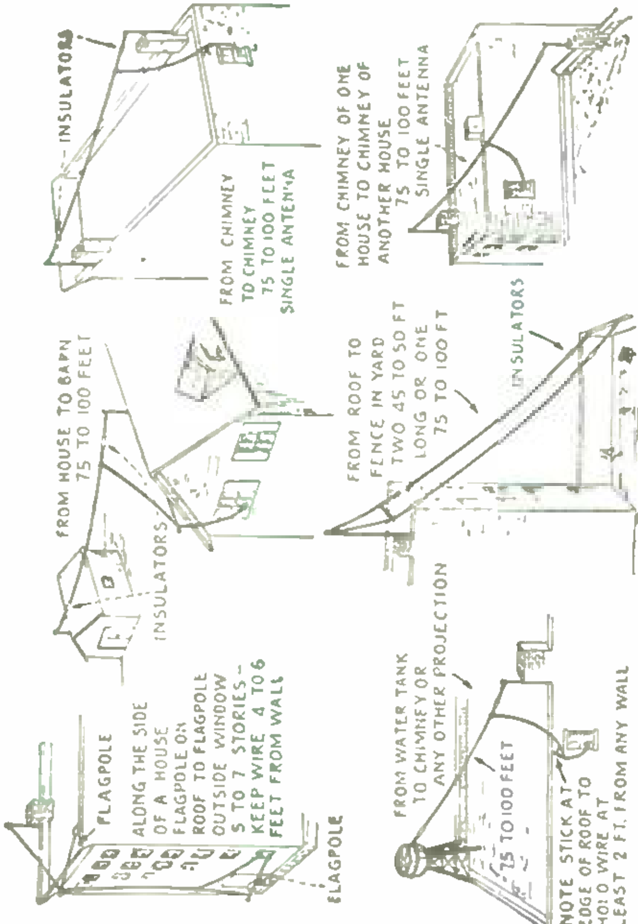


Apartment houses and hotels can have a radio telephone receiver in every apartment. A common aerial on the roof and a common receiving set in the basement with telephone or loud-speaker connections in the apartments—nothing more is required crest to crest. A large tuning fork will be heard farther than a small tuning fork, and similarly, high power sent through a large antenna will send waves farther than a small one.

For the same reason the receiving antenna must be large if the detection is to be good. The more waves that beat against a receiving antenna, the more powerful are the oscillations set up in the antenna circuit, and the more easily will they be detected.

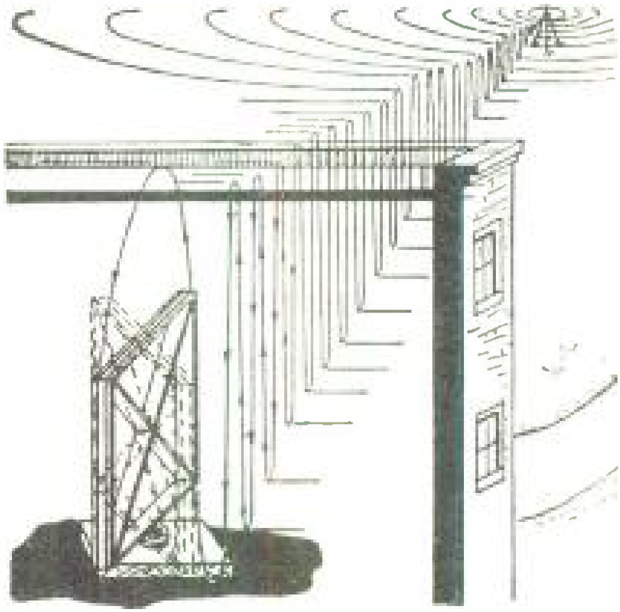
What happens in the receiving antenna circuit? The waves ripple out from the transmitting station in alternations of pressure. They strike the receiving antenna. They set up vibrations—electric vibrations—in the antenna. The result is an alternating current which surges back and forth in the antenna circuit as long as the waves beat against it. Hold a vibrating tuning fork near a piano. A sympathetic note will be heard from that string of the piano which corresponds with the note of the tuning fork. The ether is as capable of setting up sympathetic electrical vibrations in a receiving antenna circuit, as the air is capable of making a piano string vibrate and sound.

The wires of the great Trans-Atlantic stations are always so hung between the



Typical antennae that can be set up by any handy amateur towers that they extend in the direction in which the waves are traveling. Suppose the wire of the antennae were strung at right angles to the direction of motion. Clearly the waves would quickly break over them and pass on. But if the wires reach out in the direction from which the message is to be received, it is evident that waves strike every part of them and produce a much more marked effect.

The erection of tall towers and masts is expensive and troublesome. It occurred to engineers that they might be dispensed with, at least for receiving, if there were only a way of exposing enough wire in the proper shape. The result is what is called the "loop" antenna. The loop consists simply of wire wrapped around a simple frame mounted on a pivot. Such a loop antenna can be swung on its pivot in any direction, and swung it must be in order that it may receive with the maximum intensity. When the loop is end-on to the transmitting station the signal or the voice is heard with greater distinctness. Turn the loop at right angles to the direction in which the waves are coming and nothing is heard. Such a loop, mounted in a room or even in a cabinet, can receive music and speech from a broadcasting station.



In this diagram the best and the worst positions for receiving with the loop antenna are shown respectively in full and dotted lines. When the loop is turned in the direction of the oncoming waves the reception is at its best; but when the loop is turned at right angles to the direction of the waves' travel, as shown by dotted lines, the reception is at its worst. Because the loop thus indicates the direction from which signals or speech is broadcasted it is a valuable aid in navigation. Limited results have been obtained by stringing wires around the picture moulding of a room in a non-steel building. In a steel frame building the loop should be hung out of a window or mounted on the roof

For receiving broadcasted concerts a loop can be made by winding copper wire eight times around a frame four feet square. Such a loop can be hung by a string from a hook in the ceiling; thus mounted it is out of the way, and yet it can easily be turned. The accompanying diagram shows how a loop is mounted and how it receives.

It is with such loops that ships determine their position at sea by listening to the signals sent from shore by what are called "radio compass" stations. Indeed, the loop is called a "radio compass" on shipboard, and sometimes a "direction finder." The radio compass stations did wonderful work during the war. Eccles, the great English radio engineer, thus tells how they enabled the British navy to follow the movements of the German fleet before the great battle of Jutland:

"The German vessel, which on May 30 sent instructions to the German fleet by wireless, was heard at several stations on the British coast, and her bearings from each were accurately determined. Some hours later, this same vessel wirelessed another batch of instructions, and our watching stations again determined her bearings. It was found on comparing the results that she had moved about seven miles down the river. This was recognized by Sir H. B. Jackson, the First Sea Lord, as sufficient justification for ordering out the Grand Fleet and clearing the North Sea."

So with the aid of the loop the British began to pursue the Germans before they were even at sea.

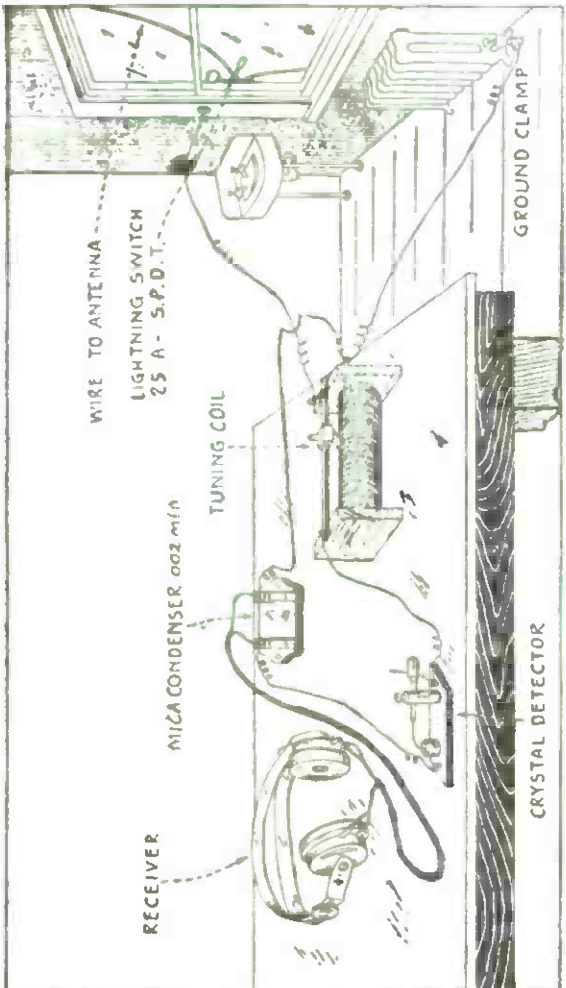
CHAPTER V.

How the Electromagnetic Waves are Detected.

YOU sing. Those in the room with you hear. What is the process of sound-transmission?

As you sing, you set the air in vibration —generate waves of air. The air waves strike the ear-drums of your hearers, and they cause the ear-drums to vibrate with exactly the same frequency as your voice from one instant to another. Puffs of air leave your lips. Each puff pushes the ear-drum of a hearer. The ear-drum recovers when the puff passes only to be subjected to another puff. Thus the ear-drum vibrates as the transmitting air vibrates.

In radio communication a somewhat similar process occurs. The transmitting antenna sets the ether in vibration so that



Simple "hook up" for a crystal detector set waves are sent out in all directions. If we are to receive the vibrations we must set a receiving antenna in electric vibration. This the waves do in striking the antenna. But the frequency is so high that no sense-organ of ours can tell whether or not the receiving antenna is electrically vibrating. The ear can hear sound directly; the eye can see light directly; but neither ear nor eye can perceive the electromagnetic waves directly.

Many forms of detectors were invented soon after Marconi demonstrated that it is possible to telegraph through space with the Hertzian waves. We need not describe them all here; for most of them are obsolete. For broadcasting receiving sets either the crystal detector or the vacuum tube is employed. The crystal detector will be described in this chapter, and the vacuum tube in the chapter entitled "What is Electricity?"

General H. H. C. Dunwoody discovered that certain crystals possess the curious property of conducting electricity better along one axis than along another. Now the alternating currents set up in a receiving antenna are of very high frequency—so high that they cannot be heard in an ordinary telephone receiver. Suppose that half of them could be extinguished altogether. They would become audible. The crystal makes it possible to separate one alternation from the other and thus to produce spurts of electricity in one direction.

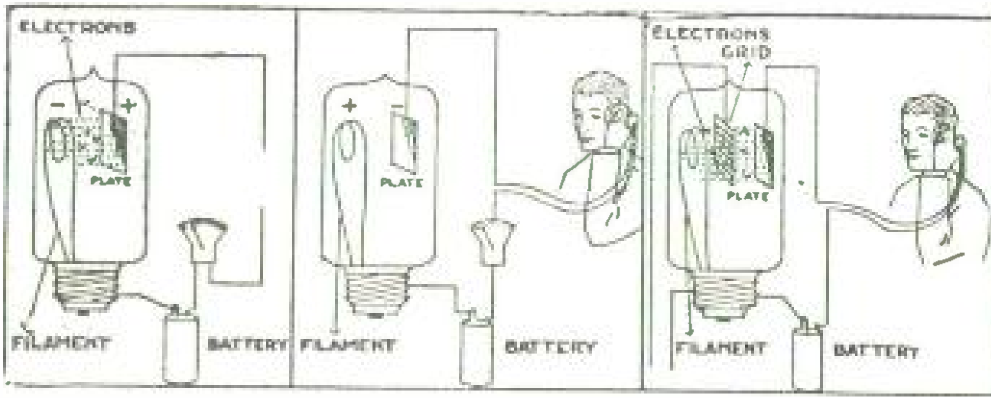
Many crystals possess this curious property of being able to suppress one of the impulses of alternating current. Examples are carborundum (carbide of silicon), anastase, molybdenite and hessite. Moreover, there are pairs of crystals, which, when placed in contact, are better conductors in one direction than in the opposite. Among them are graphite and galena, zincite and chalcopyrite. Because crystal detectors are cheap they are widely used in amateur receiving sets of small range. They cannot be used with a loud speaker without a suitable amplifier. In the accompanying diagram a simple "hook up" for a crystal detector set is shown.

CHAPTER VI.

What is Electricity?

Today we are nearer than we ever were to knowing just what is this force we call "electricity." Scientists conceive that the whole world, the chair on which you are sitting, this little book, you yourself, everything is composed of what they have agreed to call "electrons." Electricity is also composed of electrons. Therefore matter and electricity are one and the same. It is hard to realize that this is so, and yet, the evidence that it is so, is striking. Even atoms, which were once supposed to be the smallest conceivable bits of matter, are composed of electrons. A complicated atom like that of gold, for example, is like an infinitesimal solar system. It consists of a central nucleus, like our sun, around which revolve electrons, much as if they were planets.

Each atom of matter—copper, rubber, water—has just so many electrons and no



1 2 3

1: The Edison effect; 2: no effect is obtained with this connection; 3: the grid or "third electrode" is mounted between the filament and the plate

The vacuum tube has had an enormous influence on the development of Radio and particularly on the reception of broadcasted entertainment. It is probable that in the near future a tube will be no bigger than a peanut, so that it can be energized by a single dry cell more. As long as it has its proper number no one would know that it had any whatever, so far as any electrical effects are concerned. That is why a chair or a book seems so unelectrical. But all substances may be deprived of electrons or may receive more than their proper share and when that occurs the substances are electrified. If a body has fewer electrons than its proper number we say that it is positively charged and give it a plus sign (+); if it has more we say that it is negatively charged and give it a minus sign (—).

Now the ordinary state of any body is to have exactly its own number of electrons. Batteries and dynamos have peculiar properties. They can push electrons out from the negative terminal and pull them in at the positive terminal. What we call an electric current is nothing but a steady flow of electrons in a conductor. When an electric spark flashes across the terminals of a gap, electrons surge back and forth, trying to distribute themselves so that there shall be no more on one side of the gap than on the other. So long as one side has too many and the other too few the excess electrons leap across. Because they have momentum and cannot stop dead, many more leap across than are necessary to establish equilibrium. The surging back and forth continues for an imperceptible fraction of a second. When both sides have exactly the same number of electrons the spark ceases to pass.

Why have we thus briefly sketched the modern electron theory? Unless we conceive electricity as an aggregation of restless, free electrons, unless we think of electrons as having mass, however minute it may be, we cannot hope to grasp the significance of the marvelous vacuum tube in radio communication or understand how it works. This might be inferred from the fact that the vacuum tube is often called the "electron tube," a name that indicates clearly enough that electrons must play some part in its operation.

The most wonderful of all radio devices is the vacuum or electron tube. It has sometimes been called the Aladdin's lamp of radio. Certainly the lamp that Aladdin rubbed produced effects no more miraculous, no more startling.

Everyone is familiar with the electric incandescent lamp, which consists of a fila ment enclosed in an exhausted glass bulb. The filament glowed for nearly a generation before anyone suspected that it did much more than shed light. Before radio was dreamed of, before Hertz made his classic experiment, Edison had discovered a very curious property of the filament. Within one of his lamps he mounted a plate as shown in Fig. 1, p. 35. The plate did not touch the filament; it formed part of a local circuit of its own, in which a galvanometer or current indicator was included.

When Edison turned on the current and made the filament glow a strange phenomenon presented itself. The galvanometer needle was deflected, although there was no connection between the plate and the filament. Clearly electricity must have leaped the gap between the filament and the plate. Edison found that the electricity leaped across only when the connection was that shown in Fig. 1, p. 35; when the connection was that shown in Fig. 2 the galvanometer needle stood still. This phenomenon was called by scientists the "Edison effect." Edison could not explain it, nor could anyone else for about twenty years. The real nature of electricity was not known until the X-rays and radio-activity were discovered and studied. But after scientists came to the conclusion that everything in the universe is composed of electrons and that an electric current is itself nothing but a flowing stream of electrons the true nature of the Edison effect was evident.

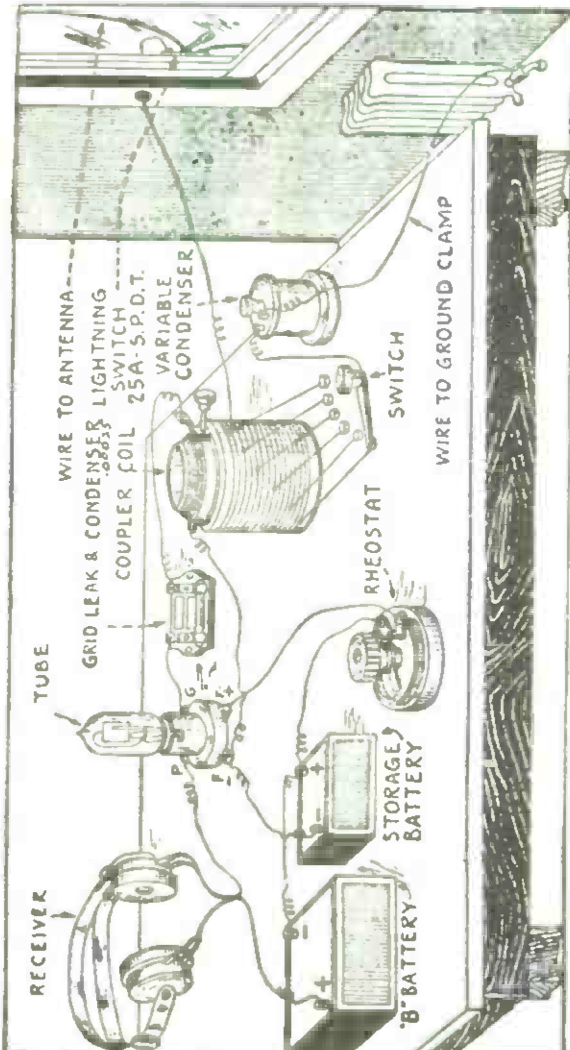
Every hot object emits electrons. A filament in a lamp is white hot; therefore it emits electrons; electrons are infinitesimal particles of *negative* electricity, and because they are negative they flow naturally toward a cold *positively* charged piece of metal. When the direction of the current in the galvanometer circuit was reversed, so that the cold plate was *negatively* charged, there was no effect at all. Everybody knows that two negatively charged bodies always repel each other, and that bodies with unlike charges (that is one *plus* and one *minus*) attract each other; but until the electron theory was framed, no one knew the reason.

Now we know that excess electrons from one body try to make up a deficiency of electrons in another body. If two bodies are negatively electrified, each has an excess of electrons; neither wants any more; they repel each other. If two bodies are positively electrified each has a deficiency of electrons; they repel each other just as if one thinks that the other is trying to steal electrons away from it. Only when excess electrons have a chance to flow from a negatively electrified body to a body which is positively electrified and which therefore needs electrons, is the phenomenon of attraction presented. It is easy to see why the electrons in a vacuum incandescent lamp behave as they do.

If electrons are always shot off by hot bodies—by red-hot stoves, for example—why were they not discovered long ago? Simply because the air stops the electrons. Remember an electron is so small that it bears about the same dimensional relation to an atom, once considered the smallest indivisible piece of matter, that a football does to a church. Since the air is composed of atoms and molecules so very much larger than electrons it is evident that an electron can be stopped as easily by an atom as a baseball is stopped by a stone wall. Because practically all the air is pumped out of incandescent lamps the electrons were able to leap across the gap between the filament and the plate in Edison's bulb. Where did they come from? They were simply pushed off in the process of pumping electrons—the electric current—through the filament, and they would be pushed off red-hot electric toasters if there were no air to stop them.

Soon after he formed his English company, Marconi engaged Professor J. A. Fleming as his chief engineer. Fleming saw possibilities in the Edison effect. Here was a bulb or tube through which a stream of electrons could pass from the hot to the cold electrode, as the filament and plate are respectively called, but not in the other direction. Fleming had long thought of receiving radio telegraph signals with the aid of an ordinary telephone. Remember that he was still working in the days when telegraph signals were sent by sparks instead of by arcs or dynamos. The oscillations that constitute a spark come in groups or trains, each group or train corresponding with a spark. There may be from 50 to 500 sparks per second. Hence there are from 50 to 500 radiated wave groups, each of which may in turn contain 20 to 100 oscillations or waves. Between two successive alternations of electricity or waves may be an interval of only a half millionth or millionth of a second. The human ear can hear not more than about 32,000 vibrations per second; the telephone diaphragm can respond to more, but not to several hundred thousand a second. What if these movements of electricity in each train could be converted into a single gush or flow of electricity in one direction? The trains would be changed into short flows all in one direction. Gushes would be received at the spark frequency of 50 to 500 per second and would be heard in a telephone. So Fleming reasoned.

There are valves called "flap valves" that act to prevent water or gas in a pipe from backing up on itself. They open in one direction only, so that the water or gas can flow only in that direction. Something like such a valve was wanted for electric waves. Fleming found it in the Edison lamp with a plate mounted near the filament. The electron stream flowed only from the filament to the plate. If the filament and the plate formed part of a telephone circuit the diaphragm of the receiver at his ear would be affected only by pulsations in one direction. There could be no pulsations in the opposite direction because the electron stream simply would not flow in that direction. Hence the rapid oscillations were converted into gushes of electricity, all in the same direction through the telephone. Because the gushes came at intervals of 50 to 100 a second they could be heard. The plate was charged now positively, now negatively, as the waves came in. When it was positively charged, the electrons streamed over to it from the filament; when it was negatively charged there was no stream at all. Clearly, one-half the oscillations were

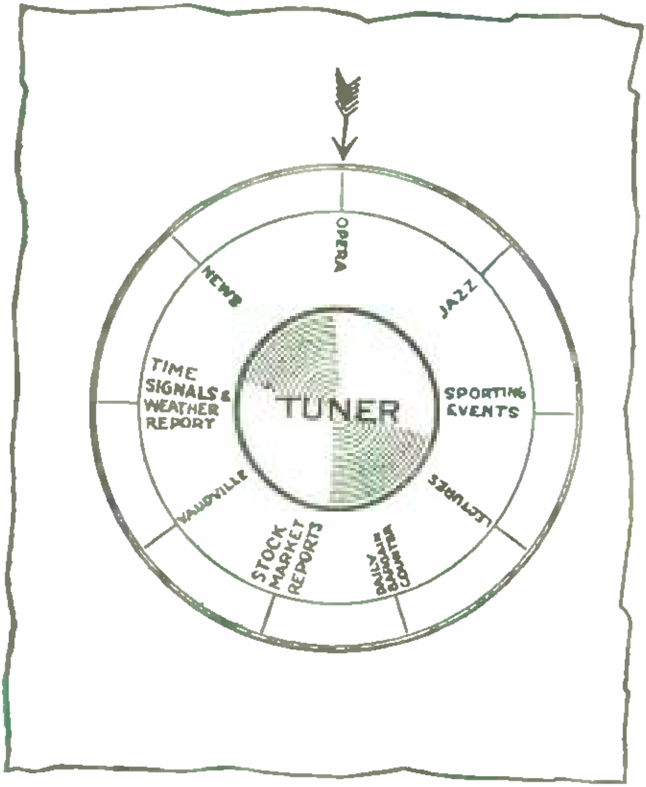


Simple "hook up" for a vacuum-tube detector set suppressed. The ether waves, in trying to set up a rapidly alternating stream of electrons in the circuit, failed every other time; for the electrons could flow only in one way. So long as a radio signal was coming in there would be a one-way current through the tube and through any other apparatus connected in series with the tube, hence through the telephone; since one-half of the impulses were suppressed the diaphragm of the telephone receiver could respond, and respond it did in the form of a high-pitched musical note, rather than clicks, because even with the oscillations reduced by one half the clicks are received at the rate of five hundred a second when the transmitting station uses a spark.

Fleming called this arrangement an "oscillation valve" because it acted like a flap-valve to permit the passage of current in one direction only. This suppression of one oscillation of an alternating current is called "rectification."

Fleming was the first to apply the Edison effect in radio communication.

The oscillation valve immediately won a place for itself as a receiver in long-distance telegraphy because of its extraordinary sensitiveness. It was an amazing invention which did much to advance radio communication.

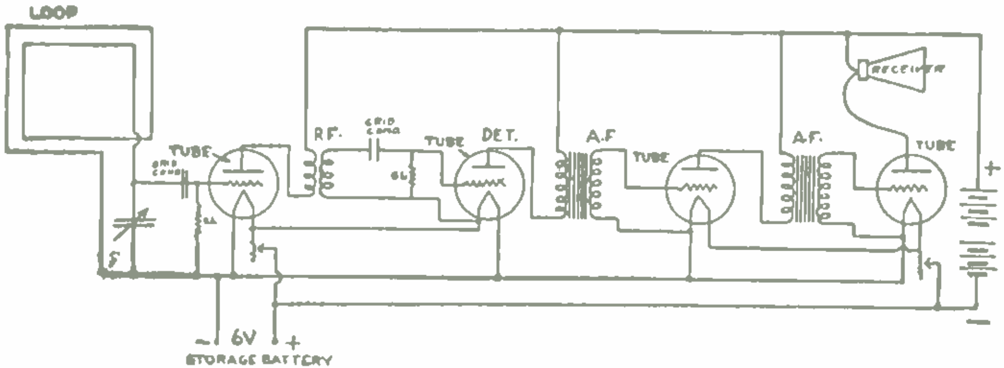


The tuning knob and dial of the future may resemble this. If you want to hear opera, news, vaudeville, or the weather report you will simply turn the knob to the proper legend on the dial. Thus you will tune in easily and quickly to receive on the wave length of the particular broadcasting station that is sending the particular kind of information or entertainment that you want to hear

But just as amazing is the improvement made by Lee DeForest which resulted in what he called the "audion."

About 1906 DeForest mounted between the filament and the plate a grid of wire connected with a battery. He found that the slightest change in the current to the grid powerfully affected the current that passed from the filament to the plate. A marvelously sensitive method of control was thus invented. The grid is like the trigger of a gun or the throttle of a locomotive. A slight movement of the finger will pull the trigger and discharge a terrible explosive; a slight pull of the throttle will set a long freight train in motion. DeForest invented a device which would not only detect the exceedingly weak currents that oscillate back and forth in a receiving antenna but also cause the telephone receiver to respond more markedly than was possible with the Fleming oscillation valve.

But that is not all. The effect detected by one vacuum valve can be magnified by a second; that of the second by a third; that of the third by a fourth. Valve can be added to valve until the original effect is amplified as much as 10,000,000,000,000 times, if need be. Thus amplified the walking of a fly becomes a thunderous



Hook up for a set employing a loop, radio frequency amplifier, detector, and two stage audio-frequency amplifier. The high frequency oscillations are received by the loop and are amplified by the first tube. This is "radio frequency amplification." By this term we mean that the signal is powerfully magnified and that static is much reduced. Then follow rectification by the detector tube and finally audio frequency amplification tramping; the ticking of a watch a deafening series of sledge-hammer blows. The term "amplification" in radio usually means several magnifications. Very little current is needed to heat the filament sufficiently to cause a flow of electrons from the filament to the plate. A few cells answer the purpose or a small storage battery. In modern vacuum or electron tubes the filament is surrounded by a sheath-like grid and a sheath-like plate.

The electrons are shot out in all directions in every incandescent lamp which is of the vacuum type. When an electrified plate is introduced they are made to flow toward it. The battery current gives them their speed and direction; it literally pulls them across.

It is the vacuum valve which has made possible the feat of telephoning from New York to San Francisco over land wires, and it is the vacuum valve which enables us to combine wire telephoning with radio telephoning. The day is not far distant when a business man will pick up his regular desk telephone receiver and say in response to Central's "Hello":

"Give me radio long distance."

And when the radio-long-distance operator asks him for the number that he wants, he says:

"Piccadilly 2167. Ask for Sir James Arkwright."

He hangs up his receiver. In half an hour his bell rings.

"All ready for London. Piccadilly 2167, Sir James Arkwright on the wire."

And that business man in Chicago will *talk* to Sir James Arkwright in London, just as easily as he talks to anyone in the United States—talk first over the land wires to a radio station on the shores of the Atlantic, then through the ether, then over wires leading from an English radio station to London. Lest this may be dismissed by a skeptic as a romantic Jules Verne dream, it may be mentioned that anyone in the United States can now telephone to Catalina Island off the coast of California by exactly the same process. Within the next few years all the great passenger liners and the fastest trains will be equipped with radio telephones. "Give me the Aquitania" or the "Twentieth Century Limited," you will say to Central, and you will telephone to a friend or a business associate on board from your home or your office.

And all this has been made possible by the vacuum valve, and the vacuum valve has been made possible because we can answer the question: "What is electricity?"

CHAPTER VII.

The Future of Radio Communication.

IN 1897 Marconi was asked:

"—and how far do you think a dispatch could thus be sent?"

"Twenty miles," was his answer.

"Why do you limit it to twenty miles?"

"I am speaking within practical limits. . . . The distance depends simply upon the amount of exciting energy, and the dimensions of the conductors from which the waves proceed."

And now we are telegraphing to Europe and Japan. Radio telephone conversations have been conducted between New York, Paris and Honolulu. Music, sermons, opera, lectures are heard by thousands.

No one dreamed of broadcasting's possibilities even ten years ago. It was regarded as a serious limitation that radio communication was not secret and that there was no more privacy about a message than there is

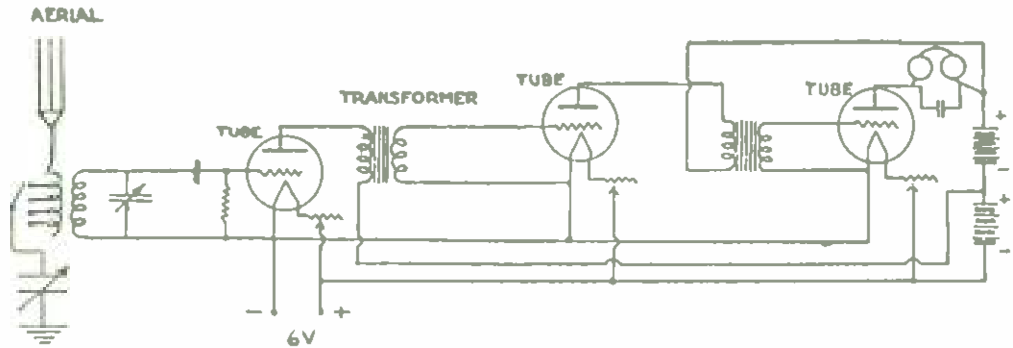


Diagram showing connections for a receiving set employing an aerial and two-stage amplification with vacuum tubes. To interpret the signs used see page 57, where a key to symbols of apparatus used in wiring diagrams will be found. Most of the receiving instruments of the day have circuits of this type. Under favorable conditions, a set arranged as here shown can receive up to 500 miles. The circuit, however, is not good for long distance loop work about a corner political meeting. What was once a drawback is now a technical virtue. Broadcasting, a new way of reaching thousands and even millions, at the same time, is the outcome.

Some day we will look back with amusement at our present instruments and our delight with them. Good as our stations are, they will be as obsolete in a few years as quill pens, crinolines, and high wheel bicycles. Pocket-receiving sets will be developed which will be marvelously efficient. Some day you will see a man stop in the middle of the street, clap a telephone receiver to his head, and listen to that which he wants to hear—the news about trouble that the Afghans are giving the British, about the murder that has shocked the town, about the election.

No backwoodsman or camper will be utterly cut off from the outer world. He too will have his portable set, and even though he is in the heart of the Canadian wilderness, he will listen to the jokes and the songs of some Broadway musical comedy. Every train will have its radio telephone. Is the train late? You call up then and there and inform your wife that dinner must be served without you.

For aught we know the stock and news

ticker may be doomed. Baseball scores, stock quotations, storm warnings—everything of general interest will be tossed into the ether and heard by him who has the proper electromagnetic ear. Every well-appointed apartment house and hotel will be a radio receiving station, and every tenant will "listen in" to broadcasted opera, to a lecture, to a speech by a great orator. Candidates will no longer travel around the country tediously in order to address a few thousands every night, but will speak to millions through some broadcasting station—speak at the same time to the ranchman in Utah and the business man in New York. Is there any stirring event? It will be heard at once in every home. Does the President address Congress? His remarks will be heard not only by the Senators and Representatives before him but perhaps by one-tenth the population of the United States. Is Congress wrangling about a tariff bill? Every one of us can "tune in" and listen to our representative and promptly "tune out" when he wearies us.

The deadening monotony of farm life will disappear. Opera? The farmer will have it, though he may live a thousand miles away from the stage. Education? We shall hear the Einsteins and Wells' of the future radio university expound their views to us with as much personal directness as if we were sitting in their presence. Sailors on lonely seas will listen too. We used to call the telegraph and the telephone "space annihilators." Space annihilation, indeed! We never knew what the term meant until radio broadcasting came. Eskimos and Patagonians, Chinese and Mexicans, Finns and Americans become next-door neighbors so far as radio is concerned and might all be in some huge auditorium. Somehow the world, for all its diameter of eight thousand miles, seems to shrivel into a little ball which can be held in the hand.

Glossary.

AERIAL: A term used interchangeably with "antenna" to designate the wire from which electric energy is radiated into the ether and also the wire by which the radiated energy is received.

ALTERNATING CURRENT: A current which flows not like water in a pipe in one direction but first in one direction and then in the opposite. A single alternation is called a "cycle." Commercial alternating currents are composed of sixty cycles a second. The number of cycles in the alternating currents used in radio is many thousands a second.

AMPLIFIER: A term used to designate the means of amplifying the electrical effect detected. The means may be either a vacuum tube (q. v.) or an amplifying unit.

AMPLITUDE: Every wave grows from zero to a maximum value at its crest. The maximum value is the amplitude and is ascertained by measuring the height of the wave crest.

ANTENNA: See aerial.

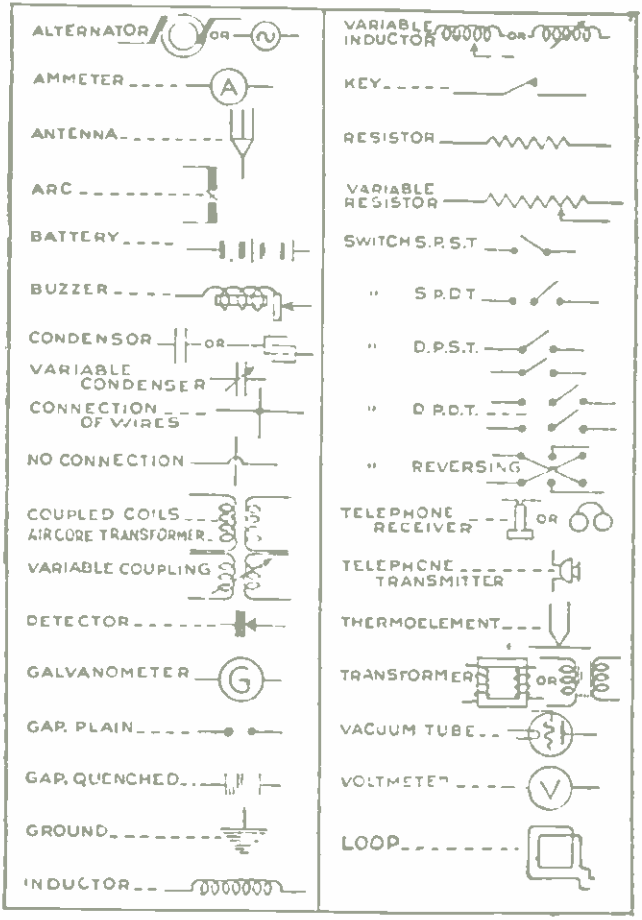
AUDIO FREQUENCY: Vibrations may or may not be audible to the human ear. When they are audible, they have audio frequency. Frequencies below 10,000 cycles per second are regarded as audio frequencies. See also "radio frequencies."

AUDION: A trade name given to one form of vacuum valve. See vacuum valve.

BROADCASTING: The sending of either telegraph or telephone communications through the ether, so that they may be received by a number of stations simultaneously.

CAPACITY: A term used chiefly in connection with condensers. A condenser stores up electricity, the amount of which depends upon its capacity. Capacities are measured in farads. Since the farad is much too large for practical radio use the unit generally employed is the micro-farad (m. f.d.) or one millionth of a farad.

CASCADE AMPLIFICATION: One vacuum valve may be added to another, so that the second amplifies the effect magnified by the first, and the third that magnified by the second, and so on. The vacuum valves are said to be arranged in cascade.



Symbols used in wiring diagrams

CHOKE-COIL: A coil wound to have great self-induction. The resulting choking action is called impedance.

CLOSE COUPLING: When mutual inductance is caused by mounting the primary and the secondary of a tuning coil very close together, the arrangement is said to be "close coupled."

CONDENSER: See also "capacity." The condenser stores up electricity. It discharges the full charge at once and under high tension. It consists usually of alternate layers of a conductor and non-conductor (dielectric). A condenser is used in radio for collecting energy and for putting circuits into resonance so as to tune them.

CONTINUOUS WAVE: A continuous wave is a wave in the ether which has a constant amplitude. It is an undamped wave and therefore travels far.

CRYSTAL DETECTOR: A detector in which a rectifying crystal is used to receive electrical effects in such a manner that they can be heard in a telephone receiver.

DETECTOR: Any device which transforms the electrical vibrations set up in the receiving antenna into visible or audible vibrations.

DIRECT CURRENT: An electric current flowing constantly in one direction.

ELECTRON: The elementary corpuscle of electricity. Electrons are always negative.

E. M. F.: Abbreviation for electromotive force. The unit of e.m.f. is the volt.

ETHER: A medium which is supposed to pervade all space and to serve as the means of transmitting the wave motion of radiant energy.

FLAT-TOP AERIAL: An aerial which has suspended wires stretched parallel to the earth.

FREQUENCY: The number of oscillations per second.

GRID LEAK: A very high, non-inductive resistance connected across the grid condenser or between the grid and the filament of a vacuum valve to permit excessive electrical charges to leak off to an external source, thus assuring stable control under all operating conditions.

GROUND: A term used to designate any connection to earth, river, or sea.

HARMONICS: Every tone is composed of a fundamental and overtones or "harmonics." Harmonics differ in length and frequency from the fundamental. At times radio operators will hear the harmonics of high-power long-wave stations, while their tuners are set for shorter waves.

HENRY: The unit of inductance.

HERTZIAN WAVES: Electromagnetic waves in the ether named after their discoverer.

HOT-WIRE AMMETER: An instrument used in radio transmission to measure amperes by means of a wire expanding in proportion to the heat generated by a current.

IMPEDANCE: The resistance offered by a wire to a current on account of the back electromotive force, irrespective of the ohmage resistance.

INDUCTANCE: Inductance is the name given to the phenomenon of transferring a current from an electrified to an unelectrified conducting body without actual contact.

KILOWATT: One thousand watts.

LOOP ANTENNA: A small frame around which the antenna wire is wrapped.

The frame is mounted so that it can be turned in all directions.

LOUD SPEAKER: A device for magnifying received signals so that they can be heard without the aid of ear-pieces.

RADIO FREQUENCY: Frequencies corresponding with vibrations beyond audibility. All frequencies above 10,000 cycles per second are termed radio frequencies. See Audio Frequency.

RECTIFIER: A device which suppresses one of the pulses of alternating current, so that the resultant current consists of a series of spurts in one direction.

REGENERATIVE CIRCUIT: A radio circuit comprising a vacuum tube so connected that the signal, after being detected and introduced into the plate circuit, is led back to or caused to react upon the grid circuit. Thus the original energy of the signal received by the grid is increased and the response is greatly amplified.

RESISTANCE: Opposition to the flow of current.

RESONANCE: Resonance exists in a given circuit when its natural frequency has the same value as the frequency of the current introduced in it.

SELECTIVITY: The ability of selecting any wave length to the exclusion of other wave lengths.

STATIC: Natural electric discharges in the atmosphere which are heard in the receiving apparatus.

TRANSFORMER: Any device for transferring electric energy from one state to another. Thus we have power transformers, amplifying transformers, telephone transformers, tuning transformers, etc.

TUNING: The selection of a particular wave length. This is done by altering capacity or induction.

VACUUM TUBE: Sometimes called electron tube or thermionic valve. A modified electric incandescent lamp of the vacuum type, which is supplied with the usual filament and with a plate and grid between the plate and the filament. The tube can act as a generator of waves, an amplifier, and a detector.

WAVE LENGTH: The distance from crest to crest of two waves.

RADIO STATIONS THROUGHOUT COUNTRY

List of Radio Broadcasting Stations of the United States Licensed by the Government to broadcast News, Music, Lectures, Market Reports, Time Signals, etc. All these stations operate on a 360-meter wave length, except the Government stations, which operate on 485 meter. There are of course slight variations in tuning which will have to be found by the individual owners of receivers.

ATLANTIC SEABOARD STATES

Station	*State*	*Call Letters*	*Controlled by*
Newark	N. J.	WJZ	Westinghouse Co.
Newark	N. J.	WOR	L. Bamberger & Co.
Jersey City	N. J.	WNO	Wireless Telephone Co.
New York	N. Y.	WJX	De Forest Radio Co.
New York	N. Y.	WDT	Ship Owners Radio Service
Ridgewood	N. Y.	WHN	Ridgewood "Times" Ptg. & Pub. Co.
Schenectady	N. Y.	WDY	General Electric Co.
New Haven	Conn	WCJ	A. C. Gilbert Co.
Hartford	Conn	WQB	C. D. Tuska Co.
Springfield	Mass.	WBZ	Westinghouse Co.
Medford Hillside	Mass.	WGI	Amer Radio Research Co.
Washington	D. C.	WDN	Church of the Convent
Washington	D. C.	WDW	Radio Construction Co.
Washington	D. C.	WJH	White & Boyer Co.
Atlanta	Ga.	4CD	Carter Electric Co.
Philadelphia	Pa.	WFI	Strawbridge & Clothier
Philadelphia	Pa.	WOO	John Wanamaker
Charlotte	N. C.	WBP	Southern Radio Corp.

MIDDLE WEST STATES

Pittsburgh	Pa.	KDKA	Westinghouse Co.
Pittsburgh	Pa.	WPB	Newspaper Printing Co
Indianapolis	Ind	WLK	Hamilton Mfg Co.
Toledo	Ohio	WDZ	Marshall Gerken Co.
Cincinnati	Ohio	WMH	Precision Equipment Co.
Detroit	Mich	WBL	Detroit News
Detroit	Mich.	KOP	Detroit Police Department
Chicago	Ill.	KYW	Westinghouse Co.
Madison	Wis.	WHA	University of Wisconsin
Omaha	Neb.	WOU	R. B. Howell
Minneapolis	Minn.	WLB	University of Minnesota
Kansas City	Mo.	9ZAB	Western Radio Co.
Lincoln	Neb.	9YY	State University

MOUNTAIN STATES

Denver	Col.	9ZAF	Reynolds Radio Co.

PACIFIC STATES

Los Angeles	Calif	KQL	Arno A. Kluge
Los Angeles	Calif	KYJ	Leo J. Meyberg Co
Los Angeles	Calif.	KZC	Western Radio Electric Co
Los Angeles	Calif.	KHJ	C. R. Kierlin
Hollywood	Calif.	KGC	Electric Lighting Co.
Oakland	Calif	KZM	Preston D. Allen
Oakland	Calif.	KZY	Atlantic & Pac. Radio Sup.
Sacramento	Calif.	KVQ	J. C. Hobrecht
San Francisco	Calif.	KDN	Leo J. Meyberg Co.
San Francisco	Calif.	KGB	Edwin L. Lorden
San Francisco	Calif.	KYY	Radio Telephone Shop
San Jose	Calif	KQW	Charles D. Herrold
Stockton	Calif	KJQ	C. O. Gould
Stockton	Calif.	KWG	Portable Wireless Tel. Co
Sunnyvale	Calif	KJJ	The Radio Shop
Seattle	Wash.	KFC	Northern Radio Elec. Co.

GULF STATES

Dallas	Texas	WRR	Police Department
Austin	Texas	5ZU	State University
Fort Worth	Texas	SWPA	Fort Worth Texas "Record"

The Publisher invites criticism and suggestions for future editions.