The Beginner's Story
of Radio
by
B. Francis Dashiell

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A clear and simple description of the fascinating mystery of Radio, written in words that are easily understood and avoiding complicated technicalities.

This book is written for the millions who, interested in radio, desire an intelligent understanding of what goes on within their receivers.

We especially recommend this book to the youth of America from whose ranks must be drawn men who will carry on, to ends now unimaginable, the work of the pioneers.

RADEX is a monthly magazine, written and published for the radio listener. It concerns itself not at all with the intricate technique of radio but devotes itself wholly to informing the man or woman, boy or girl, who is intensely interested in the modern miracle of radio.

It brings the latest accurate information about the stations of North America which are brought in by the dials of the radio receiver. It is filled with chatty, newsy letters from its readers telling of their radio experiences. It is the one magazine of the fascinating radio hobby.

Sold on newsstands throughout the world at 25 cents the copy.

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Chapter One

The Miracle of Radio   Our Story of Radio is intended primarily for beginners. And by beginners we mean those members of that vast family of enthusiasts who tune their dials successfully and log hundreds of stations, all without an adequate knowledge of the functions of a radio set. Radio receivers, like motor cars, quite generally are operated by people who, although wishing they knew just why the thing works, have been deprived of the kind of enlightenment they seek.

It is true that libraries have dozens of radio books on their shelves. But most of these "fundamentals" and "principles" are massive works which are further complicated by mathematical and technical descriptions that mean little to the average reader. The fundamentals of radio make dry reading, so dry, in fact, that much of the romance which has been associated with radio from the very beginning, is lost. Of course, professorial writers are correct when they insist that a study of fundamentals and the associated sciences is absolutely necessary for a complete mastery of the theories of radio.

But, for our purposes, we may well leave many of the theories to those who live and work in radio. We can, instead, learn something of its interesting and fascinating wonders by taking a sightseeing tour through the inner workings and ramifications of radio. Let us follow the radio waves on their journey from the originating station to our loud speakers and see what takes place.

Pull up your favorite chair before the radio. Snap on the switch and bring in some distant station by the mere twist of the wrist. Simple, isn't it? Yet what marvelous laws of nature are called into play, all perfectly coordinated, so that reception takes place. Listen to the instant and faithful reproduction of a musical program. Then close your eyes and imagine that, standing beside the receiver, the musician plays his instrument. His every movement will appear simultaneously with the music coming from the speaker. It does not seem possible that he actually may be half way around the earth. When you hear a single mellow note of a piano you must realize that the player's finger has not yet left the key. Some day television will demonstrate all this with dramatic vividness.

Still seated in your chair, suppose you imagine that you are a modern Alice approaching the Wonderland of Radio. You are entering the studio of the distant station from which the program to which you are listening, is coming. Suppose, too, that through some feat of legerdemain you can become a

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tiny bit of radio energy. Step up to the studio's microphone, speak into it, and take a seat on the sound wave your voice creates; hold on for dear life, for you are about to take on a ride unrivaled in all nature.

Immediately an unknown force whisks you out of the studio, along miles of wires to the broadcasting station. Then, through a maze of controls, tubes and coils, you rush out upon the antennas high above the station. Without further ado you are shot off into space. Higher and higher you rise, passing far into the perpetual cold of space; it seems that you will go on, and on, forever. But suddenly you are turned back toward earth, for you have met the great Heaviside reflecting radio ceiling that prevents all radio signals from flying straight out into the depths of space. You speed down, down, and soon your own antenna, tuned to the length of the wave upon which you are riding, beckons, and you slide safely home.

Once again your carrying wave glides through another maze of tubes, coils and condensers. But this time it is your own receiver that quickly amplifies and enlarges you to your normal size as you tumble from the loud speaker back into your chair. And if your journey was as much as 2,500 miles it took only one-seventieth of a second to complete it.

With the Speed of Light   The flight from the microphone to your radio was made at the incredible rate of 186,000 miles per second! Such is the speed of radio, electricity and light. A radio wave will travel around the earth in one-seventh of a second.

Vibrating sound and radio waves make up radio. Before music and speech can come from your loud speaker many things must take place. At the broadcasting studio sound waves pass through the air from the lips of speakers and singers, and from musical instruments. They strike the sensitive microphone and cause it to vibrate so as to vary the flow of an electric current. A microphone is nothing more than a refined telephone transmitter. The microphone receives sound waves from the air in much the same manner your ears enable you to hear; it is, in fact, radio's ear.

Underlying Principles   The radio transmitter takes these sound waves and converts them to a modulated or fluctuating high frequency oscillating electric current which is broadcast across the surface of the earth as a form of vibrating electromagnetic energy. The radio receiver picks up some of this energy, which is in a greatly reduced condition, and converts it back again to sound waves. The construction and action of the radio receiver is, therefore, just the reverse of the transmitter.

Every piece of metal or wire in the world is filled with

vibrating electrical currents induced by the passage of radio waves. But these waves may be sorted out by the act of tuning a radio receiver connected to the wire or antenna. Only one wave, to which the receiver is made to vibrate in harmony, is permitted to pass. This very weak signal is amplified in strength; reduced from its high radio-frequency vibration rate to a much lower audible rate, amplified again with power tubes, and fed into the speaker which is made to vibrate and thus communicate those vibrations to the air so that sound may be heard by the ear.

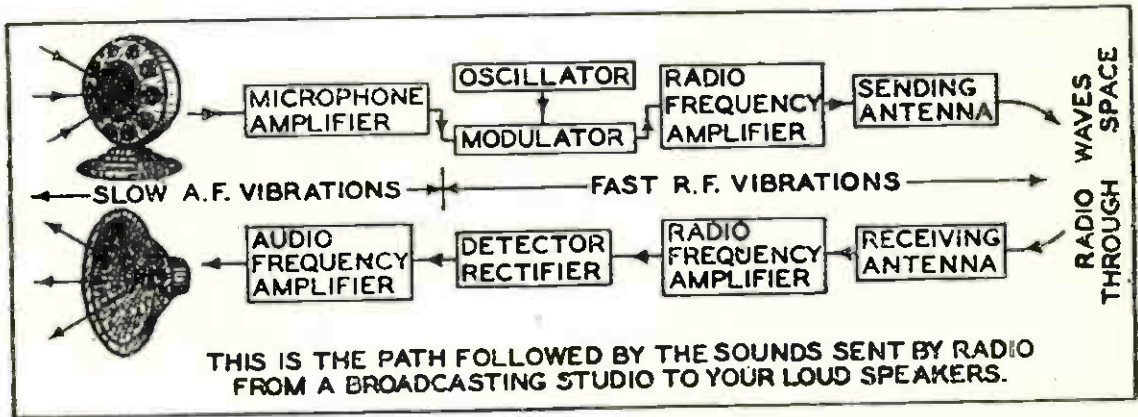THIS IS THE PATH FOLLOWED BY THE SOUNDS SENT BY RADIO FROM A BROADCASTING STUDIO TO YOUR LOUD SPEAKERS.

Figure 1

Radio is simply a means for sending sound waves through the air without the medium of conducting wires, such as are necessary for the telephone and telegraph. Radio in its earlier days was spoken of as wireless telegraphy and telephony. The higher the rate of the electrical vibrations, or the greater their frequency, the farther the radio waves will penetrate. This is the reason why short waves, or high frequencies, carry so far. The same may be said of a steam whistle—one having a shrill, high pitch will carry farther than one that is deep and low-pitched.

In order more fully to understand what makes a radio receiver work it is important that we know something about the mysterious force that makes radio possible. Radio is nothing but electricity, and now we shall discuss electricity and magnetism and how they work in radio.

Chapter Two

Electricity and Alternating Currents

We have been impressed by the fact that radio transmission and reception can be accomplished only by vibration. These vibrations are of great importance in a receiver, yet they are simply electrical currents flowing along in wave-like formations. Electricity provides the energy to keep these vibrations or *waves* in motion. When the waves are close together, the vibrations are rapid; when they are far apart, the vibrations are slow.

These vibrating wave forms can be indicated easily by drawings, such as those illustrating this chapter. The different kinds of electric currents assume various wave shapes; one vibrates slowly, like a lazy sea; another more rapidly; one flows steadily; and another pulsates in irregular waves or surges.
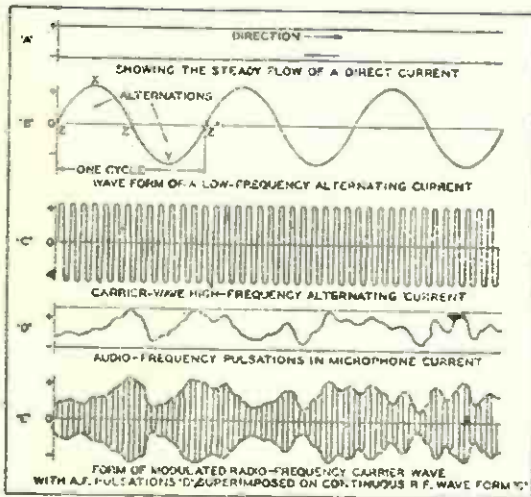

Figure 2

First, we see the *direct-current,* shown in "A" Fig. 2; it flows steadily and never changes its direction. Then there is a slowly vibrating current, with a long wavelike form, as shown by "B." A rapidly vibrating current, with short, wavelike form, is indicated at "C." Now, when direct-current, shown at "A," is varied in intensity, it begins to pulsate and takes irregular wave forms, shown by "D." The most complicated vibration is shown at "E," and it occurs when the rapidly vibrating current, shown at "C," is mixed with the pulsating wave that is indicated by "D." This is a typical radio broadcast wave.

A.F. and R.F.

We shall be forced to grasp this subject more clearly, and therefore must give some study to vibrating electric currents. Radio utilizes two classes of electrical vibrations. The slower vibrations, to which the human ear responds, are known as *audio-frequency* vibrations, and they vary in speed from 25 to 10,000 per second, as shown at "B" and "D." Now when the vibrations become very rapid the ear no longer can detect them. These, then, are inaudible, *radio-frequency* vibrations, and they range from 15,000 to more than 300,000,000 per second, as illustrated at "C."

You have guessed by now that both audio and radio-frequency vibrations are used in radio. All audio-frequency vibrations, as shown by "B," and direct-current pulsations, indicated at "D," produce audible sound. The radio-frequency vibrations, as shown at "C," provide a *continuous,* inaudible *carrier-wave.* This wave carries the audible sound waves through space.

We shall learn that the continuous, radio-frequency wave conducts the audible, audio-frequency wave into and through our radio sets. Let us now carefully study illustration "E" Fig. 2. We observe a radio-frequency carrier wave, similar to "C," but holding to the outline of an audio-frequency sound wave, similar to "D." This combination is the result of *mixing* the two wave forms together. One wave, "C," is the product of the *oscillating,* or electrically vibrating, transmitter in the broadcasting station; the other, "D," comes from the microphone in the studio. Mixing the two causes the carrier wave to assume the form of the audio, pulsating wave, so that the latter can be broadcast far and wide.

A radio wave of the character of "E" now becomes a *modulated* radio-frequency wave or current. The outline of the carrier-wave tops will conform exactly with the sound or microphone wave "D," and it is the impression of these audio-current pulsations on the rapidly vibrating radio wave that converts the original sound waves into rapidly vibrating electrical energy.

A.C. and   How are electrical vibrations created? *Al-*
D.C.   *ternating-current* has solved that problem. Without alternating currents radio could not be possible. But what are alternating currents? Alternating electricity cannot be obtained from a battery; only mechanical motion or oscillating radio tubes can produce it. Batteries give only direct-current. This direct-current flow is a movement of electricity in one direction only. No matter how much the pressure (voltage) of this movement is increased or decreased, it never changes the direction of flow. When direct-current continuously fluctuates in strength but not in direction, as shown at "D," it is called a *pulsating* or surging direct-current.

However, when the pressure behind electricity flowing through a circuit is reversed the current flow will also reverse its direction of motion. Now, if the power or pressure is periodically reversed, alternately positive and negative, at regular intervals, then the current flow will likewise reverse and periodically alternate. These, then are electric vibrations, rushing back and forth through the wires of the circuit like the swinging of a pendulum. And these alternations, or vibrations, may be so regulated as to occur at any desired rate or frequency per unit of time.

The 60-cycle The rise and fall of the flow of the current **Current** in one direction is called an *alternation;* and the second rise and fall in opposite direction is another alternation. See X and Y at "B" Fig. 2. Two alternations constitute a *cycle,* as shown at "B." The length of time required to complete the full cycle is the time period, which, in our house-lighting circuits of 60 cycles per second, is 1/60th of a second. An alternation, in this particular circuit is, therefore, 1/120th of a second in length. The 60 cycle light-circuit hum we oftentimes get in our radios therefore has a vibration sound of 120 waves per second.

The number of cycles (not alternations) that occur during one second of time is known as the *frequency* of the alternating current. In radio, where many thousands of cycles are needed, the term *kilocycle* is used; 1,000 cycles being equal to 1 kilocycle. And in short-wave work we hear of the *megacycle,* meaning 1,000,000 cycles or 1,000 kilocycles. For instance, 2.5 megacycles are equal to 2,500 kilocycles. Alternating currents having frequencies as high as 600 megacycles have been created in ultra short-wave experiments!

Alternating currents are very valuable. They can be transferred from one circuit to another without electrical contact; they vibrate through space to strike our aerials, and swarm back and forth through our receivers; they may be amplified instantly to great intensity, or reduced to the faintest whisper.

The What is electricity? It is an agent for the **Mysterious** transfer of energy; it cannot be seen or **Power** heard except through its effects. It can be produced by friction, chemical action, or mechanical motion. There are two kinds of electricity — *positive* and *negative*. These opposite kinds attract each other and therefore cause a current to flow through a conductor. Like charges tend to repel each other. The same condition is found in the *magnet,* which has *north* and *south* poles. As an example run a hard-rubber comb through the dry hair. The comb becomes charged and will attract bits of paper. If held to the radio antenna a sharp crash will be heard in the speaker, thus proving that *static electricity* was generated by friction.

Electricity can be generated by chemical action in a *battery*. The simple voltaic *cell* is the basic form. It consists of two dissimilar metals, zinc and copper, immersed in a dilute acid solution. A current will flow through a wire connecting the two metals. The *dry* cell, a more practical form, is essentially similar. Its zinc container, the negative terminal, holds the moist paste acid electrolyte and the central carbon positive electrode. Our B batteries are made up of a large number of small dry cells. *Storage batteries* retain the direct-current sent into them from an outside source

(charging operation) because of certain chemical changes in the solution and plates.

Single dry cells give 1½ volts and storage cells give 2 volts each. Connecting single cells in *series* adds the voltages of the individual cells together but does not increase the quantity of available current beyond the capacity of one of the single cells. *Parallel* connections do not increase the voltage of the entire group beyond that of a single cell, but adds the total quantity of current available together. See Fig. 3.
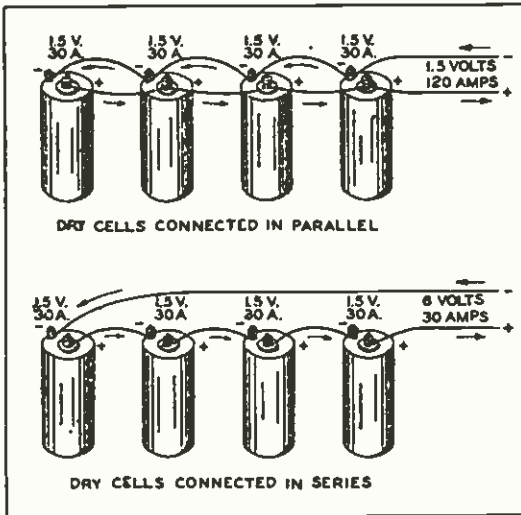
Electricity is measured by volts, amperes and watts. The *current* is the flow of energy; imagine the wire to be a pipe, and the current to be the motion of the water. The *volt* is the unit of pressure or *electro-motive-force* (e.m.f.), just as the force of water in a pipe is measured by pounds. The *ampere* is the unit of amount or quantity of electricity, just as water is measured by gallons. The *watt* is the unit of electricity consumed or created per unit of time (one hour); it is determined by multiplying volts by amperes. For instance: A device consuming one ampere per hour with a pressure of 110 volts is said to use 110 watts. A radio tube requiring 1.5 amperes at 2.5 volts consumes 3.75 watts per hour. Add all the wattages of your tubes together, plus about 25 per cent for loss of efficiency, and you will get the power consumption of your set. To this must be added also the plate currents of the tubes in *milliamperes*, which amount can be obtained only from tables of tube characteristics.

The wire through which electricity flows is a *conductor*. Copper is the best commercial material, but silver is the most nearly perfect. There are materials that prevent the flow of an electric current, such as glass, hard-rubber, bakelite, etc. They are known as *insulators*. Other materials retard the flow of electricity to various extents, and they are known as *resistances*. The unit of resistance is the *ohm*. The unit of conductivity is the opposite of resistance—the *mho*. 1,000,-000 ohms is called a *megohm*.

The ampere, volt and ohm work together in all electrical and radio circuits. Their relationship is interesting and of vast importance in making circuit calculations. Perhaps some of our readers will wish to look up *Ohm's Law* in text books and make a more complete study of its many combinations in radio.

Figure 3

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Milli means one-thousandths part of some unit, such as *milli-ampere,* which is one-thousandth of an ampere of current. *Micro* is one millionth part of an unit; *micro-volt* being one-millionth of a volt.
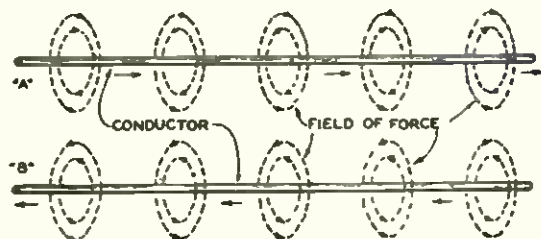
Chapter Three

**Electro-
magnetic
Induction
and
Transformers** We have found that electricity flows steadily as in the case with direct current, and that it also may periodically reverse its direction, as alternating current. Let us, then, take up the interesting subject of how an electric current can be transferred from one circuit to another, across an insulating air space, while at the same time it is amplified in strength. The practicable application of this remarkable phenomenon is the *transformer,* which makes possible the radio and audio-frequency amplification so necessary in radio reception.

Most of us are familiar with the *magnet* — a steel bar that possesses the peculiar faculty of attracting bits of iron. The two ends of a magnet are called *"north"* and *"south"* *poles,* usually indicated by N and S, respectively. Opposite poles will attract each other, while similar poles will repel. Then there are millions of *"lines of force"* existing about a magnet. They seem to stream from one pole to another. These lines, passing through the air, actually may be seen if the magnet is covered with a sheet of thin paper and then dusted over with fine iron filings.

**The
Magnetic
Field** When an electric current is flowing it is surrounded by a whirling *magnetic field* composed of lines of force always spinning around the conductor as a center. The direction of rotation of the lines of force about the wire depends upon the direction in which the electric current is flowing through the circuit. A simple rule to remember is, that if a wire is grasped with the right hand so the *extended* thumb points along the wire in the direction in which the current is flowing, the fingers will then curl around the wire and point along the direction in which the lines of force are whirling, always at right angles to the conductor.

SHOWING MAGNETIC LINES OF FORCE WHIRLING
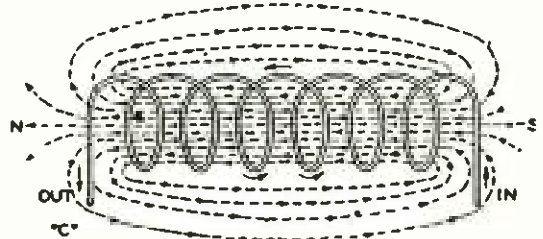ABOUT A CURRENT FLOWING THROUGH A CONDUCTOR

Figure 4

In the illustration "A" Fig. 4 we see a conductor carrying an electric current moving as indicated by the arrows. The direction of the whirls of magnetic force about the conductor is shown by the encircling arrows. The same wire is shown again at "B," but with the current direction reversed. We readily

see that the whirls of force also reverse direction. Now, if an alternating current is flowing through the wire, the magnetic lines of force also change direction every time the current reverses its direction. The number of alternations of current is the same as the frequency of the reversal of the magnetic field surrounding the conductor. It is important that the reader remember this through the following paragraphs.

A Source of Interference Wires carrying high voltage alternating currents, such as power lines, have surrounding magnetic fields that encompass all nearby aerials and create constant hum and interference. And there is little or nothing that can be done about such interference unless the receiver and aerial wires are removed from the field of force.

Let us form a wire into a single loop. All of its encircling whirls or lines of force will pull together, and a more powerful magnetic field will be built up about the loop. Now, if a number of these loops are arranged in a form of a spring-like *coil,* the cumulative effect of the individual loops will build up a still greater magnetic field of force. At "C" Fig. 5 we have such a coil. Magnetic lines of force are shown flowing through and around the coil, and they are similar to the lines that surround a steel

MAGNETIC LINES OF FORCE ABOUT A CURRENT FLOWING THROUGH A COIL OF WIRE

Figure 5

bar-magnet. If an iron bar is placed within the coil it instantly becomes a magnet, and the coil with its magnet *core* is called an *electro-magnet.*

If the direction of the current flowing through the coil is made to alternate, the entire magnetic field reverses its direction each time the current alternates. If an iron bar is inserted within the coil it, too, becomes a magnet. But this time it has no fixed North and South poles. The two poles become alternately North and South every time the alternating current changes direction through the coil. The lines of force swing back and forth, and thus we can create a rapidly moving magnetic field of force surrounding the coil. The insertion of an iron core in the coil creates an electro-magnet, and naturally the surrounding magnetic field becomes much stronger than that existing about only a coil of wire.

The Phenomena of Induction This leads us to the theory of *magnetic induction.* If a wire, having its two ends attached to a sensitive electric meter, is moved rapidly over one end of a powerful magnet, a surge of electricity will flash through the wire. Or, on

the other hand, if the wire is held stationary and the magnet quickly moved, a similar effect is observed. It is motion alone — that of a wire cutting through a magnetic field, or a magnetic field moving across a wire — that creates an electric current. We see that electricity and magnetism go hand in hand — electricity produces magnetism, and magnetism creates electricity. Electric generators and magnetos owe their existence to this simple truth. But they require motion to operate. It is the motion of the alternating-current magnetic field of force swinging back and forth that makes the transformer possible. Upon it hinges all *electro-magnetic-induction* as found in radio receivers where radio, intermediate and audio frequency stages of amplification are used.
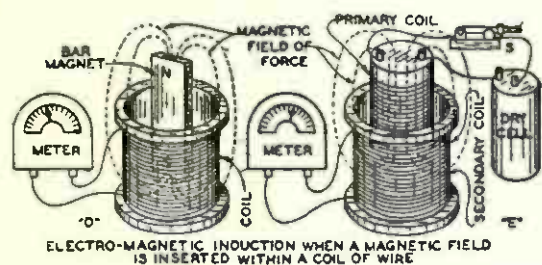

ELECTRO-MAGNETIC INDUCTION WHEN A MAGNETIC FIELD
IS INSERTED WITHIN A COIL OF WIRE

Figure 6

If a large quantity of fine insulated wire is wound into a coil, as shown at "D" Fig. 6, with the two ends connected to a sensitive meter, it will be found to create a s i n g l e electrical impulse whenever a permanent steel magnet is plunged into the coil. And when the magnet is quickly withdrawn another surge of electricity takes place but flowing in the opposite direction. These currents are *induced* by the motion of the magnetic field of force cutting across the many turns of wire in the coil. They alternate because of the back and forth motion of the magnet. If the magnet is replaced with a smaller coil that is attached to a battery, as shown at "E", Fig. 6, similar effects will be observed. Each time this inner, or *primary*, coil is inserted and removed two different surges of electricity are induced in the outer, or *secondary*, coil. The movements of the primary coil create alternations of current in the secondary.

On the other hand, when the primary coil remains stationary within the secondary, the same effect will be noticed each time the battery current is turned on and off by a switch (S) placed in the circuit. There will be a surge of current in one direction when the circuit is closed, and in the opposite direction when the switch is opened. When an iron bar is placed in the primary coil it will make a stronger magnetic field, and the induced current will be noticeably greater.

**The
Secondary
Current**
Connect an alternating current to the primary and there will be no necessity for moving the primary coil in and out of the secondary, or making and breaking the circuit with a switch or vibrator, in order to induce currents in the secondary coil. We know that an alternating current, when flowing through a coil, causes its surrounding magnetic field to reverse direc-

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tion every time the current alternates. This, then, gives a quickly and constantly changing magnetic field that cuts across the wires of the secondary coil so as to induce currents in the latter. The alternations in the primary induce a similar, rapid, alternating current in the secondary, and the lapses between surges, whenever the magnetic field reverses direction, become so short that the current appears continuously to flow.

A transformer consists of two coils of wire wrapped about a soft iron core, as shown at "F" Fig. 7. If the secondary has twice as many turns as the primary then twice as much potential will be generated. But the total number of watts generated by the secondary cannot exceed the watts consumed by the primary. For instance, a 550 watt transformer, wound with 1,000 turns of wire on the primary; connected to 110 volts and consuming 5 amperes of current, will, when using a 5,000 turn secondary, generate 550 volts, but at only one ampere, or still 550 watts. In practice, however, the transformer is not 100 percent efficient. Transformers are remarkably self-regulating; an increased drain upon the secondary current causes an increase in the current flowing through the primary. Too much rise in the secondary, or over-loading, causes the transformer to become dangerously overheated.
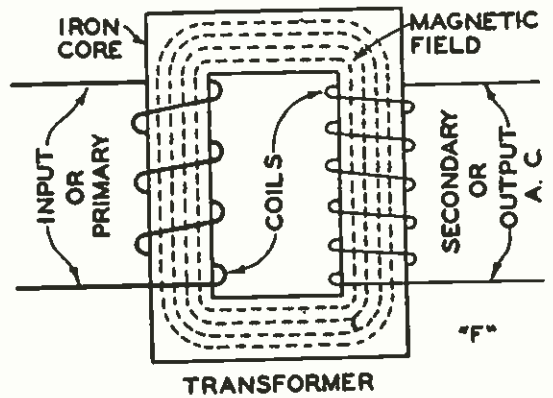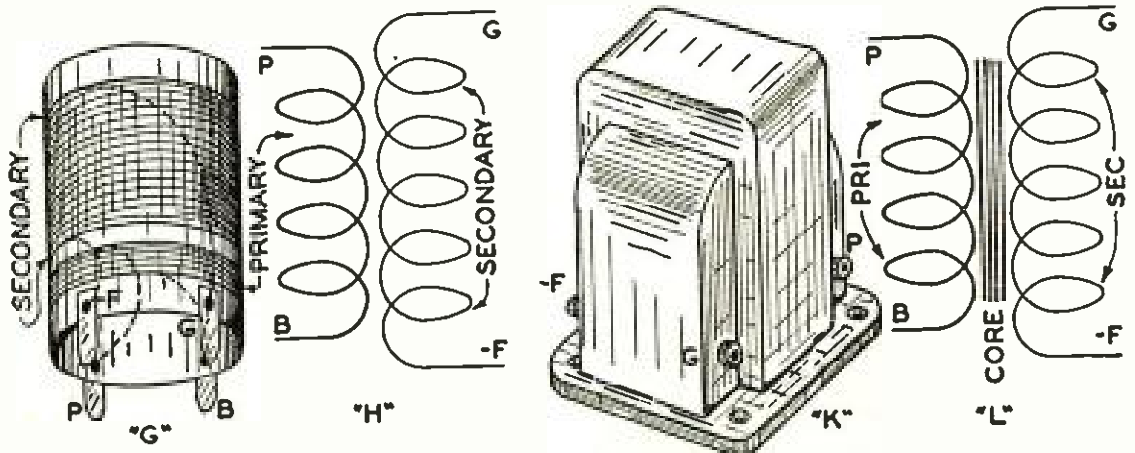

TRANSFORMER

Figure 7

RADIO AND AUDIO-FREQUENCY TRANSFORMERS

Figure 8

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The Transformer The iron-core transformer is used when the frequencies of alternating currents are low and within the audible range. Many thousands of turns of wire are used in its coils. It is used in a radio receiver to step up the potential of 110-volt a.c. to the voltage needed to operate the plates of the tubes. Its particular adaptation to radio, however, is as the *audio-frequency transformer* or *output transformer*. At "K" Fig. 8 is shown an audio-frequency transformer, and the usual symbol used in drawing radio circuits is indicated by "L."

When very high a.c. frequencies are to be amplified by transformers, such as those within the radio-frequency range, the iron core is removed and the number of turns of wire in the primary and secondary reduced to a very few. Too many turns tend to choke back the rapid alternations of current. Low frequencies will pass through large coils; high frequencies through only very small coils. And the higher the frequencies the smaller the coils that must be used. The transformer used for high or radio-frequencies is, therefore, a *radio-frequency transformer*. It is shown at "G" Fig. 8, and its radio circuit symbol is indicated by "H."

Chapter Four

Electrons, Capacity and Condensers Up to now our interest has been held by electric currents and the phenomenon of electromagnetic induction. We have been quite unfamiliar with electricity itself. We must understand further its origin if we are to become familiar with the operation of radio tubes and condensers. Electricity is definitely a material thing, cloaked in mystery. It is not a liquid, such as flowing water or gas, but a movement of energy itself.

Let us, then, devote a few brief moments to the romantic story of the *electron*. Here is the tiniest thing in all nature; an infinitesimal bit of pure negative electricity; a real particle or corpuscle of energy; something speedy, indestructible, and fixed in form and power. You cannot see an electron, even with the most powerful microscope, for it is so small that if 10,000,000,000,000 of them could be laid in a row, they would cover only one and one-half inches. Under certain conditions the electron is free to move about; or it can be held—bound—in place, as a form of potential energy.

Now we must also consider another tiny basic unit—the *atom*. It is the smallest unit particle of any one of the elements known on earth. No one has seen an atom, although most of them have diameters equal to at least 100,000 electrons! Two or more different atoms will group together to construct a single unit, or *molecule*, of any kind of substance or matter, solid or liquid.

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The Birth of Electricity The atom, being a particle of matter, has bulk and weight. Its center, however, is a core or nucleus of pure positive electricity — the *proton.* Around the center many electrons are constantly spinning—like the planets about the sun. We know that positive and negative electric charges attract each other, and, since the proton nucleus of the atom is a unit positive charge of electricity, it must, therefore, attract to its bulk a sufficient number of negative electrons exactly to balance or neutralize the proton charge. The atom, then, is electrically neutral or normal. This is the state of any mass of matter unless it has been affected in some way by outside or internal influences or disturbances.

What can affect the neutral state of any mass of atoms or molecules? Friction, mechanical motion or chemical action can set electrons free from their associated atoms. Electricity is made available simply by compelling the electrons to move away rapidly. We must realize that electricity cannot be created out of nothing. Electrons are present always in any substance; it is necessary only to set them in motion. Water, for instance, is not created by a pump; the latter simply starts the motion and keeps it going. The electric generator or battery is the pump that keeps the electrons flowing.

The Law of Conductivity Electrons can fly with the speed of light through any conductor. The spaces between the atoms and molecules of a wire are vast when viewed by an electron. It can pass through with as much ease as a fly in some great auditorium. Now, if a great many electrons are forced through a length of wire, many of them do not reach the far end, and the original current becomes reduced. If an excessive quantity of electrons try to pass through the atomic spaces of a small wire, the crowding becomes so great that the

Figure 9

friction can cause sufficient heat to melt the wire. Conductors having less space between their atoms offer more resistance to the flow of electrons than material composed of larger atoms with more open spaces between. That is why some metals are good conductors while others offer high resistances.

What happens when we set electrons free? We have seen that the atom's positive charge remains constant. Up to now it has been neutralized by the presence of a certain number of associated electrons, as shown at "A" Fig. 9. But let us remove some of the electons, as shown in "B," and we readily see that the positive charge predominates. Or we can
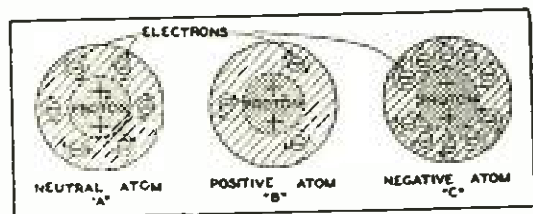
thrust some additional electrons on the neutral atom "A," and then the negative charge of the electrons predominates, as shown at "C." The work of adding to, or taking electrons from, atoms is called *ionization*. This term, in radio, refers particularly to the atoms and molecules of air and gas.

Because of the ease with which electrons can be separated from their parent atoms we find that electric charges can be developed by induction, just as we have seen currents created by electromagnetic induction in wires and coils. This new form of induction is termed *capacitative induction,* and is one of the absolute essentials in radio work. Let us see how it is accomplished.
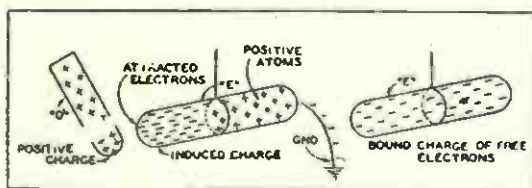

Figure 10

Rub a glass rod briskly with a piece of warm, dry flannel. The electrons will be agitated and many of them are attached to the flannel. Now, because of the resulting deficiency of electrons in the rod, the latter assumes a positive charge, as shown at "D" Fig. 10, because the positive protons of the atoms predominate, which condition is indicated at "B" Fig. 9. Thus a state of frictional or static electricity has been developed. This charged rod can be used to induce a charge—of an opposite nature—in another, but insulated, body.

Suppose we suspend a glass tube from a silk thread, as shown in "E" Fig. 10. This tube, or rod, is normally inactive and electrically neutral. But, as soon as the rod "D" is brought close to one end of "E," as shown, the positive charge on the former *attracts* as many of the electrons in "E" as are *needed* to make up the deficiency of electrons in "D." These freed electrons rush to the end of "E" where they are *bound* on the surface by induction. This is called a *bound charge.* But, at the other end of "E," the atoms are deficient in electrons, and a positive state persists. Some refer to this as the *repelled* positive charge.

If we touch the far end of "E" with a grounded wire (GND), a number of surplus earth electrons will rush into "E" to replace those electrons bound at the end next to "D." Each positive atom receives its quota of electrons and, upon removal of the wire, we discover that "E" now has a large excess charge or supply of electrons. Remove the charged rod "D." The electrons distribute themselves evenly over "D," which now is negatively charged through the inductive effects of the positive charge on "D." Bring "D" close to "E" and, if in a dark room, a tiny spark will be seen as the surplus electrons jump off "E" to seek the positive or electronically deficient atoms of "D." There they recombine, and the charges are neutralized, with both "D" and "E" returning to their normal state. The amount of charge that can be induced on

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"E" is determined by the area of the surface, the kind of material, and the insulation (in this case a silk thread) which prevents the electrons from leaking off. This, then, is the *capacity* of a body to hold an electric charge. Many other interesting experiments with capacity and induction can be made by the amateur. That of the electrophorus (described in any text book or encyclopedia) is the most popular and entertaining. It is capable of producing strong shocks and brilliant sparks.

Principle of the Condenser At this point, we come, quite naturally, to a discussion of the *condenser*. It is a device absolutely necessary in radio, and has the ability to receive, hold, and yield a charge of electricity. A condenser is constructed by placing two parallel conducting surfaces on opposite sides of some insulating material, called the *dielectric,* as shown in "F." This arrangement provides a *fixed condenser*. The capacity of this condenser can be increased by enlarging the area of the surfaces, or the addition of several units, connected as shown in "G."
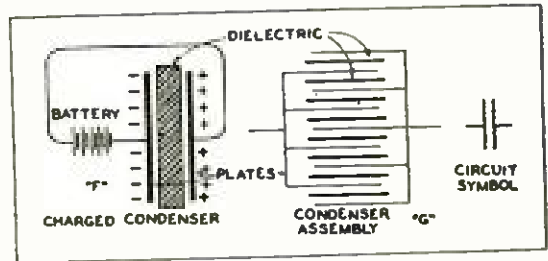

Figure 11

When placed in an electric circuit the condenser is a *blocking* or insulating device. An electric current cannot pass. However, when connected to a battery, the condenser will store up electrons which can be later discharged into the circuit. At "F" Fig. 11 we see a simple condenser and battery. If electrons accumulate on the negative side, then the opposite side becomes deficient in electrons. Remove the battery. The condenser is now charged with opposite electric charges bound on the two opposite sides by attraction. There is a form of electrical strain and stress in the material used as the dielectric. This strain can be released instantly in the form of a momentary flow of electricity if the two opposite sides of "F" are touched together with a wire conductor.

A condenser can pass an alternating current although at the same time, it effectively blocks a direct current. When an alternating current is impressed upon both sides of a condenser it is charged and discharged—first in one direction, then in the opposite—although the current does not actually *pass* through the condenser. Current really flows *into* and *out* of a condenser. The first alternation—call it negative—will give the plates a negative charge, then, as the second — the postive — alternation appears, the negatively charged condenser discharges into the circuit and prepares to receive a positive charge. Thus, current flows to and from a condenser at every cycle of an alternating current. Apparently, therefore, a condenser *seems* to pass a current of alter-

nating electricity. And it is this principle that gives us a powerful device to control the tuning of our radio receivers, as we shall see in a subsequent chapter.

Measuring Capacity   The capacity of a condenser depends upon the dimensions of its conducting surfaces or *plates,* and the type and thickness of the dielectric. This capacity is measured by a unit called the *farad.* But even one farad is too immense to use—it would make a condenser as large as a great building. So we use a unit of capacity that is more in keeping with the size of radio condensers. It is the *micro-farad,* meaning one-millionth part of a farad. A still smaller unit, called the *micro-microfarad,* is one millionth of one-millionth of a farad. Thus, we write the capacity of a condenser, for instance, as 0.0005 of a microfarad (mfd), or, more conveniently, 500 micro-microfarads (mmfd).

Our radio receivers use several types of condensers. The fixed condensers are divided into the *by-pass, blocking,* or *filter* types. The larger filter types are more carefully constructed, most of them being known as *electrolytic* condensers. These give large capacity with the minimum use of space. The variable types are known as tuning and adjusting condensers.
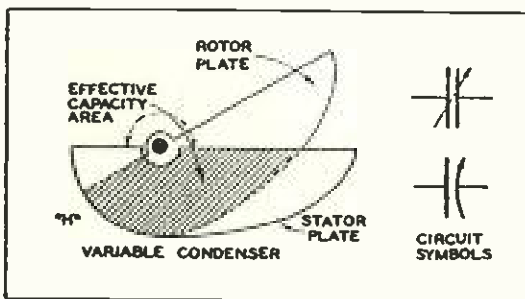

VARIABLE CONDENSER

Figure 12

The *variable condenser* is unique with radio. It is constructed of interlocking, spaced metal plates using air as the dielectric. One set of semi-circular stationary plates, connected together, forms one surface of the condenser. These are the *stator* plates. Another set of spaced plates, which can be rotated between the stator plates by a shaft, is called the *rotor.* They are used to vary the capacity of the condenser continuously from zero to maximum by changing the area of the plates opposite each other, as shown in "H" Fig. 12.

Tuning a Radio Receiver   Condensers, as we have learned, pass only alternating currents. Low-frequency alternating currents pass only through large condensers. High frequencies will pass through small condensers. In other words, it takes a large capacity condenser to permit low or audio-frequency currents to flow, but a small capacity condenser will pass high, or radio-frequency currents. The variable condenser, therefore, can be made to pass high and low frequency alternating currents simply by adjusting it to the proper capacity. In radio sets, these condensers have sufficient size to pass radio currents having frequencies be-

tween 1500 and 550 kilocycles or 200 and 550 meters respectively.

A number of units, placed on a single shaft and turned with one dial, simultaneously tune a similiar number of inductance coils. Capacities of these condensers range from 0.00035 mfd. (350 mmfd) to 0.0005 mfd. (500 mmfd.). Short wave condensers are much smaller and range from 10 to 320 mmfds. The tiny *adjusting, balancing or trimmer* condensers, used to offset mechanical irregularities in large variable condenser construction when lined up in a *gang* unit, have capacities ranging from 3 to 35 mmfds.

Now that we understand how condenser capacity controls the frequency of the alternating current passing through the radio circuit, we shall be better able to realize how condensers are used to *tune* radio circuits to any desired frequency flowing in the receiving antenna.

Chapter Five

Tuning and the Radio-Frequency Circuit While studying the actions of condensers we made the interesting discovery that when a condenser is set to a given capacity, it will permit an alternating current of a given frequency to pass. Then, when the capacity is changed somewhat, another alternating current of a different frequency will flow. Therefore, because of this definite relationship between capacity and frequency, we can make use of the variable condenser to select any frequency of broadcast wave that may be desired. The selection of these certain frequencies, or radio waves, is performed only in the *radio-frequency circuit* by the act of *tuning*.

If the frequency of the broadcast wave or signal that is being received is high, a condenser of small capacity is used (a small portion of the variable condenser's total plate area); when the frequency is low, the capacity must be large (all of the variable condenser's plate area in use). For reception, a variable condenser having a maximum capacity of .0005 micro-farad (500 micro-microfarads) will permit all frequencies between 550,000 and 1,500,000 cycles (550 and 1,500 kilocycles) to pass through the circuit which it tunes.

Return to the receiving set for a moment. If we adjust the dial that controls the tuning condenser, we will find that we have set the condenser to some given capacity (value unknown), and that it will then be in *tune* with some given frequency. At this setting the condenser offers no resistance to just one particular electrical vibration coming down from the antenna yet to all other frequencies it presents an effective resistance. Tuning a receiver is a simple matter. Let us see how it works.

Tuning a Receiver   The resistance a condenser offers to the "apparent" flow of electricity is called *capacitive reactance*. Now, when the condenser is tuned to a state of *minimum* reactance, a given frequency will flow easily through the circuit. A tuned radio circuit, therefore, permits the passage of just one frequency, and prevents the flow of unwanted frequencies. This tuning effect enables us to select any particular radio signal from the chaos of vibrating waves that exists in the air about us.

But the condenser alone is not the only instrument at our command for the control of electrical vibrations in our radio sets. A single coil of wire—an *inductance*—also offers considerable resistance to the flow of an alternating current. And, like the condenser, its resistance to an alternating current is also a reactance—*inductive reactance*. The higher the frequency of the current, the greater will be the reactance of the coil; the lower the frequency, the smaller the reactance. Also, like condensers, small coils pass high frequencies; and large coils pass the low frequencies. That is why short wave receivers use small radio-frequency coils, or inductances, and broadcast receivers use larger coils.

Purpose of the Coils   Tune in a station with a fixed inductance, and then change the number of turns of wire on the coil. Immediately we vary the amount of inductance or reactance the coil presents to the flow of the given frequency, and that station is tuned out. But a new station frequency will be tuned in. We have, therefore, changed the reactance so that a *new* radio frequency will flow easily through the coil. The coil inductance has been tuned to a given wave length or broadcast frequency. In the early days of radio, coils were tuned by means of switches and sliders. Today, in modern radio, we tune the inductances simply by means of variable condensers.

A coiled conductor, wound into an inductance, can be tuned by a variable capacity "shunted" around the coil. Such a coil is a radio-frequency coil, transformer or inductance, and all tuning is confined to the radio-frequency portion of a radio circuit. The coil must be tuned in order to create a point where one frequency will pass without opposition. This condition is called *resonance*. We can find hundreds of points of resonance as we slowly turn the tuning condenser shaft. The circuit now offers minimum reactance, and at this resonant point the tuned-in radio signal will flow at its maximum strength. Other signals will be tuned out.

The "Why" of Tuning   What is inductive reactance? Why does it permit a single frequency of alternating current to be selected for passage through the circuit while all other frequencies, which also may be present, are choked back?

We have seen, in Chapter Two, that an alternating current will build magnetic fields of force about a coil through which the current flows. When the voltage drops from maximum there also is a failure of the surrounding magnetic field. The magnetic lines of force collapse upon the turns of wire, and induce additional voltages in the coil, just when the next alternation of current is beginning to appear from the other direction. Thus, these two currents tend to oppose each other, and the effect is called *counter-electromotive-force, self-inductance,* or reactance.

Impeding All But One Frequency Self-inductance, then, tends to prevent the flow of alternating or pulsating currents through a coil of wire. However, there will be one certain frequency which will vibrate at the proper rate so that its self-induction will rise and fall *between* the orig-

Figure 13

inal current alternations at the proper moment. Both will be in step and there will be no a.c. resistance, or self-induced reactance that will hinder the flow of the original current. Reactance is measured in ohms, and *impedance,* which is a combination of wire resistance, reactance and capacity, also is indicated in ohms.
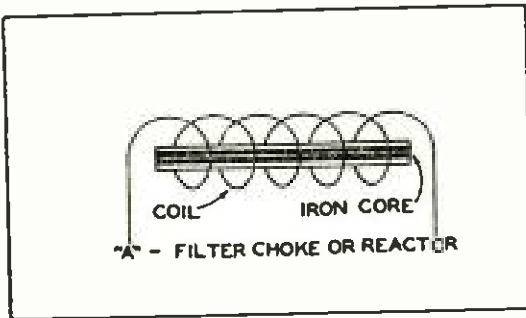
The unit of self-inductance is called the *henry.* Smaller units are: *the millihenry,* which is one-thousandth part of a henry; and the *microhenry,* the millionth part of a henry. In a coil of considerable inductance—about 30 to 50 henries—

which offers high reactance against the flow of most all alternating, pulsating, or rippling currents, the high reactance voltage developed will prevent potential changes in the current. This type of coil is called a *choke, reactor,* or *filter,* and the symbol used to indicate it in radio diagrams is shown at "A" Fig. 13. Such coils have heavy iron cores with many turns of wire. The filtering effect tends to smooth out all pulsations and ripples. But we will hear more about chokes and filters when we discuss the power units of radio sets.
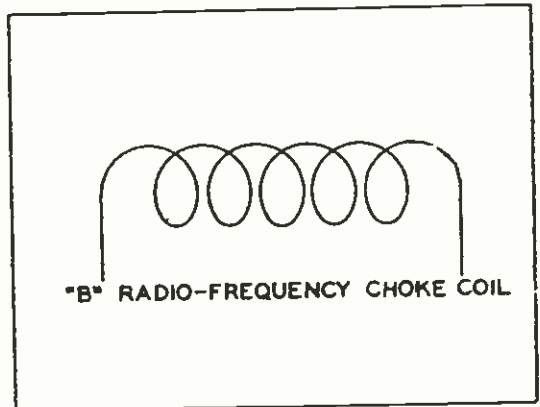

Figure 14

The Primary Circuit Smaller inductances used in radio circuits are know as *radio-frequency chokes.* The circuit diagram symbol is shown at "B" Fig. 14. They are

wound on open tubes, and have values ranging from .05 henry (50 millihenries), down to .0005 henry (500 microhenries). These tiny coils choke back the faster radio frequencies, but permit the passage of the slower audio-frequency currents.

When we tune a radio circuit we simply turn a dial and adjust the capacity of one or more variable condensers. By so doing we bring the tuning inductance and the capacitance in resonance. The high reactance of the coil is balanced by the low reactance of the condenser when tuned to some given radio frequency. Such a tuning arrangement is shown in "C" Fig. 15. The variable condenser VC1 is connected across the ends of the coil L2. A change of VC1 will change the total reactance so as to tune in some *other* radio frequency. Any slight movement of the condenser rotor plates will change this state of balance to another point of resonance. Each change, then, tunes in some new signal.
Any slight movement of the condenser rotor plates will change this state of balance to another point of resonance. Each change, then, tunes in some new signal.

The Secondary Circuit Connect a small, second coil (L1) between the antenna and ground, and *couple* it inductively to the inductance L2, which is tuned by the condenser VC1. We now obtain the scheme shown at "D" Fig. 16. The small coil—about ten turns—becomes the primary; the larger coil — about 70 turns — becomes the secondary. Both, so arranged, make a radio-frequency transformer (see illustrations "G" and "H" Fig. 8, page 13). By tuning the secondary of this transformer we provide an *elementary radio-frequency circuit*. Only the radio-frequency circuits of a receiver are tuned. It is here that the *selectivity* of the set is determined, and where *radio-frequency amplification* of the weak, original signals from the antenna is accomplished by the transformer action of the r.f. inductances or coils.
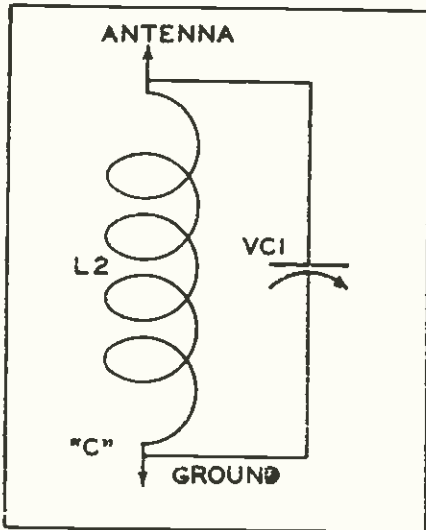

Figure 15

Hundreds of weak electrical vibrations are being constantly induced in the radio antenna by every passing radio wave. The broadcast wave, from the transmitting station, is a swinging, vibrating magnetic field. As it cuts past any metallic conductor within its range, it induces a slight current of electricity in the conductor. This action, is similar to that

described in Chapter Three. (See D and E, Fig. 8, page 13. If it were not possible for us to tune our sets, all of these induced waves would pass through in a bedlam of interference. That is why, when a receiver is not selective and has poor tuning and resonance, there is much station interference.

The T. R. F. In the diagram "D" Fig. 16, which now **Circuit** makes use of the radio circuit symbols shown in Chapters Three and Four, we see the primary coil L1. It permits most of the radio waves to pass down to earth because its reactance is very low; it is an *untuned* circuit. The currents passing through L1 will induce stronger currents in the secondary L2. But the inductance value of L2 is higher and, therefore, only those frequencies falling within its resonant limits—the broadcast band—will be reproduced.

It is necessary to tune out all frequencies induced in L2, within its resonant limits, but retain a single wave for further amplification. This selection can be accomplished by varying the capacity reactance of the condenser VC2. The tuned signal, in this case, is stronger than the one selected by the arrangement shown in "C" Fig 15, for we have had the benefit of transformer action, or radio-frequency amplification.

Building Up We can add a second radio-frequency unit, **the Signal** similar in all details to the first, shown at "D" Fig. 16, and thus provide two *stages* of radio-frequency transformers and tuning. At "E" Fig. 17 these two stages are seen. The tuned and amplified signal from the coil L2, is passed to the primary coil L3 of the second r.f. transformer. It induces stronger amplification in the secondary coil, L4, which is tuned anew by the condenser, VC2.

And we can add still another unit, and there will be *three* stages of r.f. amplification and tuning, as shown completely at "E." The strong, and now sharply tuned signal, from L4, is passed to the primary L5 of r.f. transformer No. 3. Here. it induces. in the secondary coil L6, which is tuned by VC3, a very powerful current. The three stages of induction, amplification and tuning, provide a sharply resonant circuit extending from L1 to L6. A change of VC1 will require changes in

Figure 16

VC2 and VC3 so as to make all three radio-frequency stages again resonant at some particular radio frequency coming

ANTENNA NO. 1 — NO. 2 — NO. 3 — SEC — PRI — SEC — PRI — SEC — PRI — VC1 — B1 — VC2 — B2 — VC3 — B3 — L1 — L2 — L3 — L4 — L5 — L6 — GROUND — TO AUDIO AMPLIFIER

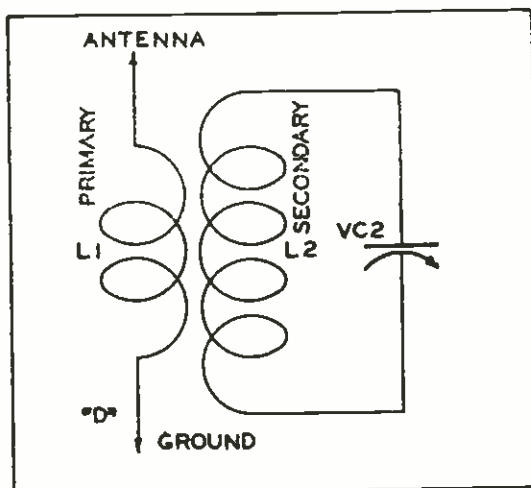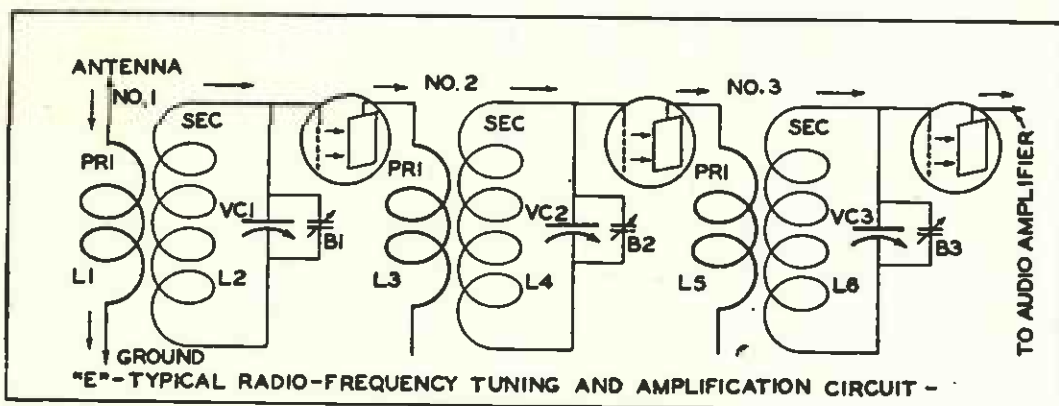"E"—TYPICAL RADIO-FREQUENCY TUNING AND AMPLIFICATION CIRCUIT —

Figure 17

from the antenna. If the coils L2, L4 and L6 are identical, and the condensers VC1, VC2 and VC3 similar, the tuning can be accomplished by placing the rotor plates of the condensers on a single shaft and turning them simultaneously with one dial. Slight variations in VC1, VC2 and VC3, can be balanced by the tiny balancing condensers B1, B2 and B3. A radio-frequency circuit, sharply tuned and balanced, will pass but one frequency at a time. The signal is increased in intensity, or *amplitude,* and is ready to be sent to the detector and thence into the audio-frequency circuit for further amplification before it will operate the loud speaker.

Chapter Six

Radio Tubes and How They Work During our study of electrons, those tiny units of negative electricity, we found that they may be released from their parent atoms by means of friction, and through the effects of mechanical, magnetic and chemical actions. But there is still another agency by which means electrons may be set free. This, as we shall now see, is *heat.* When electrons are agitated by heat they may be made to carry a current of electricity through air, gas or a vacuum; this action has made possible the *electron tube* or *radio tube.*

Matter, which is merely a substantial mass of adhering atoms and molecules, appears as solids and fluids. It is easily affected by heat, for the atoms quickly become agitated. Metals melt and liquids boil; water passes off in vapor as steam. The negative electrons, normally bound to parent atoms by the attracting force of the positive protons, begin to vibrate faster than their normal speed when heat is applied to a metal. The electrons soon break away and fly off into the immediately adjacent space. In fact, the electrons literally boil away. If the metal is highly *radio-active,* the clouds of emitted electrons are very dense.

Basic Tube This action, then, makes it possible to pro-
Principles vide a *source* of electrons. In the radio tube,
x-ray tube and others, we obtain electrons from a *cathode* —
the electrode or terminal from which negative electricity
flows. This cathode may be heated, so that it will emit elec-
trons, by either of two methods—the *directly-heated filament*
type, or the *indirectly-heated cathode* type. The former is a
filament of high-resistance wire which can be heated to in-
candescence by connecting across a source of current. The
latter type is a separate metal sleeve heated by an insulated,
internal filament. The first type is usually referred to as a
filament tube, and the latter as a cathode tube.

Filaments are used with
direct current sources, such
as batteries or rectified and
filtered alternating current.
If an ordinary filament is
used with a.c., there will be
a hum, for the thin filament
will tend to cool a bit be-
tween cycles and give off
pulsations of electrons cor-
responding to the frequency
of the a.c. heating source.
The cathode heater is heavier
and retains its heat longer
and is not affected by the al-
ternations in the separate
heater filament. Cathode
tubes are used with a.c. The
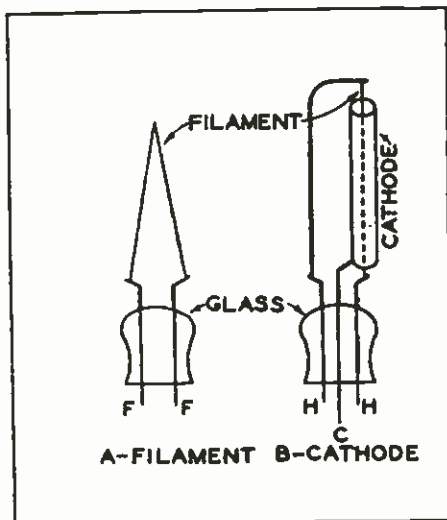few filament tubes for use

Figure 18

with a.c. have heavy filaments that are slow to change their
heat retaining properties, and are not affected by tempera-
ture changes between the rapid alternations of potential. This
is the reason why tubes heat slowly and cool slowly when a
radio set is turned on or off. The thicker and heavier the fila-
ment or cathode sleeve the slower the tube heats up, but the
less likely it is to give off the annoying a.c. hum.

The "A" A filament type of cathode is shown at "A"
Circuit Fig. 18. The indirect or cathode-heater type
is shown at "B." The filament of the first, or the heater of
the second, should be connected across a voltage sufficient to
heat the wires to the correct operating temperature. The fila-
ment or cathode heating supply is called the *"A" source*, and
its generating device is the *"A" battery* or *current*.

The cathode, as we have seen, is the electrode from
which electrons flow. A positive electrode, to which the elec-
trons will be attracted (unlike charges attract each other),
is called an *anode*. Let us, then, place a positive electrode—
an anode—close to the cathode. It will attract the electrons

shooting off in all directions from the hot cathode. In a radio tube this anode is called the *plate*.

The "B" Circuit   The plate is made positive by connecting to a source of current called the *"B" supply*. The source that supplies this powerful potential is called the *"B" battery*. Plates are shaped so as to encircle the cathode like a sleeve or tube. At "C" Fig. 19 is shown a filament connected to its "A" supply, and a plate attached to its "B" battery. The filament, as a whole, is connected to the negative terminal of the "B" battery so the cathode will be made negative with respect to the positive state of the plate.

At this point the two electrodes must be enclosed in a glass tube from which all air has been exhausted. Otherwise the fine wire of the filament would be consumed in the oxygen of the air. When the "A" current is turned off the filament is cold and no electrons can be emitted. But as soon as the filament becomes red-hot a dense cloud of electrons bursts forth and surrounds the cathode. Under the attracting power of the positive plate, the emitted electrons are pulled in an endless stream toward the plate. Thus a flow of electricity is maintained, and the "B" current flowing across the gap between the cathode and plate, and through the external circuit, as indicated by the arrows in illustrations "C," is called the *plate current*.

Figure 19

The Two-Element Tubes   Now, if the "B" battery connections should be reversed, electrons can not flow from the cathode to the plate. A tube, therefore, permits electrons to flow *only* when the plate is positive. Let us connect an alternating current to the plate. We discover that the plate becomes alternately positive and negative, and that the tube can be utilized as a *half-wave rectifier* of alternating currents, for it permits only the positive half of each cycle to flow when the plate is also positive. If the current has a frequency of 60 cycles (120 alternations),

Figure 20

only the positive alternations (60) will flow to the plate. The negative alternations (also 60) will be cut off, and the resulting plate current will consist of a series of 60 impulses of direct current per second, as shown at "D" Fig. 20. The pulses or vibrations can be filtered and smoothed out with condensers and filters (choke coils) as will be explained in Chapter Four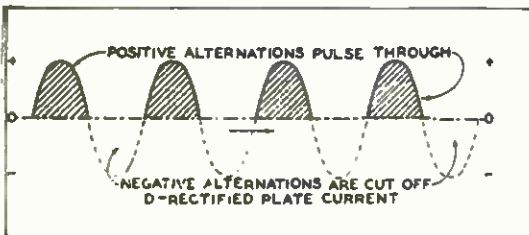teen. (For other examples of alternating currents see Chapter Two.) A tube using only a cathode or filament heater and a plate is called a *diode* or *two-element* type. Such tubes are types 2Z3, 12Z3, and—81. Elaborations which provide *full-wave* rectification of alternating current are found in types 5Z3, 25Z3, 25Z5. —80, —82, —83 and —84.

The Three-Element Tube   Suppose we add a *third* element or electrode to the diode tube. Thomas Edison discovered the current carrying properties of the two-element tube. But it was Dr. Lee DeForest who, many years afterward, found out how to control this *Edison effect* and make the radio tube possible. DeForest called the third electrode a *grid* or *control-grid*. It is placed *between* the cathode and plate. The tube now becomes a *triode,* or *three-element* type. For many years the triode was the only type of radio tube in use. The grid is a screen or grating closely enclosing the cathode. It becomes the *valve* or *trigger* by which we can regulate the flow of electrons from the cathode to the plate. In Europe radio tubes are called *valves*.

Effect of the Grid   At "E" and "F" Figs. 21 and 22 we see how a triode tube appears when its grid is in place. A tube, in which the grid has been made negative by a negative *bias* from a small *"C"* battery source, or by the negative-alternation half of one cycle of alternating current, is shown at "E." The negative grid tends to repel the emitted electrons back to the cathode from which they come. Therefore, practically no plate current flows in the circuit, as indicated by a sensitive *milliammeter* placed in the external part of the complete circuit. But, when the grid is neutral, the usual plate current flows. However, when the grid is made positive, it works to augment the pull of the positive plate, and the plate current actually increases, as will be indicated by the milliammeter. Some few electrons will be attract-
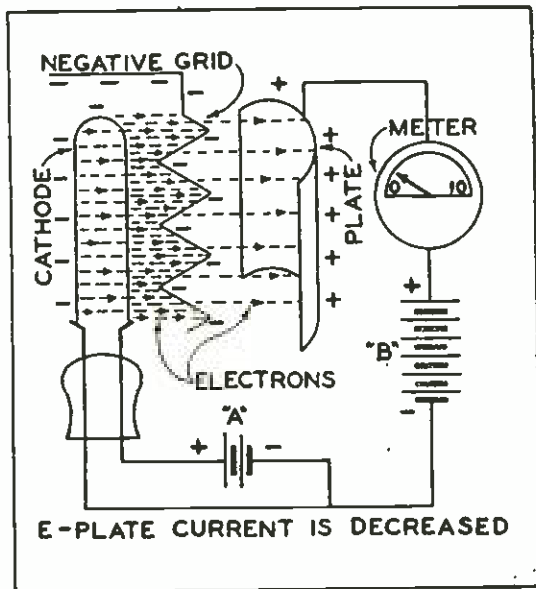

Figure 21

27

ed to the positive grid, but they can be sent back into the cathode circuit by means of grid leaks and resistors.
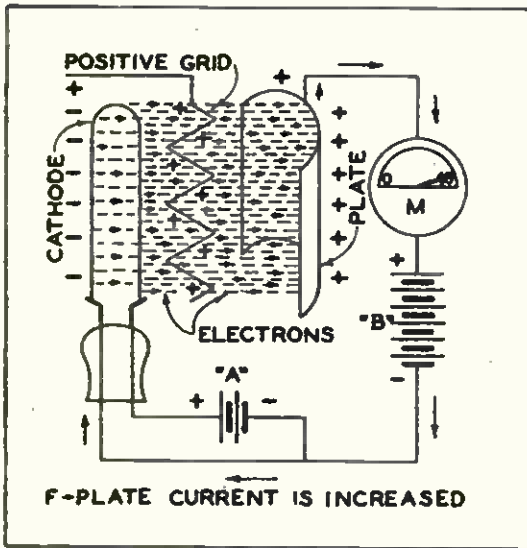
The grid requires very little energy for its operation.

Figure 22

Its trigger-like effect controls the very much greater potential of the plate current. The grid regulates the flow of plate current much like a small but easily operated valve in a pipe that carries a great stream of water under excessively high pressure. Therefore, the grid energy is reflected in the plate current as an amplification of the original potential. A tiny voltage impressed on the grid will control the conductivity between the cathode and the plate. This grid potential is called the *input* or *signal voltage*. The slightest changes or variations in the signal voltage will be noted as much greater changes in the plate current by the milliammeter.

Tubes that show considerable *self-amplification* are called *high-mu* types; their *amplification factor* is high. For instance, if the plate potential changes 50 volts when the grid potential is changed 5 volts, the amplification factor will be 50 divided by 5, or 10. This factor may also be called the *gain* of the tube. Triode tube types are: 2A3, —01A, —10, —12A, —20, —26, —27, —30, —31, —37, —45, —56, —71A, —76, —99, and the new "acorn" 955 tube for ultra-short-wave reception. The radio circuit symbols used in schematic diagrams are shown at "G" Fig. 23.

Figure 23

The Four Element Type The triode tube stood as the acme of tube perfection for many years. Then came a decided improvement which made the tube more useful for certain purposes. Between the plate and grid a small degree of capacity or condenser effect is present. In sensitive receivers its presence causes untold trouble and regeneration noises. But we can obviate this nuisance by placing still another—the fourth—electrode in the tube. It is a grid-like screen surrounding the control-grid, but between

that grid and the plate. This *screen*, as it is called, will not obstruct the flow of electrons from the cathode to the plate, but it interposes an effective capacity shield between the two elements. We now have a *tetrode*, or *four-element* tube. Typical types are: —22, —24A, —32, —35, —36, —39 and —44. The usual circuit symbol is shown at "H". Fig. 24.

When the high-speed electrons shoot from the cathode they strike the plate with great velocity. They knock additional electrons free from the atoms of the plate material.

These electrons, in addition to those activated atoms of gas in the tube which have been struck by the flying electrons and turned into *ions* because of the loss of electrons, and which constitute the so-called *space charge*, provide a blockading blanket of ionized gas (negative and positive ions). Much of this blanket is the *secondary emission* caused by impact with the plate; it must be eliminated so that the full flow of plate current will take place.

Figure 24

Adding a So a new electrode—the fifth—is added. It
Suppressor is placed between the plate and screen of a tetrode tube, and connected to the cathode. This new element is called the *suppressor-grid*, or simply the *suppressor*. Its action is to repel the secondary emission by forcing those space-filling electrons back to where they belong, and thus prevent their interference with working electrons. Such a tube is a *pentode*, or *five-element* type. Examples are: 2A5, 6A4, 6C6, 6D6, —33, —34, —38, —41, —42, —43, —46, —47 and —77. Slight elaborations are found in types 57 and 58. The circuit symbol is shown at "K". Fig. 25.

Some tubes—the screen-grid tetrodes — have their control-grid connections at the top of the tube in the form of a *cap* instead of the pin in the base. Tube *bases* have from 4 to 7 *prongs* or *pins* which make contact with their respective *sockets*. The

Figure 25

heater or filament and cathode of a tube is considered as one electrode although there are three prongs on the base—two for the heater and one for the cathode. There are separate

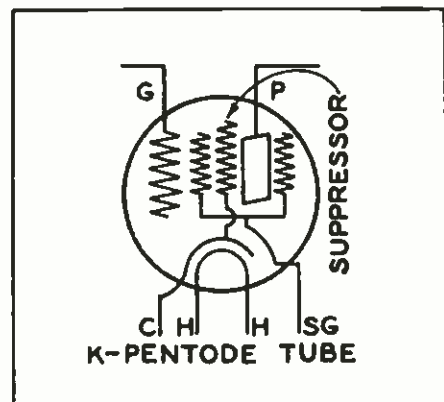prongs for the control-grid (when it is not connected to a top cap terminal), the plate, the screen, and, in the 57 and 58, for the suppressor. Although a tube may have five prongs on the base and a grid cap on the top—six terminals in all—it will be merely a four-element or tetrode tube, such as a —24A or —35. See "H" Fig. 24.

There are more than 70 types of receiving tubes offered the radio public today, and the end does not seem at hand. Then, too, there are many transmitting and general-purpose tubes. Additional grids, plates and heaters are used in some of the newer special-purpose tubes. A single tube is made to function as two or three separate types. We find the *duplex-diode triodes* (2A6, —55, —75 and —85); the *triple-grids* (—59, —77, —78, —79 and —89); the *duplex-diode pen-todes* (2B7 and 6B7); and the *pentagrid-converters* (1A6, 2A7, 6A7 and 6F7), coming into general use, particularly in the universal and midget sets.

Chapter Seven

How Radio Waves are Transmitted and Detected   Perhaps at this time it will be well to see what happens to the radio wave that is sent out from a broadcasting station. It will be remembered that when a wave is emitted from the sending antenna it is in the form of vibrating energy and motion. This was described in Chapters One and Two. And we have learned that a similar wave is picked up by the receiving antenna. It can be tuned and amplified in the radio-frequency circuit of a receiver, as shown in Fig. 17 page 24. But, the reader will ask, how are broad-

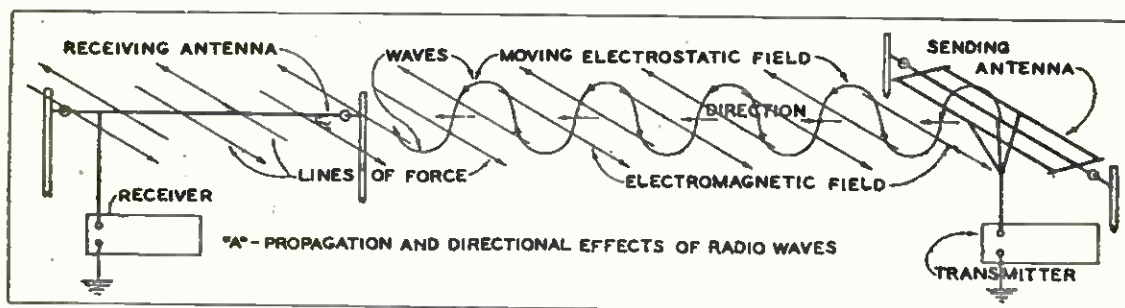

Figure 26

cast waves propagated through the air and finally detected by the radio receiver?

The theory of radio wave motion is the most complicated feature met with in our study of radio, and if the reader is to understand how signals are transmitted and detected it will be necessary to devote at least a few moments to the subject. Fortunately, however, radio wave forms may be easily illus-

trated by wavy lines that depict the electrical oscillations. In Chapter Two several forms of alternating-current wave motions were given; more will be shown in this chapter.

The Carrier Wave What happens between the sending and receiving antennas when a radio wave is being transmitted? In the illustration "A" Fig. 26, at the right, we see a broadcasting station and antenna. At the left is a receiving antenna and set. The sending antenna is connected to the oscillatig circuit of the transmitter; it becomes highly charged with a radio-frequency voltage (high-frequency alternating current). The terrific speed of the vibrations together with the powerful charging current creates an *electrostatic field* about the antenna. This field vibrates with each alternation of the antenna charging current. In "A" the waves of the field are shown as they are pushed out into space. Each wave is forced one wave length farther away when a new a.c. cycle oscillates through the antenna. Therefore the vibrations in the electrostatic field sweeping out through space appear simultaneously with the cycles of radio-frequency antenna current. This emission, passing out in all directions, is the carrier wave which transmits speech and music from the broadcasting studio.

The Magnetic Field The waves of the electric field move outward like ripples that appear when a stone is thrown into a pond of still water. Accompanying this forward movement is an associated *electromagnetic field.* See Chapter Three. And were it not for this speeding wave of magnetic energy, radio reception would be impossible. Curiously enough, the magnetic field moves in a direction always at *right angles* to the movement of the electrostatic field. At each reversal (alternation) of antenna current—and the broadcast electric field—the direction of the magnetic field also reverses. In other words, the magnetic field swings back and forth, from right to left, and from left to right. This movement is indicated in "A" by the arrows.

If the magnetic lines of force of a moving magnetic field cut across a wire they will generate an electric current. This was explained in Chapter Three. This occurs in the receiving antenna. When the antenna, shown in "A," is crossed by a rapidly swinging electromagnetic field, a wave of current is induced in it every time the field changes direction.

Antenna Induction If a broadcasting station transmits on a frequency of 1,000 kilocycles, for instance, its wave will have 1,000,000 complete vibrations or cycles per second. The accompanying magnetic field will also make 1,000,000 *complete* reversals in direction. As these lines of force swing back and forth over the antenna like some gigantic pendulum they induce an alternating current having a frequency of 1,000,000 cycles (1,000 kilocycles)—the same

as the original current in the broadcasting system. Any receiver tuned to resonance at 1,000 kilocycles will respond to this wave. And millions of sets can be attached to antennas covering the earth only a few inches apart without diminishing the original strength of the broadcast electric and magnetic fields; all will receive an equal amount of energy from the passing lines of force!

The induced currents are very weak. It becomes necessary to utilize the principles of radio-frequency amplification (explained in Chapter Five) to "step up" the original energy to greater strength. The resulting signals, which are greatly amplified radio carrier-waves, vibrate at terrific speeds. Neither the human ear nor mechanical devices can respond by vibrating at similar speeds. The *inaudible* signal, when delivered from the output of the tuned r.f. amplifying circuit (shown at "E" in Fig. 17 page 24), must be altered in form and slowed down to an *audible* rate before it can be used to produce sound. This, then, is the function of the *detector*.

The
Detector
Tube
The first part of this book explained that a radio receiver is quite similar to a radio transmitter. Its tubes perform exactly the same duties as the much larger ones in the broadcasting station. But they operate in a reverse arrangement. However, an additional tube is used by the receiver—the detector tube.

The detector *rectifies* or *demodulates* the modulated radio-frequency alternating current wave received in the antenna by separating the audio frequencies (created by the microphone) from the radio frequency carrier wave (created by the transmitter). A "scrambled" or modulated carrier wave is shown at "E," Fig. 2 page 6. As a result the current flowing from the detector tube toward the loud speaker will be similar to the microphone current ("D" in Fig. 2).

Figure 27

When we studied the electron tube in the preceding chapter we did not learn how the tube operates to *detect* radio waves or signals. The name "detector" really is a misnomer, for the tube actually is a rectifier. It takes an alternating current and changes it to a pulsating direct current. But these pulses occur at the same intervals as the alternations in the alternating current. They are too fast to produce audible sound vibrations in the loud speaker. The *average* of these pulses (See E in Fig. 27) provides a slowly fluctuating current that surges the same as the

current flowing from the microphone. This current can be amplified further by the *audio-amplifying* circuit. Any degree of energy can be developed for the operation of loud speakers at great volume.

Rectifying the Carrier "B" shows a typical modulated radio-frequency carrier wave; it is also similar to the wave form shown at "E," Fig. 2 page 6. This inaudible wave is made up of two halves; the lower—negative; and the upper—positive. Each of the two halves—positive and negative—has been modulated equally by the audible microphone current to give it the fluctuating outline that follows the variations in the microphone current. Each half is continuously balanced or neutralized by the opposite alternation. So the tendency of the slow fluctuations of one half to vibrate the loud speaker cone will be offset by an equal pull in the opposite direction. Therefore, we must eliminate one half of the wave—the lower half, or negative alternation.

By eliminating one half of the wave more current flows on the retained half than on the reduced half. The better a tube eliminates one half of the wave the more efficiently it rectifies. "B" shows an unaltered carrier wave; "C" indicates the effect of poor rectification; and "D" pictures a wave form that has been perfectly rectified. Elementary diode tube rectification was discussed at some length in Chapter Six.

The A. F. and R. F. Components Ordinarily the grid of a tube becomes alternately positive and negative under the influence of the r.f. potential impressed upon it. The grid of the detector, however, is held at a constant negative charge; hence it cannot become positive when the positive alternations appear; it simply becomes a little *less* negative. Therefore, a corresponding *rise* in the positive plate current occurs. This rise fluctuates in voltage and flows from the plate as an average of the rectified alternations, as shown in "D." It is an audio current, similar to the fluctuating direct current coming from the microphone in the broadcast studio.

Figure 28

But the plate current from the detector is made up of both the rectified r.f. alternations and the average of these pulsations, as shown in "D." The r.f. vibrations now are useless; they will be troublesome and must be discarded. These pulsations form the *radio-frequency component*. Only the average plate current, also shown at "D," and, more clearly, at "E," can be utilized to operate the loud speaker. This
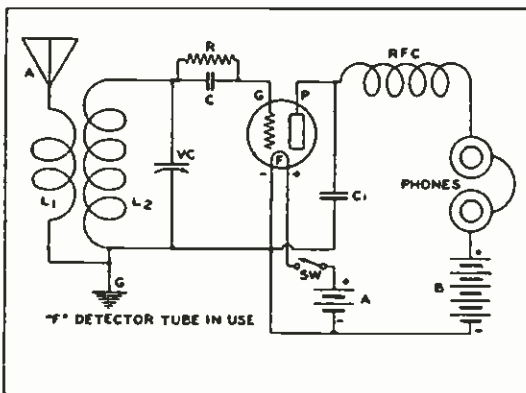
is called the *audio-frequency component*. How are these two components separated so that the audio-frequency current can perform useful work?

A Simple Circuit At "F" Fig. 28, we see a typical detector-tube circuit. All the symbols used have been explained in previous chapters. The antenna current passes through the primary coil L1 and induces stronger currents in the secondary L2 which is tuned to resonance by the condenser VC. A selected signal can be impressed on the grid G. But G is given a negative charge. The grid condenser C and grid leak R are connected close to G. The condenser C permits high-frequency alternations to pass to the grid, and holds back any direct current. The leak R permits any excess of electrons on G to leak back slowly into the circuit. Each time G lowers its negative potential (when a positive alternation is impressed upon it) a certain number of electrons slip across from the filament to the plate and cause a rise in the plate current. The detection method shown here is the *grid leak* and *condenser* scheme. It is sensitive and gives best results on distant, weak signals. But it is not so stable when the resistance of the leak R has a high value. It is the *grid-bias* method which is in almost universal use today.

Choking Out the R. F. The radio-frequency pulsations in the plate current cannot pass through the radio-frequency choke RFC because of its high reactance to high speed alternating currents. But the condenser C1 offers a low reactance path to high frequency currents, and becomes the by-passing path by which the r.f. component is turned back into a neutral circuit. The average flow or fluctuating a.f. component easily passes through RFC because of the negligible reactance to low frequencies, but is blocked by the condenser C1 because of its high reactance to low frequencies. Therefore, only a slow, fluctuating plate current, shown at "E," passes through RFC and into the remainder of the circuit. The phones, shown in diagram "F." may be substituted by the primary coil of an audio-frequency transformer, so that the a.f. component may be further amplified before passing into the loud speaker.

Chapter Eight

The Audio Amplification Circuit — In the last chapter we took leave of the audio or low-frequency current just after it emerged from the plate of the detector tube. We now find that it is ready for further amplification and operation of the loud speaker. This current—an average of the many radio-frequency waves that pulse through the plate circuit, can readily be turned into mechanical motion and audible sound waves. That is why we call it an *audio-current*. Its relatively slow wave motion has been pictured in "E," Fig. 27.

The plate current from the detector is still very weak. Yet it is thousands of times stronger than the original antenna current, for it has been amplified by passing through one or more tube and radio-frequency transformer stages of amplification. But now we must increase the strength of the detected signal, and, this, too, is accomplished by amplification. The circuit used to increase the original a.f. current coming from the detector tube is called the *audio-frequency amplifier*, just as the circuit used to increase the original r.f. current from the antenna was called the radio-frequency amplifier.

We have learned about the *stages* of radio-frequency amplification, using r.f. transformers in the circuit *preceding* the detector; in this chapter we shall read about the stages of audio-frequency amplification using a.f. transformers, that are located in the circuit immediately *following* the detector.

Building Up the Signal — The characteristics of the current flowing from the detector are the same regardless of whether the receiver is a simple outfit or the most complicated superheterodyne circuit known to radio science. The variations or pulsations of potential may be small, weak, and irregular, but by sending the current through one or more stages of a.f. amplification (a stage consists of a transformer and a tube) we find that larger and more powerful variations in potential are obtained.

Fluctuations in an otherwise evenly flowing current in the plate circuit of a detector tend constantly to vary the magnetic strength of a magnet in a telephone that may be connected in series in the circuit. A vibrating motion is given the diaphram of the telephone, and variations in current, due to vibrations of the microphone in the broadcast studio, cause a similar variation or displacement of the telephone diaphram. It is then only that audible sound can be heard.

The Phone Coil — This action may be better described by referring to "A" Fig. 29. The signal from the detector is strong enough only to make itself heard when

telephones are used. We see a coil of wire wound about a steel magnet; it is wound with thousands of turns of fine wire —number 40, and its resistance may fall between 1,000 and 2,000 ohms. Directly over the end of the magnetic core is a thin, iron disc called the *diaphram*. The center of the diaphram is co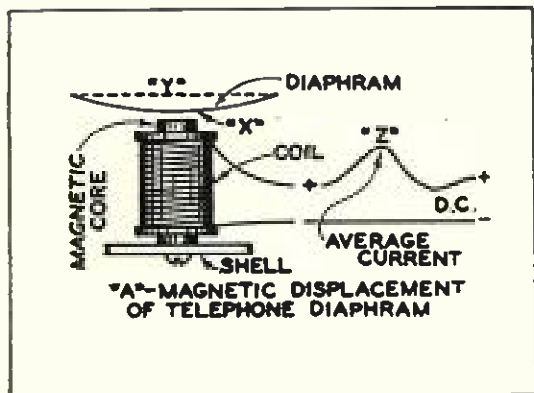ntinuously depressed toward the magnet, as indicated at "x." The slightest variation in current flowing through the coil changes the degree of magnetism in the core, and causes the pull on the diaphram to change accordingly. A pulsation in plate current, shown at "z," will cause the diaphram to move from "x" to "y." As a result a click is heard in the telephone. And a series of such clicks, having irregular spacing and intensity, will reproduce sounds.

Figure 29

Should the pulsations passing through the telephone coil vary, for instance, at a rate of 6,000 times a second, the diaphram will also vibrate at the same rate. However, we quickly discover that there is a limit to the speed of mechanical vibration; the pitch of the sound goes higher and higher; inertia can no longer be overcome; and the diaphram movement finally ceases. This, then, is the limit of mechanical and human reception of audio-frequency sound waves; only electrical vibrations or oscillations can continue on into the higher or radio frequencies.

Transformer Coupling   When the current output from the plate of a detector tube is amplified through the action of one or more a.f. stages placed in series, the amplification stages are said to be operated in *cascade*. The output of the first tube is *coupled* to the input of the second tube, and so on. Tubes can be grouped together in audio amplification by means of *transformer*, *resistance* and *impedance* coupling. But, since transformer coupling is almost universally in use, let us study only its action and application to radio in this chapter. Transformer action has been described in detail in Chapter Three.

Audio transformers have ratios between the number of turns of wire in the secondary and primary windings of from 3 to 1 to about 10 to 1. But the ratio of sound amplification is much greater; for instance, a 3 to 1 transformer may give an audibility of twenty times the original, and two such transformer stages may give an amplification of 400 times. The secondary, which creates the amplified current, is wound with many thousand turns of wire so fine that about 300 strands are laid to each inch. The primary, which receives

the current to be amplified, has fewer turns—in the case of the 3 to 1 transformer it has one-third the number of turns in the secondary. About 3000 turns comprise the average primary coil.

In the a.f. transformer the primary coil is wound over an iron core. The two terminals are marked B and P. A layer of insulating material then is placed over the primary coil. The secondary is wound on with many layers, and the two ends are brought out to the terminals marked −F and G. As indicated in "K" and "L" Fig. 8 page 13: P is the plate connection to the tube; B goes to the positive "B" battery or d.c. plate supply; G connects to the grid of the tube; and −F attaches to the negative "A" or "C" battery. G will be the outside or ending wire of the secondary, and the inner or starting wire is the −F terminal. The inside end of the primary is marked P, and the ending wire goes to the "B" supply. However, in certain circuits, it may be necessary to reverse the primary connections for best results.

The "C" In the foregoing it will be noted that the in-
Battery ner end of the secondary coil is connected to −F which is a negative A or C potential. Since we are dealing with the audio end of the receiver, where sound is being reproduced, we are particularly interested in the quality of tone and sound. It becomes necessary, therefore, to connect a "C" battery into the grid circuit of the audio tube. Negative biasing of the control grid of an audio tube maintains the grid at a negative potential at all times with respect to the filament. The grid can never become positive; it only fluctuates more or less negative than its normal state when the

Figure 30

pulsations of input signal potential are impressed upon the grid. This bias varies from 3 volts to as much as 60 volts for different tubes.

In illustration "B" Fig. 30 we see a transformer coupling the detector tube to the first audio tube. This is the *first* a.f. transformer. The a.f. tubes in an audio circuit following the detector are named in the order of their arrangement—first, second, etc. The last is the output or power tube. The r.f. tubes in the radio-frequency circuit preceding the detector are also similarly numbered (see Chapter Five).

Action The *average fluctuations* of the plate current
of the flow through the primary coil of the trans-
Transformer former shown at "B." A transformer will operate if pulsating or fluctuating direct-current passes through its primary. An alternating current, then, is induced
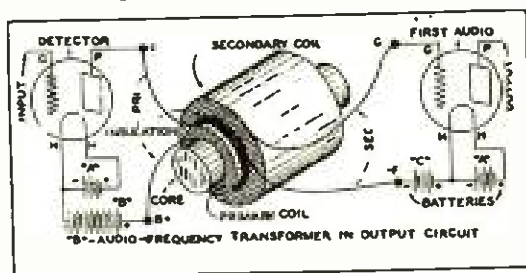
in the secondary, for we have learned that whenever a primary current is increased in potential value a voltage moving in one direction will be induced in the secondary. And, when the primary current is decreased in potential a voltage moving in the opposite direction will be induced in the secondary. This induced alternating current rises and falls in amplitude exactly in harmony with the changes in value of the fluctuating direct-current flowing in and out of the primary coil.
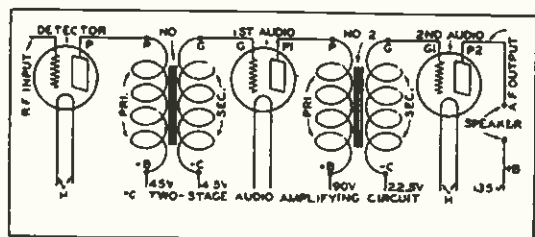

Figure 31

The output of the transformer's secondary coil, therefore, is an amplified current having the same characteristics as the primary current. Now, if the output from G, of the secondary, is connected to the grid of a second tube it provides a still greater control of a more powerful plate current. So, we see, at the right of the transformer shown at "B" Fig. 30, this second tube, or the *first audio tube*. The plate of this tube can be connected to a pair of headphones. and the volume of sound will be much greater than that heard when only a detector tube is used, as shown, for instance, at "F," in Fig. 28 page 33. Or the plate can be attached to P of the primary of another, or *second* audio transformer—beginning a *second audio stage*—for further amplification and greater audibility.

The Complete Audio Circuit   At "C" Fig. 31, is shown a diagram of an audio amplifying circuit. It is explained by symbols which have been previously described. The current from the detector plate (P) actuates the primary of the audio transformer No. 1, the output of which is impressed upon the grid (G) of the first audio tube. The plate potential of this tube (P1) is maintained at a higher potential than that on the detector, and the amplified grid voltage will give greater control (at G) and more pronounced variations in the plate current. The output (from P1) of the first a.f. tube operates the primary of the second audio transformer No. 2. The induced voltage in the secondary of No. 2 is much greater than that in the secondary of the preceding transformer (No. 1), and the voltage impressed on the grid (G1) of the second a.f. tube controls even a still greater plate potential (P2) which operates the loud speaker.

The Power Stage   Most receivers employ the *push-pull* method of audio amplification. At "D" is shown this form of coupling. Two power tubes are connected with their filaments in parallel. The a.f. transformer, shown at the left, is called the *input transformer;* its primary being connected to the plate output of the preceding first audio or *driver* tube,

or it may be operated directly from the plate of the detector tube. The *split* secondary, however, has three terminals. One is a center tap (−C or −F); and the two ends (G) connect to the grids of the two power tubes. The plates of these two tubes connect to the outer ends of the *split primary* coil of the *output transformer,* shown at the right; and the center tap connects to the plate or B supply. The secondary of this output transformer feeds an alternating current directly into the loud speaker windings, and thus prevents the fine windings of the speaker voice coil from being burned out by the heavy surges of direct current.

Figure 32

Although two tubes are used in this type of circuit they really provide only single-tube audio amplification. This is because one tube remains idle while the other works. Both alternations to each cycle of the alternating current flowing from the secondary of the input transformer operate the grids of the two tubes alternately—one alternation pushes while the other pulls. Amplification is not generally increased by the use of the push-pull method, and *twice* the signal input voltage is required. But there is a better reproduction with less hum, and the output circuit provides more than twice the flow of current (measured in milliamperes) of a single tube of similar type. There is little or no distortion even under full volume.

Chapter Nine

The Complete The preceding eight chapters have been de-
T. R. F. voted to a study of the essentials of radio,
Receiver and we have discovered how a number of
electrical devices perform important duties in our radio sets.
The underlying principles of these parts have been explained,
while the standard symbols used in all schematic diagrams
of radio circuits have been illustrated. At this time, there-
fore, we should be prepared to recognize these symbols when
used in the description of radio circuits. Let us, then, as-
semble the different symbols, with which we are now familiar,
in a schematic radio-circuit diagram, and proceed with the
construction of a complete tuned radio-frequency receiver.

We find, in Chapter Three, illustrations "G" and "H"
Fig. 8, page 13, a radio-frequency transformer; in Chapter
Four, at "H" Fig. 12, page 18, a variable condenser; in Chap-
ter Five, at "D", Fig. 16, page 23, the explanation of how a
r.f. transformer is tuned by a variable condenser; also, at
"E", Fig. 17, how several to these tuned units can be as-
sembled in r.f. stages so as to form a tuned radio-frequency
amplification circuit; in Chapter Six, the description of the
actions of radio tubes; in Chapter Seven, at F, Fig. 28, page
33, a typical detector circuit; and, in Chapter Eight, the prin-
ciples of audio amplification, with a standard circuit diagram
illustrated at C, Fig. 31.

The Complete We are ready, now, to take the tuned radio-
Diagram frequency circuit (E), shown in Fig. 17, page
24, and add to it the detector (F) given in Fig. 28. Then, to
the latter, we will connect the audio-frequency circuit (C),
Fig. 31. As a result of the combination of these three inde-
pendent circuits, we will have a complete five-tube tuned
radio-frequency receiver of good selectivity and sensitivity.
Selectivity is the degree to which a receiver is able to select
and separate radio signals of different frequencies; *sensitiv-
ity* should not be confused with selectivity, for a receiver
may have one without the other. Sensitivity is the distance-
getting ability of a set and the degree of its responsiveness
to extremely weak signals.

So, after we have assembled the three independent, ele-
mentary circuits into one unit, we find the result illustrated
at A. At the left we see the primary (L_1) of the *first* radio-
frequency (No. 1) transformer connected between the an-
tenna and the ground. Its secondary (L_2) is tuned to res-
onance by the variable condenser (VC_1). The upper, or high
potential, end of this coil feeds an induced alternating cur-
rent of radio frequency to the control-grid of the *first* r.f.
tube; the lower, or low potential, end of the coil is grounded
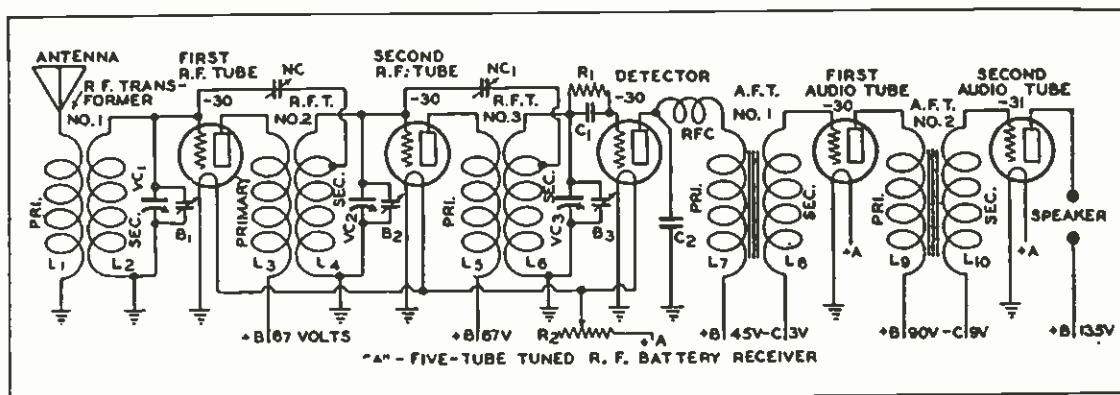to the chassis. The plate of the first r.f. tube connects to the

Figure 33

primary (L_3) of the *second* radio-frequency transformer (No. 2), and its circuit then continues to a source of positive potential, such as a "B" battery. About 67 volts is the proper potential for this plate in an elementary circuit of this type.

The R. F. Circuit The primary (L_3) is coupled inductively to the secondary (L_4) which is tuned by a second variable condenser (VC_2). The upper end of the secondary feeds to the control-grid of the *second* radio-frequency tube, just as L_2 fed the grid of the first r.f. tube. As before, the lower end of the secondary is grounded. The plate of the second r.f. tube connects to the primary (L_5) of the *third* radio-frequency transformer (No. 3), and then continues to a positive "B" voltage. The coil (L_5) is coupled inductively to its secondary (L_6).

And the secondary (L_6), similar to the secondaries L_2 and L_4, is tuned by a third condenser (VC_3). And it also feeds the amplified r.f. potential to the control-grid of a third tube. This is the detector tube, and a small grid-condenser (C_1) is placed in series between L_6 and the grid. Then it is shunted by a high-resistance grid-leak resistor (R_1). The lower end of the detector grid-coil (L_6) also is grounded, but in some cases, particularly if the detector is regenerative, the set will work better if the lower end is connected to the positive terminal of the "A" battery.

At this point we take leave of the radio-frequency amplifying portion of the assembled radio circuit. The greatly amplified r.f. signal from the antenna is now turned over by the secondary (L_6) of the last of the three radio-frequency transformers to the input grid of the detector for detection and rectification. Then, after this effect has been accomplished, the detected signal must be further amplified for audio purposes.

The A. F. Circuit If we follow the circuit given in A we can trace the detected signal as it passes from the plate of the detector tube. Its a.f. component enters the r.f. choke coil (RFC) and then goes into the primary (L_7) of

the *first* audio-frequency transformer (No. 1); the r.f. component is turned back by the reactance of the choke, and is passed readily through the bypass condenser (C_2) into the neutral part of the circuit. After emerging from the primary (L_7) this circuit continues to a source of positive potential ("B" battery), which, since the detector plate is involved, seldom is more than 45 volts.

Now, as we know, the secondary of the first a.f. transformer (L_8) feeds its output to the grid of the *first* audio tube. But the lower end of this coil is not grounded; it must be connected to a source of negative electricity, such as a "C" battery of -3 to -6 volts. The pulsating-current output from the plate of the first audio tube (see Chapter Eight) controls the inductive operation of the primary (L_9) of the *second* a.f. transformer, the lower end of which connects to a positive source of "B" voltage. The amplified potential in the secondary (L_{10}) feeds the grid of the *second* or *output* audio power tube. The lower end of the secondary (L_{10}) also connects to a negative "C" battery, but of greater potential.

The output from the plate of the audio power tube feeds directly into the loud speaker, or the primary of an *output transformer*. This plate must be operated with a higher potential than the plates of any of the preceding tubes. There are several variations of audio amplification, as explained in Chapter Eight, and the push-pull circuit, Fig. 32, may be substituted for the last audio tube in our completed assembly.

The three variable condensers used for tuning can be placed on a single shaft in a gang unit, so the three secondaries (L_2, L_4 and L_6) will be tuned simultaneously. And, in order to offset slight mechanical inequalities in the condensers or windings of the coils, the tiny trimmer condensers (B_1, B_2 and B_3) are used to equalize the resonance of the three r.f. stages.

Building the Receiver For those who may wish actually to construct this tuned radio-frequency receiver, the following specifications are given: The three r.f. transformers are wound on card, fiber or bakelite tubes that are about two inches in diameter and three inches long. Use double cotton covered copper wire, No. 26, for this purpose. The primary will have 12 turns, and the secondary 65 turns, both wound evenly and in the same direction. A space of about ⅛ of an inch is left between the ending of the primary winding and the beginning of the secondary winding. Illustration "G" Fig. 8, shows the arrangement of a radio-frequency transformer. Remember that the transformers must be exact duplicates.

The secondaries are tuned simultaneously by a three-section, variable gang-condenser with each unit having similar capacities of .00035 mfd (350 mmfds). The small trimmer condensers may have capacities of about 50 mmfds. The two

radio-frequency tubes, the detector and the first audio tubes, are of the -30 type, which uses two volts for the filament and draws a minimum of current. The negative terminals of the three filaments are grounded; the other three are brought together and connected to the positive terminal of the "A" battery *through* a series 20-ohm rheostat (R_2) used for the control of volume.

The resistance of the grid leak (R_1) is from 2 to 4 megohms; the grid condenser (C_1) has a capacity of .00025 mfd (250 mmfds); the bypass condenser (C_2) has a capacity of .001 mfd (1000 mmfds); the radio frequency choke coil (RFC), between the detector plate and the first audio transformer, has a value of approximately 40 millihenrys; both of the audio transformers should have turn ratios of three to one.

A Regenerative Detector   A *regenerative detector* and its subsequent amplification effects will add remarkably to the sensitivity of any t.r.f. receiver. Regeneration gives tremendous increases in the sensitivity of a detector. This means greater distance, and the actual reception of very weak signals. The regenerative detector requires a *three-circuit tuner*. The detector shown in the assembled circuit at "A," utilizes a *two-circuit* tuner (the r.f. transformer). But we can add a third coil, and this will provide regenerative action.

This third coil, in a three-circuit tuner of a regenerative detector, is called the *tickler coil*. Its position is indicated in illustration "B." It has about 20 turns of wire, No. 26, wound on a short length of tube that will fit *within* the upper end of the second-

Figure 34

ary coil (L_6). A shaft must be provided so the tickler can be rotated back and forth. The amount of regeneration obtained depends upon the position of the tickler, and we are thus enabled to regulate the amount of inductive *feed-back* returned by the detector plate circuit into its own grid circuit.

The Tickler Coil   The action of the tickler is simple. Look at illustration B. When a signal is induced in the secondary (L_6) by the primary (L_5), the grid of the detector tube is given an alternating-current charge. The detector plate current immediately rises and falls in pulsating waves. These waves have the same frequency as the alternations impressed upon the grid of the tube by the grid coil (L_6). Then, since the entire plate current is flowing also through the tickler, which is placed in series, a powerful mag-

netic field is created around the tickler. The tickler, then, in-
duces another alternating current in the secondary (L_6) in
addition to the current originally induced by the primary
(L_5). In effect, this action is the same as if the secondary had
two primary coils—one at either end. The additional induced
current created by the magnetic field of the tickler seems to
appear simultaneously with the original current and causes
no interference. However, such feed-back action, which is re-
impressed upon the grid of the detector and results in a re-
amplified plate current, tends indefinitely to increase. The
detector will break into *oscillation* with annoying howls and
whistles, but the rotation of the tickler controls the point of
oscillation, and a careful operator can prevent regenerative
noises.

A tickler may be added to the typical detector circuit (F)
Fig. 28. The coils of that circuit (L_1 and L_2), together with a
tickler, will make the three-circuit tuner shown in B of this
chapter. Regenerative receivers are not always held in high
esteem because of their tendency to cause noises in nearby re-
ceivers by re-radiation. However, with some modifications,
they are widely used for amateur and short wave reception.
A small, well-designed tuned radio-frequency receiver with
a regenerative detector will be hard to beat for distant re-
ception of weak signals by means of phones. The several crit-
ical adjustments, however, have militated against tuned-
radio-frequency receivers using variable tickler control of re-
generation. The regenerative detector, however, is one of the
fundamental and elementary types.

Neutralizing   *Neutralization* will eliminate unstable re-
the Circuit   ceiver operation with oscillation noises. This
condition is due to the capacity that exists between the grid
and the plate of a three-electrode (triode) tube. These capac-
ities must be balanced out by means of *neutralizing con-
densers*. Examine the r.f. circuit of the assembled receiver
shown in "A" Fig. 33. Count down from the tops of the sec-
ondary coils L_4 and L_6 exactly 15 turns. Attach short lengths
of wire and run the two ends to two tiny neutralizing con-
densers, each of 25 mmfds. capacity. Then connect the op-
posite ends of the condensers to the control grids of the first
and second r.f. tubes, respectively. These condensers are
shown at NC and NC_1, in "A."

Neutralize the circuit as follows: Remove one filament
wire from the socket of the first r.f. tube (with the unlighted
tube remaining in the socket). Then, with all tubes in place
and lighted, tune in a station on about 1000 kilocycles. Ad-
just the screw in the first neutralizing condenser (NC) with
an insulated tool until the signal can no longer be heard. The
adjustment will be critical. Replace the filament wire to its
socket terminal, and the signal will again come in at normal
strength. Next remove one filament lead from the socket of
the second r.f. tube. Adjust the screw of the second neutraliz-

ing condenser (NC,) until the signal cannot be heard. Replace the filament wire, and the signal will again come in. The set is now properly neutralized. However, other adjustments may be required when signals are being received on 600 and 1500 kilocycles.

A Screen-Grid Neutralization is not necessary on sets that
T. R. F. use screen-grid tubes. And, of course, it is not
Receiver always used on sets that use the three-electrode tubes. In illustration "C" Fig. 35, we observe that the circuit diagram of our assembled t.r.f. receiver may be so altered as to use pentode tubes in the r.f. stages, and push-pull power amplification in the audio output stage. The set will be more sensitive and selective; neutralization is not needed, and more power and better tone can be obtained from the loud speaker.

Figure 35

The circuit shown at "C" is essentially the same as that shown at A, except that more bypass condensers (C) are added (all of them being .01 mfd. capacity) and neither grid leak nor grid condenser is used with the detector. Two type 34 two-volt tubes are used. They are super-control pentodes and are very effective. The detector and first audio tubes are type -30s, as before, but two -31s are used in the push-pull power stage. Volume control is obtained by varying the negative bias to the grids of the r.f. amplifier tubes. A suitable potentiometer is used for this purpose.

Chapter Ten

The Super-   The superheterodyne receiver is, without
heterodyne   question, the world's most popular type of
Receiver   radio set. We can find its principles operating
in practically every broadcast, all-wave and automobile radio
now being manufactured. And, because of the constant stream
of multi-purpose tubes and improved circuits, there appears
to be no end to the possibilities of the superheterodyne receiver.

Previous chapters described the functions of many of the
unit parts that go into the assembly of a radio set. A complete
t.r.f. receiver was assembled in Chapter Nine. And, by now,
the reader should understand wave motion and frequency,
and how the tuned-radio-frequency receiver just mentioned
uses two different currents in its circuit—radio and audio
frequencies. The superheterodyne set, to most persons, has
been cloaked in mystery and considered a highly compli-
cated type of receiver. But it really is very simple in its opera-
tion. So, at this time, we are prepared to take up some new
principles of radio and, by the mere addition of two new
units to the t.r.f. set described in Chapter Nine, create a sup-
erheterodyne receiver.

Defining   The word *super* really is a nonentity in any
the Set   description of the super-heterodyne circuit.
This prefix is being attached to so many names in the com-
mercial world that it seldom impresses the reader. Therefore,
super-heterodyne means a *heterodyne* set having great power
and sensitivity. The word hetero-dyne is derived from the
Greek words *hetero*, meaning different or unlike, and *dyne*,
meaning power or force.

From these definitions we assume that the super-hetero-
dyne receiver operates because of different forces. Such ac-
tually is the case. Naturally these forces are electricity—two
separate alternating currents. One is the radio signal that is
picked up by the antenna, and the other is a locally generated
current. These two forces are arranged to act at the same time
on the same circuit, and, as a result, the frequency of the
incoming signal will be *lowered* and held constant without
impairing its audio-frequency characteristics or sound modu-
lation. All subsequent amplifications within the receiver will
be accomplished at this particular frequency.

These *two* currents, vibrating at high or radio frequen-
cies, act *against* each other (for they must be produced simul-
taneously) and produce a *third,* or resultant current, which
is used for the operation of the receiver. The new current
vibrates at what is called the *beat frequency.* It becomes

necessary, now, to turn to an elementary principle of sound and music to learn how a third and different radio frequency can be created, and why it is called a beat frequency.

The Beat Frequency If two closely adjacent piano keys are struck sharply at the same instant, the notes from each associated wire that is set into vibration cannot be heard separately. What we do hear is a peculiar sound having a tone that is different from those given off singly by either of the two wires. This new, or third, tone, is caused by the slow vibrations or beats set up by the interference created between the two original sound waves. Beats are usually produced through interference or interaction between two sound or radio waves having slightly different periods of vibration.

The number of beats per second, caused by this interaction between two slightly different wave vibrations, is equal to the *difference* between their respective vibration rates. For instance, if each of the two piano wires vibrates 5,000 and 6,000 times a second, then the resultant sound wave will have a beat frequency of 1,000 vibrations a second. And the pitch of its tone, of course, will be *lower* than the pitch of either of the two original sound waves.

Now it is possible to apply this same principle to radio, and, instead of sound waves, we will make use of the terrific vibrations of radio-frequency currents. Should we apply two such currents simultaneously, as, for instance, one having a frequency of 1,000,000 cycles a second and the other a frequency of 1,100,000 cycles, a resultant electric wave will be created by the interference of the vibrations that do not coincide except at regular intervals, and which will have a frequency of 100,000 vibrations a second. This means there will be 100,000 beats a second—the difference between 1,-000,000 cycles and 1,100,000 cycles. In this case the frequency of the resulting beat wave is 100 kilocycles (3,000 meters wave length), as against frequencies of 1,000 and 1,-100 kilocycles (wave lengths of 300 and 275 meters, respectively) for the two separate radio waves which act to produce the beats.

The method of using two opposing radio frequencies to create a beat frequency is called the *heterodyne effect*. Quite frequently, when tuning in radio stations, the listener will notice a similar beat effect. The *heterodyning* of radio stations that are too close together on the dial to be tuned out is of common occurrence. All that can be heard is a throbbing sound, or beat, that rises and falls in waves, and which renders the two programs meaningless.

The Oscillator To produce a beat frequency, a *local* radio-frequency current must be applied *simultaneously* with the radio-signal frequency that is coming in through the antenna. This current is obtained from a local

oscillating circuit which is inductively coupled to the antenna input or radio-frequency amplification stage of the receiver. The antenna current meets in unison with the local current, which is of a slightly different frequency, being either higher or lower. This sets up a beat frequency. The oscillator of a superheterodyne receiver is the most complicated part of the circuit. The least abuse of its careful alignment will throw off the readings on the tuning dial, and frequently weaken or even prevent the reception of signals.
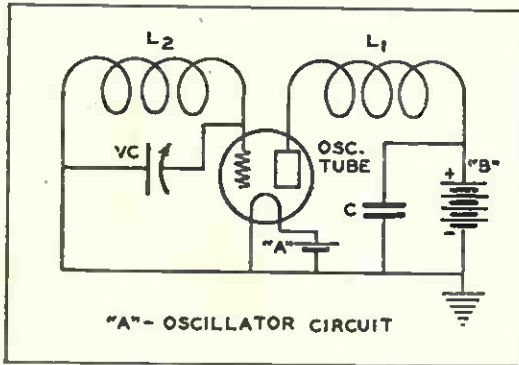

"A" – OSCILLATOR CIRCUIT

Figure 36

At "A" Fig. 36 is shown a typical oscillator circuit. It is generally known that a radio tube will, in addition to its ability to amplify signals, generate a radio-frequency alternating current. Giant-size vacuum tubes are used in radio stations to create and broadcast powerful oscillating, or high frequency electric waves. In exactly the same manner a tiny receiving tube can be made to provide the local oscillations needed to beat against the incoming signal. To act as an oscillator it is necessary only to couple the plate or output circuit of the tube to its own grid or input circuit. A set of two coils, similar to a r.f. transformer, is used for the purpose.

Generating the Oscillations The action of an oscillator is not difficult to understand once the reader grasps how the current flows in and out of the circuit. The term "oscillate" means to swing back and forth, a movement like the pendulum in a clock, or vibration. The tube, shown in "A," starts to heat up the moment the radio set is turned on. An emission of electrons instantly flows, but becoming faster and faster as the filament and cathode get hotter, and the stream attracted toward the positive plate quickly reaches its maximum density. Then, of course, the flow of plate current, as it passes through the circuit and its coil L_1, increases to its maximum potential. At this time, also, there is a magnetic field surrounding the coil, and it is building up in intensity. So, when the radio set is turned on, we have a condition of acceleration; the heating tube; an increasing flow of electrons; a mounting rise in the voltage of the plate current; and the spreading electro-magnetic field around the coil L_1. These actions compare to the acceleration of a motor car as it reaches full speed from a standing position. It is this acceleration, created when the set is turned on, that gives the original *shock* to the oscillator and incites it into action.

During the tiny fraction of a second while the magnetic

field of force about the coil L_1 (see Chapter Three) is building up in strength, it is also inducing an *increasing* voltage in the grid coil L_2. But, as this coil is connected to the grid of the tube, the potential is being impressed on the grid. The grid, as we have learned, controls the flow of electrons within the tube and the plate current in the circuit. As the grid gains in its charge, due to the voltage being induced in L_2, it begins to slow down the flow of plate current and finally stops it entirely. Then, as no current is flowing through L_1, the surrounding magnetic field quickly collapses. The *inward* movement of the lines of force causes them again to cut across coil L_2, but in a direction *opposite* to that which was taken when the plate current increased. So, a second surge of potential will be induced in L_2, but flowing in the opposite direction, and which immediately induces an opposite charge on the grid of the oscillator tube. This completes one cycle, or oscillation, in the current flowing through the coils L_1 and L_2.

The charge now impressed on the grid permits the electrons again to flow and increase the plate current; the magnetic field builds up anew; a current surge of opposite direction is induced in L_2; a new charge is impressed on the grid; the plate current is again shut off; and the process goes on and on as long as power is supplied to the tube and circuit. The action is very fast; faster indeed than any vibration the eye can imagine. It reaches radio-frequency proportions, which means that oscillations as frequent as 50,000,000 times a second can be created in an ultra-short wave circuit!

The Intermediate Frequency The rate of frequency of the oscillations set up in coil L_2 depends upon the size of the inductances. And varying the capacity of the oscillator condenser VC changes the frequency at which the oscillations will occur. For instance, if the local current flowing through an oscillator is made to vibrate at a rate of 400,-000 times a second, it, therefore, will have a frequency of that many cycles, or 400 kilocycles. When it is tuned *against* an incoming radio wave of 575,000 cycles, or 575 kilocycles, it will create a beat wave having a frequency of 175,000 cycles, or 175 kilocycles. This beat wave is called the *intermediate frequency*. It is *always lower* than either the transmitted radio wave or the locally generated oscillating wave, because it is equal to the arithmetical difference between the two original frequencies. An intermediate-frequency current can be amplified with less loss than the original high signal frequency, and nearly as efficiently as the low audio frequencies.

The tuned-radio-frequency circuit shown in Chapter Nine was that of a receiver utilizing radio and audio frequencies and their amplification; in this chapter we shall place the intermediate frequency, as its name implies, *between* the radio and audio frequencies. The new circuit, then,

will amplify all three of the frequencies, each separately—the radio, intermediate and audio, in the order indicated.

The First Detector   The path followed by the three different frequencies as they flow through a superheterodyne receiver is shown at "B." At the left the intercepted r.f.
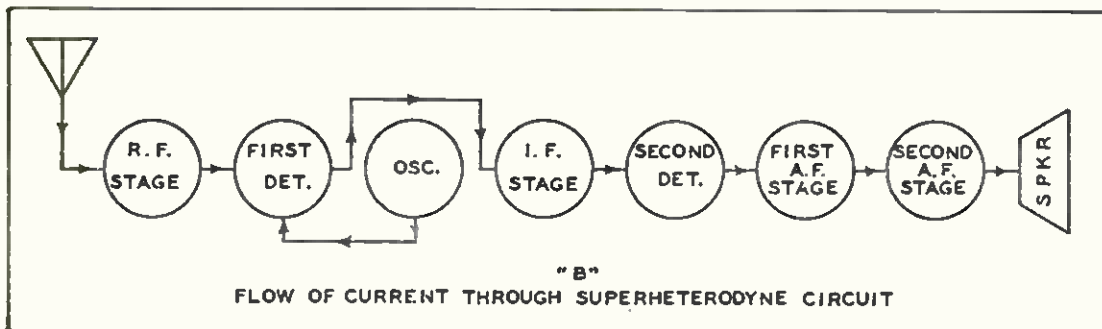

"B"
FLOW OF CURRENT THROUGH SUPERHETERODYNE CIRCUIT

Figure 37

signal passes through the radio-frequency amplification stage, as explained in previous chapters. The amplified output is sent into the first detector. Here the incoming r.f. signals are *combined* or *mixed* with the locally generated r.f. oscillating current. The resulting beat, or lowered, frequency, emerges from the output of the first detector as an intermediate frequency, ready for still further amplification.

The third tube is the oscillator, and its oscillating output is returned to the first detector for mixing with the incoming radio signals. The fourth tube is the intermediate-frequency amplifier that boosts up the output of the first detector. In some receivers there may be several i.f. stages and tubes.

The Second Detector   After the intermediate-frequency current has been sufficiently amplified by passing through the fourth tube or stage, shown in "B," it becomes necessary to repeat the detecting or rectifying process, using what is called a *second detector*. This is the fifth tube in the diagram. The second detector is the same as any type of detector in any receiver. The first detector is used to rectify the beat frequency and pass it along, as an intermediate frequency to the i.f. amplification stages. The second detector simply rectifies the amplified intermediate frequency and changes it to a pulsating, audio current for further amplification. The sixth and seventh tubes, shown in "B," amplify the audio currents in the conventional manner.

Amplification of intermediate frequencies is obtained in much the same manner as that for radio frequencies. Intermediate-frequency transformers are similar in detail to r.f. transformers (see Chapter Three), but are designed to operate only on one frequency—the intermediate frequency of the set.   For instance, if this intermediate frequency happens to be 175 kilocycles, it is said to be the *peak frequency*

the r.f. tuning condensers and the oscillator tuning condenser are mounted on a single shaft for one-knob control. Perfect *tracking* of all the condensers is obtained by carefully adjusting the resonance of the circuits with small trimmers.

A Typical Circuit   A typical superheterodyne circuit is shown at "C" Fig. 38. The antenna coil, with primary L_1 and secondary L_2, couples the antenna to the grid of the radio-frequency tube. The output is further amplified by a r. f. transformer, using coils L_3 and L_4. This increased signal is then impressed upon the control-grid of the first detector. The secondaries, L_2 and L_4, are tuned simultaneously by the variable tuning condensers VC_1 and VC_2. Up to now this portion of the circuit is similar to the t.r.f. circuit given in Chapter Nine.

The oscillator tube creates a local r.f. current in the coils L_5 and L_6. This energy is transferred to the first detector by means of a third coil wound close to L_5. The third coil is called the *pickup coil,* and is indicated at L_7. The point of contact with the first detector is the cathode of the tube, but other contacts, such as the control-grid, screen-grid, etc., are used by different circuit designs.

The unidirectional output of the first detector tube then passes through the primary L_8 of the first i.f. transformer. An alternating current having an intermediate or beat frequency is induced in the secondary L_9. This secondary is untuned. The amplified output from the i.f. tube passes into the primary of L_{10} of the second i.f. transformer, and induces a stronger current in the secondary coil L_{11}. The grid of the second detector is controlled by this amplified i.f. current which is then rectified and passed out through the plate circuit as an audio-frequency direct current (see Chapter Seven). This flows through the primary L_{12} of the first audio transformer. The amplified output from L_{13} passes into the last power tube in the audio-frequency amplifying circuit and emerges ready for conversion into sound at the loud speaker.

of the receiver. And intermediate-frequency transformers constructed to pass only 175 kilocycles are said to be *peaked* at this particular frequency.

Since these transformers pass but the one frequency it is not necessary to tune them with variable condensers as is the case with radio-frequency transformers. More wire is used in winding the i.f. transformer because it must have a high reactance against the lower frequency. The resonance of the i.f. transformer is set at the frequency at which the maker decides to peak the receiver, and sometimes small fixed or adjustable trimmer condensers are used to balance the circuit and make resonance to the peak frequency sharper. The transformer must be shielded carefully, otherwise it may pick up unwanted signals and cause no end of interference and trouble.

The tuning and circuit adjustment of the oscillator must be such that there will be a constant difference between its own frequency and that of any incoming signal. For instance, if a receiver is peaked at 175 kilocycles, the following should be the case: At one end of the dial a station is tuned in on 1,400 kilocycles, and the oscillator must generate a current having a frequency of 1,575 kilocycles if the intermediate frequency of 175 kilocycles is to be maintained; at the center of the dial a station broadcasting on 950 kilocycles is tuned in, and the oscillator must generate a current of 1,125 kilocycles; and at the other end of the dial a station on 600 kilocycles is tuned in, and the oscillator must generate 775 kilocycles.

This relationship, between the oscillator tuning and the r.f. circuit tuning, must be constant throughout the entire
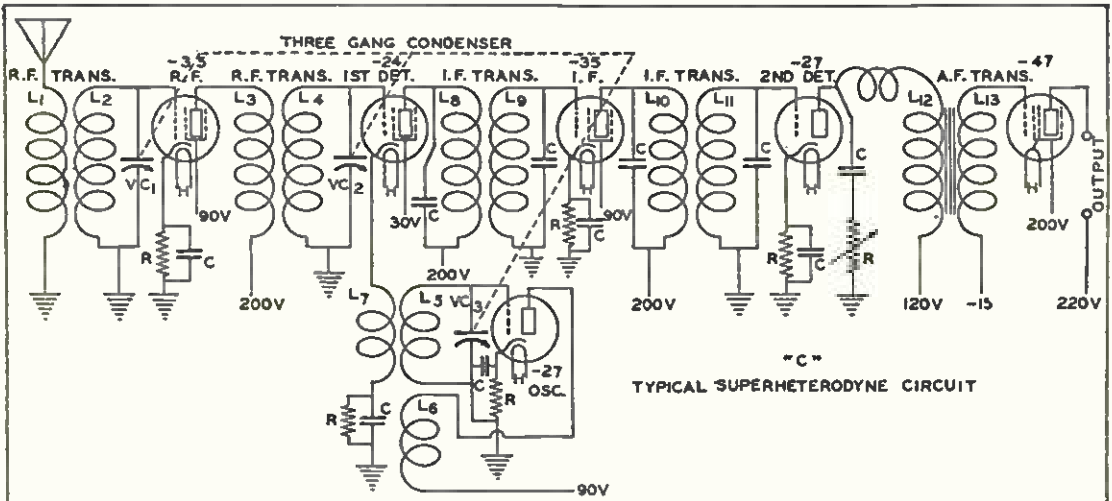

Figure 38

range of the receiver if the dial is to read correctly. In modern receivers a constant difference is easily maintained, and

Chapter Eleven

The Short Waves of Radio   To the experienced student of radio the short waves present an old story. On the other hand, however, to the average broadcast listener or newcomer in the field of radio, the realm of the short waves appears to be a region of mystery. Now that a rapidly multiplying host of enthusiastic short-wave listeners is springing up throughout the land, it will not be amiss to discuss the fascinating and useful short waves of radio.

The average radio listener has confined his tuning to that limited portion of the *wave band* which is the broadcast region. It is embraced between the upper and lower limits of the tuning dial, or 550 meters to 200 meters. Or, speaking in terms of frequencies, these limits are 545 kilocycles and 1,500 kilocycles. For years only commercial radio men were familiar with the vastness of the ether outside of these limits. A great army of amateur radio operators confined their activities to a small portion of the wave band. Most of the transmissions outside of the broadcast range were in *International Wireless code*. But there are stations in every country of the world broadcasting programs on short waves, and all of these furnish entertainment and thrills.

The Long Waves   Above the 550 meters (or *below* 545 kilocycles) limit of the broadcast band are the *long waves*. They extend upward to more than 20,000 meters (15 kcs.) in length. Great power is needed to send these waves through the air; they are not economical, but commercial code signals are sent this way to relieve some of the congestion in the more efficient short-wave band.

Below 200 meters (or *above* 1,500 kilocycles) will be found the interesting *short waves* of radio. Immediately below the 200 meters limit the waves really are not of the short variety; most experts contend that the short waves are below 100 meters. The lower practical limit of the short-wave band is about 10 meters (30,000 kilocycles, or 30 megacycles). Below this is an experimental radio band about ten meters wide.

The Short Waves   In the short-wave band (200 to 10 meters, or 1,500 to 30,000 kcs.) will be found both sound broadcasting and code signals, each confined to an individual portion of the band. It should be remembered that *all* of the radio business of the world must be placed in an electrical wave band hemmed in by an upper limit of about 20,000 meters and a lower limit of 10 meters (15 to 30,000 kcs.). In the familiar broadcast band a total of 345 meters separates its upper and lower limits; a difference of but 950 kilocycles. Yet, in the short-wave band, where only 190 mé-

ters separates its upper and lower limits, there is a spread of 28,500 kilocycles as compared to the 950 in the broadcast band. But, in the long-wave band, where a difference of 19,-455 meters separates the upper and lower limits, there is a frequency difference of only 535 kilocycles.

This means, then, that if radio stations are assigned frequencies which differ by ten kilocycles: In the long-wave band, where tuning is not sharp and such a frequency difference too small, only 53 stations could operate; in the broadcast band 95 stations can broadcast nicely without interference; but, in the short-wave band, a total of 2,850 stations can be placed. In the entire electrical wave band a total of 2,998 stations could thus be assigned. Ninety-six per cent of the total, however, would be in the shortwave band. Perhaps this explanation will prove to the reader something of the great value of short waves to radio.

Many It is a fact, however, that many times
Short-Wave 3,000 stations are scattered throughout the
Stations world in this wave band. Distance weakens
signals, and widely separated stations can be operated on the same frequency without interference. And, in the short waves, where operation is more economical and efficient, stations are crowded much closer than in our example of an ideal separation of ten kilocycles.

The reader has studied wave motion as well as the characteristics of radio or electrical waves (Chapters Two and Seven). It might be well for the reader to understand that radio transmission on short waves or by high frequencies is the most economical method. The rapid electrical vibrations of the transmitting station carry farther than the slow vibrations or oscillations of the long-wave stations. Of two stations with equal power, one operating on 10,000 meters (30 kcs.) will not carry as far as the station sending out a wave 100 meters in length (3,000 kcs.). The short-wave station will send its wave with only a small fraction of the power needed by a long-wave station to cover the same distance. This is due, in part, to the rapid vibration and penetrating power of the high radio frequencies from the short-wave stations. A similar effect is noted with sounds; a shrill, high-pitched whistle can be heard at a greater distance than a deep, lowtoned whistle.

Reflected But this is not the only reason why the
Waves short waves are so efficient. We know that
heat and light rays can be *reflected*. The short radio waves have high frequencies of vibration but not as high as heat and light. But they are high enough to reflect to some degree.

Now, a radio wave, when it is shot away from its sending antenna, will travel outward by two routes—one, the *ground wave,* and the other, the *sky wave*. The ground wave soon disappears. This is the reason why we can hear nearby

stations with only a ground wire and no antenna. The sky wave is a *radiated* wave (see Chapter Seven). High above us in the outer air is an electrical region called the *Kennelly-Heaviside Layer*. When radio waves reach this outer atmosphere they are turned back toward the earth. Changes or undulations in the reflecting surfaces of this distance layer are believed to cause much of the fading with which we are so familiar.

But reflection of the sky wave results in what is termed a *skip-distance effect*. This phenomenon varies according to the wave lengths used and whether daylight or darkness exists. Darkness always aids radio transmissions, particularly on the longer waves. Certain of the short waves seem just as strong during the day as at night.

Skip-Distance Effect   When the radio wave is reflected from the sky it comes down at an angle, far beyond the limits of the ground wave. Between the vanishing point of the quickly absorbed ground wave and the beginning of the area covered when the reflected wave strikes the earth there will be a wide area not reached by any radiation from this particular wave. Signals cannot be heard, for the receiver is located *within* the skip-distance region. These skip distances are seldom noticed on the broadcast waves, never on the very long waves but are troublesome on most of the short waves. Most likely this effect is the cause for much dissatisfaction when certain short-wave stations cannot be heard on the best receiving sets.

When the reflected sky wave reaches earth it may be many hundreds of miles from its starting point. It will be of full strength when it strikes and then slowly die out over a distance of thousands of miles. This accounts for the reports of long distance reception on short waves. For instance, a 30-meter (10-megacycles) signal may be heard regularly on its ground wave up to about 60 miles from its starting point. Then the ground wave dies out. The
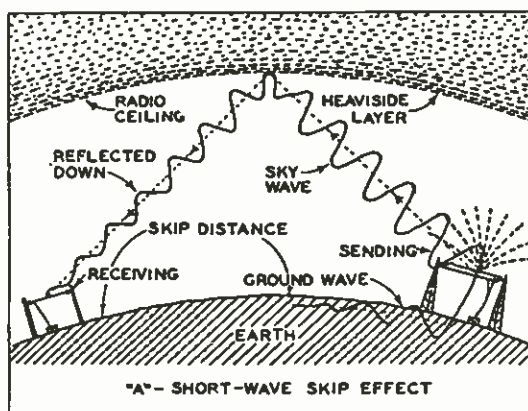

Figure 39

reflected sky wave may not strike earth until about 400 miles farther away. Thus there is a dead area, skipped over by the sky wave, where the skip-effect will be noted. From the point 400 miles away to even more than 5,000 miles the reflected sky waves cover the surface, and the station can be heard. This effect is shown by the illustration "A" Fig. 39.

Wave
Motion
Let us consider wave motion and its four *components*—power, intensity or *amplitude; speed; wave length* (distance between successive waves); and *frequency* (number of times waves occur in one unit of time). Amplitude is determined by the power or energy applied at the transmitter. Speed is fixed; it is that of light, 186,000 miles a second, or 299,820,000 meters a second (see Chapters One and Seven). Since speed is fixed by nature's law. but wave length and frequency are variable by tuning the inductances and capacities, we find there is a direct relationship between the latter two variables. For instance, if a radio signal that measures 100 meters between its waves, passes a fixed point during one second, a total of 3,000,000 waves would appear. This figure, then, is the frequency of the waves, and is written 3,000 kilocycles.

Amplitude
and
Attenuation
Water waves may be used in a popular way, to visualize radio waves. Radio waves, however, move out in *all* directions, while water waves travel only along the surface. On the ocean, if waves travel 1,000 feet a minute and the distance between crests is 200 feet (a wave length), then five such waves will pass by in one minute. This is the frequency of the waves. The amplitude will be the height of a wave. Great storms stir up high waves of considerable amplitude. Such waves move out far from the center of the storm that creates them. On the other hand, tiny ripples caused by tossing a stone into a pond soon disappear because their amplitude is insignificant. The rate at which the amplitude of waves dies down to a level surface (an absence of all energy) is called the *attenuation* of the waves. The above examples serve to explain wave actions in radio.

Because of the relationship between frequency and wave length it is possible to determine either one of these factors if the other is known. To find the *frequency* in *cycles* divide the fixed speed of 299,820,000 meters by the wave length in meters. To find the *wave length* in *meters* divide the same constant by the frequency in *cycles*.

Above 20,000
Meters
The practical limits of the radio wave band lie between 10 meters, for short waves, and 20,000 meters, for very long waves. But what lies beyond these limits? Why stop there? Can radio use wave lengths below 10 meters and above 20,000 meters? The interested student and reader will want to know the answer, so let us take a brief excursion into Nature's laboratory of wave lengths and frequencies and discover their vibrating sources.

In the region above 20,000 meters (below 15,000 cycles) there is still a small part available for radio. It is neither satisfactory nor efficient. It is the upper limit of the radio frequencies and approaches the audio frequencies (see Chapter Two). When the frequency of vibrations becomes less

than 10,000 a second the human ear will respond and hear the waves as *sound*. The lowest vibration frequency is about 25. Soon all forms of vibration cease and we reach the end of the long wave lengths.

Below 10 Meters But it is the region below the ten-meter end of the radio band that holds our interest. From ten to one meter (30,000 to 300,000 kilocycles, or 30 to 300 megacycles) is the *ultra* short-wave band which is used principally for experimental purposes. Below one meter we find the end of the radio-wave band just as we found its top up around 30,000 meters.

What lies below one meter of wave length, or a frequency of 300,000 kilocycles? First there is a region where high-frequency electrical vibrations can be created. They are not radio waves. Interesting experiments have been conducted in this band—between one meter and one thousandth of a meter. Such vibrations can burn without heat, create fever, and actually kill. Visions of lethal rays are being pictured by experimenters in this field.

The Realm of Light Next in the shortening wave band is a region of *heat waves*, closely followed by *infra-red rays*. Infra-red vibrations are not visible. They will penetrate fog and smoke.

The next wave band is visible *light*. Light is a wave motion; it comes to us in a wave-length band which lies between 75 one-hundred millionths of a meter to 35 one-hundred millionths of a meter. The frequency limits range from four billion kilocycles a second to eight billion kilocycles! Light, as we see it, is white. But all of us are familiar with the spreading out of a tiny beam of white light by means of a glass prism into the red, orange, yellow, green, blue and violet colors of the *spectrum*. The spectrum spreads out the component colors of white light in the order of their wave lengths, the longest waves being at the red end and the shortest waves at the violet end. It is this effect that has given the name spectrum to the radio wave-length band, as, for instance, *broadcast spectrum*, etc.

Cosmic Rays Next come the *ultra-violet rays* with about 6,500,000 waves to one inch! Then appear the *x-rays*. *Radium*, which emits short, penetrating rays, has even shorter waves. Still unknown and constantly sought after, are the *cosmic rays*. They are believed to have the shortest wave lengths known—the bottom of the wave-motion band of Nature.

Thus we have seen that the vibrations in Nature's wave-length band appear between wide limits. Radio occupies only a small portion of the total. The entire band, with the radio portion, is shown at "B" Fig. 40. And, as the short waves

control nearly all of the radio spectrum, they are the key to the future of radio.

A Short-Wave Receiver   Because the short-wave spectrum holds nine-tenths of all radio operations, it is natural that most listeners, after their initiation to radio through the regular broadcast channels, should turn to the short waves. There happen to be four methods by which we can listen to short waves. First, and the best, is by means of specially built *short-wave receivers;* second, with *all-wave receivers;* third, by using a *short-wave converter*, in combination with a broadcast set; and fourth, the plug-in of a *short-wave adapter.*
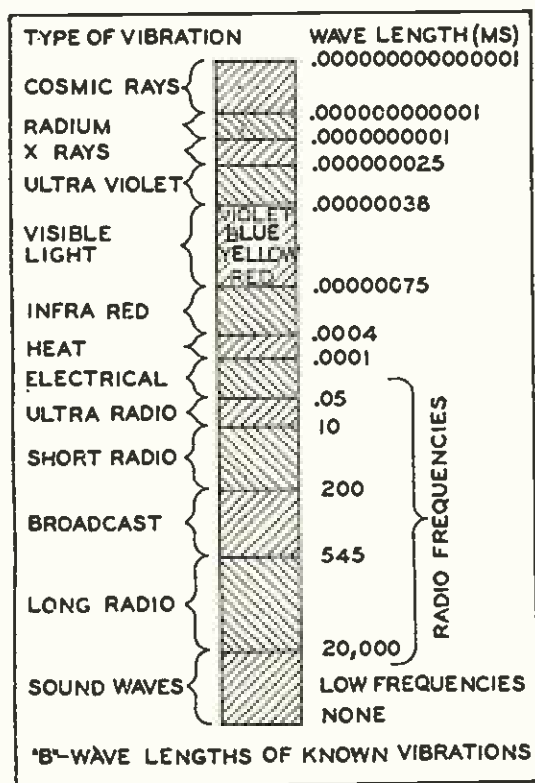

TYPE OF VIBRATION	WAVE LENGTH (MS)
COSMIC RAYS	.0000000000000001
RADIUM	.00000000001
X RAYS	.0000000001
ULTRA VIOLET	.000000025
	.00000038
VISIBLE LIGHT (VIOLET, BLUE, YELLOW, RED)	
	.00000075
INFRA RED	
HEAT	.0004
ELECTRICAL	.0001
ULTRA RADIO	.05
	10
SHORT RADIO	
	200
BROADCAST	
	545
LONG RADIO	
	20,000
SOUND WAVES	LOW FREQUENCIES
	NONE

"B"-WAVE LENGTHS OF KNOWN VIBRATIONS

Figure 40

The short-wave receiver is not essentially different from the broadcast sets described in Chapters Seven, Nine and Ten. Its r.f. coils are smaller and divided into groups, each to cover a particular wave band. One coil will not be sufficient to pass all the alternating current frequencies between 10 and 200 meters. Therefore, it is a common practice to use sets of r.f. transformers, usually interchangeable, but often arranged with switches instead, having windings that are resonant over the 10-20, 20-40, 40-80, and 80-200 meters wave bands. These inductances are tuned in the conventional manner, but the variable condensers are smaller than those used in broadcast sets.

The smaller the coil and the fewer its turns of wire, the less a.c. resistance (reactance) it offers to the fast vibrations of the short waves (see Chapter Three). For the very short waves—10 to 25 meters—the coils of the r.f. transformer consist of about half a dozen turns of wire. Because of the nature of the high frequencies, from 12,000 to 30,000 kilocycles a second, insulation is difficult. For instance, in Chapter Four we saw that high frequencies will pass through a very tiny condenser or capacity. This is why energy losses with short waves are difficult to control. The least capacity effect causes some energy to leak away. Unless a receiver intended to operate in the short waves is properly constructed it will be next to useless.
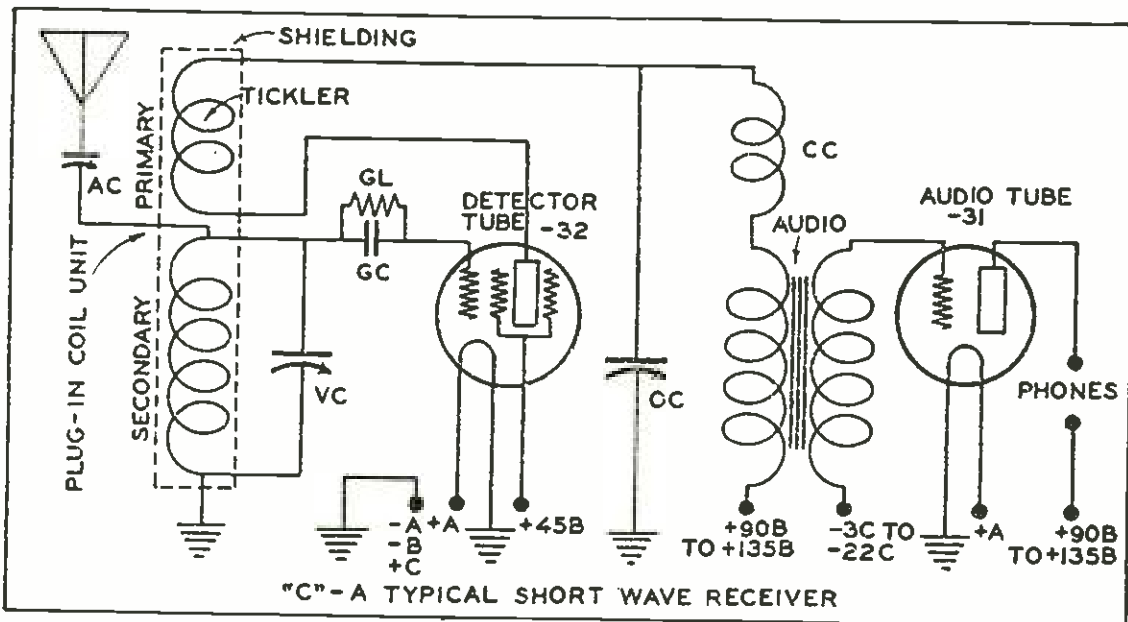
SHIELDING

TICKLER

PRIMARY

AC

PLUG-IN COIL UNIT

SECONDARY

GL

GC

VC

DETECTOR TUBE -32

CC

AUDIO

DETECTOR TUBE -32

AUDIO TUBE -31

PHONES

-A +A
-B
+C

+45B

-90B
TO +135B

-3C TO
-22C

+A

+90B
TO +135B

"C"-A TYPICAL SHORT WAVE RECEIVER

Figure 41

Typical Circuit   At "C" Fig. 41 is shown the circuit of a typical two-tube short-wave receiver. It closely resembles the average small broadcast receiver. However, in order to obtain the necessary sensitivity these types of sets use the *feed-back* principle, as explained in Chapter Nine.

A set of four *plug-in coils* is required to cover the entire band in this short-wave receiver. They are wound on the forms sold for the purpose, as shown at "D" Fig. 42. The forms are standard four-pin bases, about 1¼ inches in diameter and 2½ inches high.

The first coil covers the 10 to 20 meters band. Its secondary is wound with 6 turns of No. 22 enameled wire. The turns are kept about 3/16 inch apart. The primary or *tickler* is closely wound with 4 turns of No. 30 enameled wire. A space of ⅛ inch is left between the primary and secondary windings. All the coils use the same size wire, as above specified.

The R. F. Coils   For the 20 to 40 meters coil place 12 turns on the secondary and wind it in a space one inch long; the primary has 6 turns also closely wound, as on the first coil. The 40 to 80 meters coil has 24 turns on the secondary wound so as to average 16 turns to one inch of length; the primary has 7 turns. The 80 to 200 meters coil has 50 turns on the secondary and 15 turns on the primary, all closely wound.

The variable condenser (VC Fig. 41) used to tune the secondaries of the r.f. transformers or plug-in coils, has a maximum capacity of .00014 microfarad. The tiny antenna condenser (AC) is about 35 mmfds. capacity. The choke coil

59

| 10-20 M | 20-40 M | 40-80 M | 80-200 M | SECONDARY |

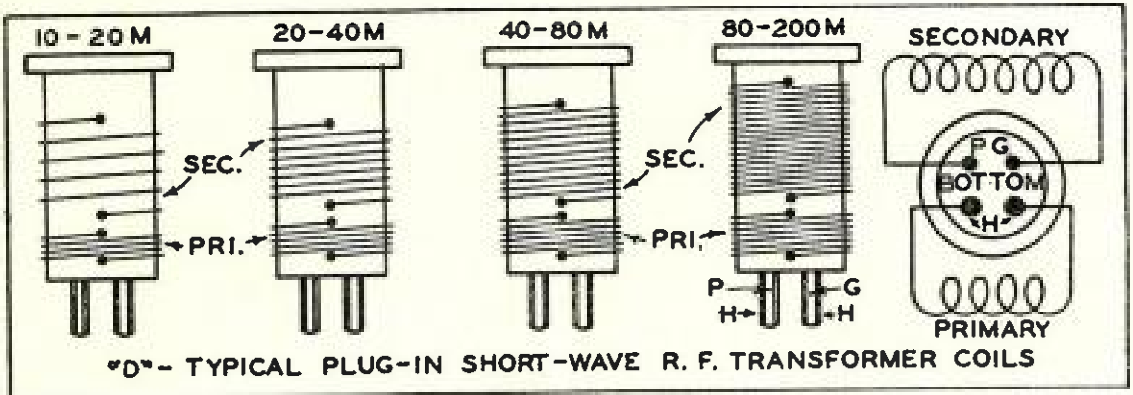"D"- TYPICAL PLUG-IN SHORT-WAVE R. F. TRANSFORMER COILS

Figure 42

(CC) should have an inductance of 2.7 millihenrys. Regeneration or feed-back is controlled by the oscillation condenser (OC) which has a capacity of 250 mmfds. The detector gridleak (GL) has a resistance of 2 to 5 megohms, and its condenser (GC) has a capacity of 100 mmfds. The audio amplifying stage is the conventional type and is connected to the detector output through a high-ratio (6 to 1) audio-frequency transformer.

Chapter Twelve

All-Wave Receivers and S. W. Converters .. The ideal method for reception of short waves, particularly the very shortest, requires a number of separate short-wave receivers, each tuning between resonant limits of about 30 meters. In this manner it would be possible to use a small radio frequency transformer of limited range without resorting to the plug-in arrangement described in Chapter Eleven. The variable condenser would easily tune such a small coil, and congested signals would be spread out over a wide range on the tuning dial. Better tuning could thus be obtained, and many more stations on the short waves would be logged.

The trend, however, except in commercial and amateur stations where efficiency is the watchword, is not to make use of a number of receivers, but to combine every channel of the wave-band spectrum into a single, easily manipulated unit. This is why the *all-wave* receiver has become so popular. It embraces, within its tuning limits, all of the short-wave band and the broadcast band as well. Some receivers tune into the long-wave band in addition to the short and broadcast waves. This tuning is for European reception where many stations broadcast on the higher waves up to 2,000 meters (150 kilocycles).

The   The all-wave receiver is simply a standard
All-Wave   type of radio set, either tuned-radio-fre-
Receiver   quency (t.r.f.) or superheterodyne. The lat-
ter is in almost universal use. There is nothing of a mysteri-
ous nature about its design and construction. The only real
difference is the tuning range, which, in this case, covers a far
wider scope than the ordinary broadcast receiver.

In previous discussions we studied tuned-radio-fre-
quency and superheterodyne receivers. (Chapters Nine and
Ten.) But these receivers were capable only of responding to
signals in the broadcast band—between 200 and 550 meters.
This range was the limit of resonance for the r.f. coils and
transformers used in the receivers. A single coil, in this case,
was used to cover the entire wave band.

But, as we learned in Chapter Eleven, the short waves,
between 200 and 10 meters in length, cannot be received
through a single coil or r.f. transformer. That is why the
short-wave receiver shown in Chapter Eleven required a num-
ber of interchangeable r.f. coils or transformers, each of
which covered a definite wave band. The resonant range of a
r.f. coil to high-frequency alternating currents becomes more
and more limited as the waves become *shorter*.

Several   This fact is easily understood by a study of
Coils   the coils used to cover certain wave lengths
Required   and plugged into the short-wave receiver
shown in Chapter Eleven. With all the information given in
that, and several preceding chapters, concerning resonance,
induction, and the tuning of coils carrying radio-frequency
currents, the reader should be able readily to understand
why a single coil of wire, wound into a radio-frequency trans-
former, cannot present perfect conductivity to *all* frequencies
of alternating currents between 30,000 and 545 kilocycles—
the range of the average all-wave radio receiver.

For that reason the plug-in system was originated, using
coils similar to the types described in Chapter Eleven. If a
larger coil is added to the series required to cover the short-
wave band, then the broadcast band, too, can be covered. This
was the beginning of the all-wave idea. There is no limit to
the number and sizes of the additional coil or coils that can
be plugged into the set so that signals of *any* wave length can
be heard. But, in this type of construction, the outstanding
drawback is that, while the r.f. coils are interchangeable, the
variable condensers used for tuning have fixed capacity limits.

Thus the two important features of a tuned-radio-fre-
quency circuit (capacity and inductance) are not maintained
with a balanced ratio when the coils are shifted for the recep-
tion of signals over the different wave bands. To make this
scientifically correct it would be necessary also to change the
size of the condensers.

Small Tuning Condensers   To make this a little more clear, we should remember that a variable condenser of small capacity calls for a greater interleaving of the plates in order to increase its total capacity. On the other hand a large condenser calls for a very slight movement of its rotor plates in order to reach the capacity obtained by the larger movement of a small condenser.

When short waves are tuned in, a small coil and a small variable condenser are necessary. But, as the waves become longer, larger coils and larger condenser capacities are needed. Now, if a large tuning condenser is used, a very slight movement is required to tune a small coil. And a greater movement is required to reach the larger capacities needed to tune a larger coil to a longer wave length.

But if we use a small tuning condenser for a small r.f. coil, so as to obtain fine shades of tuning or capacity adjustment needed for separating the short waves, the condenser capacity would be far too small to tune the large coils used for reception of the longer waves in the broadcast band.

All-Wave Tuning Difficulties   These things, then, will explain to the reader why inequalities exist in the so-called all-wave tuning circuit. The all-wave receiver, quite naturally, will favor certain wave bands, where the inductances of the coils and the capacities of the condensers blend together in the proper ratio so as to tune in certain stations with perfect resonance. Outside of these favorable portions of the dial the set will not operate as nicely on the remaining wave bands. All this is to be expected, for the best all-wave receiver that can be made will prove unsatisfactory unless its variable condenser and r.f. coil values balance so as to maintain a proper ratio throughout the tuning limits. The proper design of these two important circuits is necessary if the all-wave receiver is to work equally as well throughout the short and broad-cast-wave range. This problem has been admirably met in most all-wave radio sets.

Let us, first, return for a moment to the simple short-wave receiver described in Chapter Eleven. If the coils and condensers used should be given less inductance and capacity, then the tuning range of each plug-in unit would be lessened, but the tuning and separation of stations would not be so exacting. The dial movement would then be greater between otherwise "hair-line" separated stations. In other words we would *spread* out the stations farther apart on the dial.

Band Spreading ..   The average coil or r.f. transformer covers so much of the wave band that extremely slow and careful tuning is required to bring in a station. But it is possible to spread out *any* portion of the short-wave band—some portion, for instance, where far-away stations

are congested and hard to separate. The method of spreading out some portion of the wave band is called *band spreading*.

The band-spread method makes it easier to locate and tune distant stations. It does not, of course, add to the sensitivity of the set; it merely makes tuning easier and not so sharp by creating a certain portion of the tuning scale that can be tuned with small units of capacity, just as if the set were built with the small coils and condensers previously mentioned as being the ideal short-wave receiver.

At "A" Fig. 43, the secondary winding of the plug-in r.f. coil that was used in the short-wave receiver shown in "C" Fig. 41 page 59, will be seen, but the remainder of the circuit is not indicated. The band spreading operation is confined entirely to the tuning coil and its condenser. The tuning condenser (VC) is shown in "A" Fig. 43.

The   The band-spread method shown at "A" is the
Additional   most simple arrangement known, and it is
Condenser   quite efficient and satisfactory. A small variable condenser, having one-third the capacity of the larger tuning condenser (VC) is shunted across the latter. The small condenser is shown at VC_1. This is all that is necessary in order to introduce the band spreading operation to the basic short-wave set described in Chapter Eleven.

If VC is set at zero capacity, and the tuning of the secondary coil is accomplished by turning VC_1, then the latter condenser will tune one-third of the wave length limits of VC. Not all the stations tuned in with VC can be heard but those that are picked up will be spaced three times as far apart on the dial of VC_1 as when on the dial of

BAND SPREADING METHODS

Figure 43

VC. Thus the stations are separated, as that particular waveband is spread out around the dial.

Now, if VC is set at one-third of its capacity and the short-wave set tuned by VC_1, it will respond to stations usually heard between the one-third and two-thirds capacity setting of VC. They will be spaced three times as far apart on the dial. If VC is set at two-thirds capacity, and the tuning done by VC_1, then the stations usually heard between two-third and full capacity of VC will be heard, and again they will be three times as far apart on the dial of VC_1, covering the dial from end to end.

Another   All tuning, in the band-spread system, is
Scheme   done by the small condenser VC, *after* VC
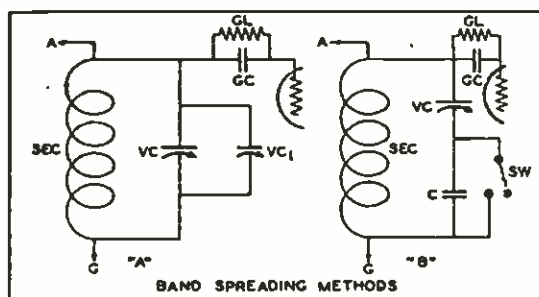has been set stationary so as to select the desired portion of

the wave band covered by the particular plug-in coil being used. The principal difficulty is in setting both VC and VC, to the proper relationship so that a station which has been previously logged can again be located. There are several schemes for band spreading, but the one shown at "A" is the most widely used.

In order to eliminate the use of the variable condenser VC, with its tuning requirements, the method shown at "B", Fig. 43, may be used. A small, fixed condenser (C) is connected in *series* with the tuning condenser VC. It is shunted with a switch so it can be cut in or out of the circuit at will. It is known that if two condensers are connected in series the capacity of both will be greatly reduced. The capacity of C, in our short-wave circuit, should be about .0005 (50 mmfds.) mfd. Now, when C is in the circuit, VC will have the capacity of a much smaller condenser, and stations tuned in by it will be more widely separated on the dial of VC.

All-Wave Coils   The plug-in system, which can also be used in any all-wave set, is not in general favor because of the necessity for manual manipulation of the r.f. coils when changing from one wave band to another. This system, however, is the ideal arrangement for short-wave reception. Modern all-wave sets do not use the plug-in method but have a permanent installation of coils. They can be cut in and out of the circuit at will simply by turning a small switch. Of course, there is some loss of energy because of the *dead ends* of the coils and connections. However, in the newer types of all-wave sets the dead-end loss is held down to such a small minimum that it is not a serious matter.
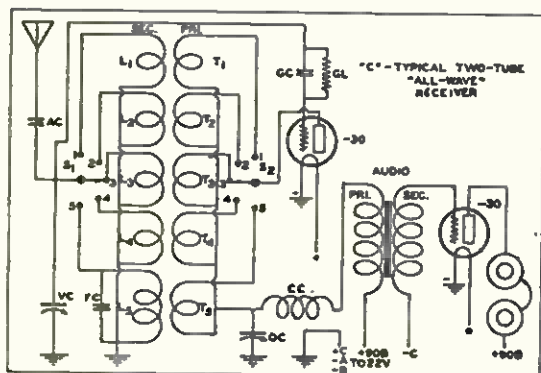

Figure 44

At "C", Fig. 44, is shown the circuit of a typical all-wave receiver. It does not use the plug-in method, but switches the various coils in and out by means of two switches (S_1 and S_2) operated simultaneously by a single knob. The individual r.f. transformers or coils used in this small all-wave set are the same plug-in coils described in Chapter Eleven and used in that short-wave set. The circuit, too, is identical. There is no difference between the two circuits except that the coils are permanent and connected at will by means of switches. An additional r.f. coil is used to cover the broadcast band.

The Broadcast R. F. Coil   However, the coils wound for the short-wave receiver were made only to cover the short-wave bands up to 200 meters. Provision must be made to cover the broadcast band as well, so an additional

coil is wound for the 200 to 550 meters band. Since this coil is tuned by the variable condenser VC, which is too small in capacity fully to tune the coil, a small fixed condenser, FC, of about .0001 mfd. capacity, is shunted across the broadcast coil, L_5, as a permanent feature. The antenna condenser AC is not needed when the broadcast band is being used. The coil used for the broadcast band should have 80 turns of wire on the secondary and 22 turns on the primary, wound to the same specifications given in the previous chapter.

An all-wave receiver having many tubes and a superheterodyne circuit becomes very complicated. Several sets of coils are needed so as to cover all the wave bands. If the reader will consider the superheterodyne circuit shown at "C" in Chapter Ten, and then apply in his mind the many coils indicated at "C" in this chapter to all the radio-frequency and oscillator circuits, he will obtain some idea of the circuit of a modern multi-tube all-wave receiver. All of the coils, antenna, radio-frequency and oscillator circuits, require simultaneous shifting with a single switch-knob in one operation when changing from one wave band to another.

Short-Wave It is possible to utilize any broadcast super-
Converter heterodyne or tuned-radio-frequency receiver when listening to the short waves. In order to tune below 200 meters we must connect a separate unit to our standard broadcast receiver. This unit is called a *short-wave converter.*

Next to a carefully built all-wave receiver for efficiency comes the short-wave converter. It is merely a small short-wave set. But it contains an oscillator which is used to produce local radio-frequency oscillations that are mixed with the high-f r e q u e n c y short-wave signals coming in from the antenna. The mixing of these two different frequencies creates a *lower* frequency, which, if the converter has been properly designed, will fall within the tuning range of the broadcast

Figure 45

receiver. The action of the oscillator and the production of these beat frequencies was described in detail in Chapter Ten.

The converter takes the incoming short-wave signals, mixes them with the locally produced r.f. oscillations, and passes the resulting beat frequency to the broadcast receiver. This output, since it is a beat frequency, has a lower frequency that is within the range of the broadcast set—200 to 550 meters. In other words, the converter *converts* the short-wave radio signals to longer wave signals so they can be ap-
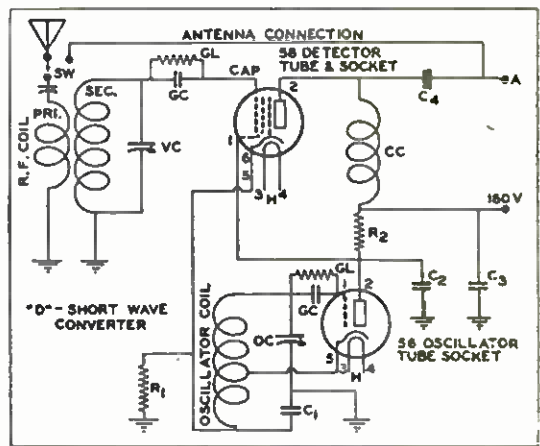
plied to the broadcast receiver just as if they were broadcast station signals. The broadcast receiver, however, must be tuned to the output frequency of the converter. It requires no further tuning or adjustment except for volume. All signal tuning is controlled by the converter dials.

Typical Converter Circuit
At "D", Fig. 45, is shown the circuit of a short-wave converter. As in the typical all-wave circuit, shown at "C", Fig. 44, the r.f. coils used are those described for the short-wave receiver illustrated in Chapter Eleven. Either the plug-in method or the all-wave scheme can be used for changing the coils. Of course, the broadcast coil will not be required in the converter. In the converter circuit it will be noted, however, that a different arrangement is used. The tickler winding of the r.f. coils becomes the antenna primary of the converter circuit.

An oscillator must also be added. And a series of oscillator coil units must be made, one for each of the different r.f. coils illustrated and described in "D", Fig. 42, page 60. The oscillator coils are wound on similar forms. The oscillator coil to be used with the 10-20 meters r.f. coil, has 4 turns with a tap taken off 1 1/3 turns from the *bottom*. For the 20-40 meters coil wind on 8 turns with a tapped connection taken 2 2/3 turns from the bottom; for the 40-80 meters oscillator coil wind on 18 turns with a tap taken off at 6 turns from the bottom; and for the 80-200 meters oscillator coil wind on 40 turns with a tap taken 15 turns from the bottom.

One contact of the socket that is used to hold the plug-in oscillator coils connects to the tap on the coil and to the cathode of the oscillator tube. This is shown in "D", Fig. 45. Only three prongs of the coil base and three contacts of the socket are used. The output of the converter connects to the antenna terminal of the broadcast receiver. The filaments of the converter tubes may be heated by current taken from the broadcast receiver with a *wafer adapter* placed beneath one of the broadcast-set tubes. The 180 volts plate supply for the converter is taken from some point in the broadcast receiver that is close to the filtered B supply from the voltage divider system.

Chapter Thirteen

The Power Unit— Rectification Electric power to operate a radio receiver can be obtained from three sources—batteries, battery eliminators, and the power-pack unit that is built into the receiver. Batteries *generate* their own direct current. But other devices, such as eliminators and power packs, *deliver* direct current at the same time they are working on an alternating current. This alternating current, as the reader now understands, is useless when it comes to the operation of the plate circuits of a radio receiver. That is why we have had battery receivers for so long; before the eliminator was invented.

Some arrangement, then, must be made to provide a direct-current supply for the operation of the all-electric receiver. But, since the world standard of 110-volt, 60-cycle alternating current only is available in nearly every locality, most receivers are made to operate on this house-lighting power. Battery sets, except when provided with power from the usual group of batteries, cannot run directly on the lighting-power lines, unless "A" and "B" battery eliminators are used.

It is a fact that batteries provide the best form of smooth, direct current. On the other hand, however, batteries are not economical; they are unsightly, bulky and quickly lose strength. When the alternating current that flows in the wires of our homes is used to run a radio receiver, its characteristics must be altered so the current flows as smoothly and evenly as that which comes from a battery.

Battery Eliminators If alternating current is available, but only a battery set is used, the batteries may be discarded and *"A" and "B" battery eliminators* utilized. They take the 60-cycle power from the house wiring circuit and convert it into a smooth, quiet power that is similar to battery power. Eliminators are connected to the receiver as if they were "A" and "B" batteries.

In restricted down-town localities in some large cities 110-volt direct current only is available. It is not wholly satisfactory for radio. Eliminators cannot be used, and all-electric sets are useless. To overcome this fault some manufacturers offer a.c.-d.c. sets. The 110 volts of the power line, however, is the limit of potential available for the internal circuits of the receiver. This is much lower than that used in modern a.c. sets.

The modern a.c. receiver is nothing more or less than a battery receiver in principle. It operates on power provided by "A" and "B" eliminators which in turn connect to the a.c. lighting circuit in the house. But, in modern sets, these elim-

inators become the *power-pack* or *power-unit* which is built into the receiver as an integral part of its chassis and circuit.

The Power   Since the power necessary to operate a mod-
Transformer   ern, multi-tube radio receiver varies in po-
tential from only a few volts to several hundred volts—considerably above and below the 110 volts flowing in the power or lighting lines, it is essential that an alternating-current *transformer* be utilized to provide the several different voltages required.

Ordinarily we might believe that a number of separate transformers would be needed—each creating the voltage required by every particular circuit in the receiver. But instead of such an imposing array of transformers it is possible to construct a *single* transformer that will do the work of all. Such a device is called a *power transformer*.
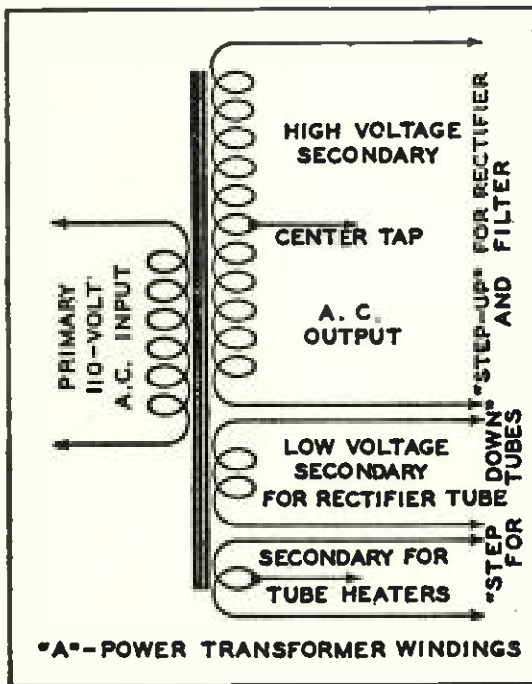

Figure 46

The power transformer is connected to the 110-volt power line. An alternating current flows through its primary coil. This sets up a swinging m a g n e t i c field around the primary, and another alternating current, of higher or lower voltage, as the case may be, will be *induced* in a second coil which is wound over the first so as to be within its magnetic field. The voltage induced in the secondary depends upon the *ratio* between the number of turns of wire wound on the primary and the secondary. For instance, if a "one or two" ratio exists between the number of turns in the two coils, then *twice* as many volts will be induced in the secondary as are f l o w i n g through the primary. Transformer action has been discussed in considerable detail in Chapter Three.

Has Several   But, instead of winding a *single* secondary
Secondaries   coil over the inside primary coil on the power
transformer, we may add as many individual secondaries as we please. The number of turns of wire on each controls the voltage it will deliver. A small secondary is used to provide the low voltage required for the filaments and heaters of the tubes; another furnishes higher voltages for still other purposes and circuits; and the outlet of a large secondary gives

the high potential necessary for the plate circuits of the tubes.

At "A", Fig. 46, is shown a diagram circuit of a power transformer. While it is similar in effect to that also shown at "F" and "L", Figs. 7 and 8, page 13, it will be noted that it has several secondary windings. The high-potential secondary is a "step-up" transformer; low-potential secondaries are "step-down" transformers.

Using It is possible to *reduce* the voltage of any sec-
Resistors ondary output by introducing a resistance in series with the wires leading to the various points of the receiver. Thus the different voltages required by the tubes and units in a modern radio set can be controlled by a power transformer having only three or four secondary windings, and the intelligent use of *resistors* of the proper resistance placed wherever required.

Although the proper electric current and voltages needed to operate a receiver can be obtained from the power transformer, the fact still remains that the current furnished by the secondary coils is alternating in character. It has the same frequency as the 110-volt current flowing through the primary coil. But radio sets require direct current and, therefore, it becomes necessary to *convert* this alternating current into a direct current.

The The device that makes such a conversion is
Rectifier called a *rectifier*. There are several types in use. The oldest known rectifier is the *electrolytic* rectifier. It is not particularly efficient, but is quite satisfactory. Then there is a *dry-metal* rectifier, used mostly in *trickle chargers* for storage batteries, where a low current is essential. The most widely used and most efficient type is a *rectifier tube* of the *hot-cathode* type. Considerable previous discussion of radio tubes and rectification will be found in Chapter Six.

The rectifier, as its name would imply, takes an alternating current, which changes continuously from negative to positive, and converts it into a direct current which *remains* steadily negative and positive. As has been explained previously in this series, rectification action takes place simply by holding back the passage of the negative alternations of each cycle of the current and permitting the passage of the positive alternations. Thus a rectified current, as pictured by the curved lines or cycles at "D" of Chapter Six, consists of a series of quick pulsations or surges that occur every time a positive alternation is allowed to pass through the rectifier. The *rate* at which these pulsations occur is equal to the number of positive alternations in the original current.

If the lighting current is the standard 60-cycle kind, then it has 60 positive and 60 negative alternations. As one of each combine to make one cycle there will be 120 alternations or 60 cycles per second. Now, if we *cut off* the 60 nega-

tive alternations by the rectification action, then the 60 positive alternations will remain. The rectified current, as a result, will have a frequency of 60 positive pulsations of direct current each second. But this current, if passed through an audio circuit, will produce a *hum* having 60 vibrations a second. Further treatment, then, is necessary.

The Power Unit Let us look briefly at all the actions which take place in the eliminator or power-pack unit. The effect of the rectifier is to change the alternating current into a direct current that is composed of short, rapid impulses of electricity. But, before this interrupted current can be used by the radio set, the impulses or voltage fluctuations must be smoothed out. There must be a steady flow of current so hum and noise will be eliminated. So, immediately following the power-transformer output and the rectifying device, is the *filter circuit*. This circuit contains large capacity *filter condensers, iron-core choke coils,* and a large resistance *load* or *voltage-divider system.*

The choke coils are placed in *series* with the output from the rectifier. They offer a high a.c. resistance or impedance to the rapidly pulsating current. This inductance smooths out the hum and *ripple* caused by the rectified interruptions of current. Condensers, too, are used across the two leads from the rectifier, in parallel with the resistance load; they act to store up energy. This energy is released at the moments occurring between the pulses of current, and it equalizes the voltage of the output by building up the gaps to a level equal to the potential of the rectified current. The effect, then, of the filter system is to smooth out the ripples or waves in the rectified current so that it flows as steadily and uniformly as battery power.

The Electrolytic Rectifier The oldest form of rectifier is the *electrolytic* type. If two metallic sheets, one of *aluminum* and one of *lead*, are arranged parallel but insulated by a slight separation, and immersed in a solution of borax and water, they will act as a rectifier of alternating current. The rectifying unit should be placed in series with one of the two wires carrying the alternating current. The aluminum plate is the positive electrode, and the lead will be the negative terminal. Current flows *toward* the positive electrode. Its metal surface then becomes momentarily oxidized, and tiny bubbles of gas will form on the plate. Thus the current cannot flow between the plates because of the resistance of this film of gas. Now, when the current reverses, as it does in an alternating-current circuit, it will flow *from* the positive to the negative electrode. The positive alternations are not permitted to pass, but the negative alternations go through. This results in uni-directional pulsations of electricity.

Electrolytic rectifiers are used for charging storage bat-

teries, and in "A" and "B" eliminators. But the appearance and care that is associated with a number of these cells used in the eliminator makes them more or less unsatisfactory. Illustration "B", Fig. 47, shows an electrolytic rectifier connected in the secondary or output circuit of the power transformer shown in "A", Fig. 46.

The Tube Rectifier This rectifier is a simple vacuum tube containing a filament and a plate. When the filament is heated to incandescence an intense cloud of electrons is emitted. Now, if a *positively* charged object is placed within the electronic field, the electrons will fly toward the object because of the natural attraction of a positive charge for a negative charge—opposites attract and likes repel.

In Chapter Six we learned that, if a metal plate or anode surrounds a filament, it will attract all the electrons emitted by the red-hot filament, heater or cathode. The filament also is connected to one terminal of the electric power line that is to be rectified, and the plate to the other terminal. As long

Figure 47

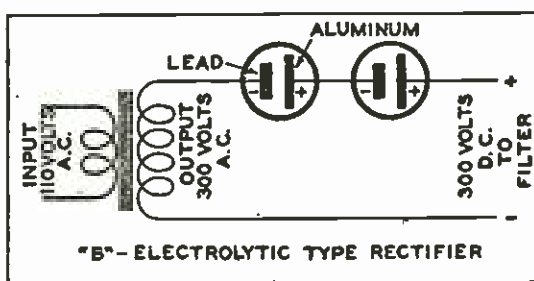as the plate is given a positive charge electrons will fly across the gap.

A current of electricity, then, will flow *from the plate toward the filament*. But, when the potential of the plate is reversed, or made negative, the stream of electrons instantly *will be repelled*, and, without this movement of electrons toward the plate, no current can flow in the circuit.

Now, connect the two elements of the tube to an alternating current. The filament is heated by a separate source. The alternating current then will flow in *one* direction only, because, when the positive alternations are impressed on the plate, electrons will flow. But, when the plate receives the negative alternation, current cannot flow between the filament and the plate. This briefly explains rectification or the uni-directional flow of electricity between the two elements of a diode tube. The effect is known as *half-wave* rectification. The types of tubes used are styles 81 and 12Z3.

Full-Wave Rectification Rectifier tubes generally used in modern radio power units have *two* plates instead of one. They are *full-wave* rectifiers. Because this type is highly efficient and better known to the reader it will be discussed in detail, and illustrated in our diagram of the complete power unit. The full-wave rectifier passes *both* halves of the alternating potential from the power transformer, and the uni-directional d.c. output resulting from each half-cycle or

alternation of the a.c. input will be supplied to the circuit at twice the rate of the impulses from a half-wave rectifier. This speeding up of the pulsations provides a more nearly even flow of current without such large gaps occurring between the voltage fluctuations. This action makes the work of filtering out of hum much simpler.
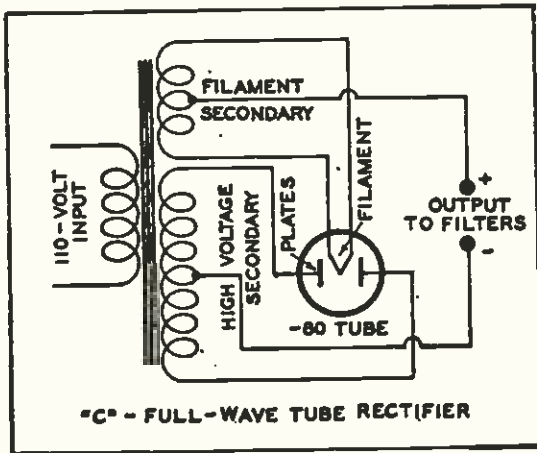

Figure 48

At "C" is shown a tube with its two plates and filament connected in an alternating-current circuit. Each plate is connected to the terminals of the high-potential secondary of the power transformer. The potential of the plates will change, alternately, from positive to negative, as the current alternates back and forth through the secondary coil in which it is induced.

How It **Works** When one plate is given a positive charge, the other plate becomes negative, as shown at the left in "D" Fig. 49. Then, when the potential *reverses* at the following half-cycle the first plate becomes negative, and the other plate, positive. This effect is shown at the right, in "D." In both cases electrons flow toward the plate that happens to be positively charged at the time. The flow is indicated by the arrows in "D." Between times, neither plate has a positive nor negative charge. Electrons do not flow.
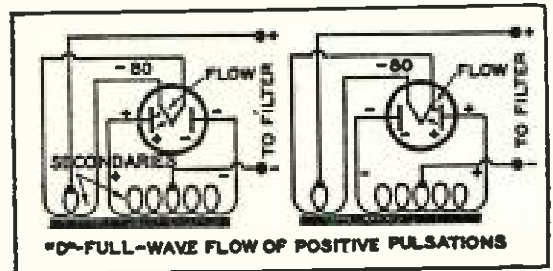

Figure 49

Two plates utilized in this way work alternately and pass quick impulses of current, first from one, then from the other, into the circuit, but always in one direction. This current is a direct or uni-directional current. Its flow is broken up into 120 short pulses of potential, or fluctuations of voltage, every second. A similar effect would be given if the switch in a battery circuit should be opened and closed 120 times a second.

Let us again examine briefly the circuit shown at "C" Fig. 48. The filament of the tube, which can be a type 80, 82, 83, 84, 5Z3 or 25Z5, is connected to the heater winding of the power transformer. The exact center of this transformer secondary winding is tapped with a connection that is used for

the *positive terminal* of the d.c. output from the high-potential rectifier. The two plates of the tube are connected to the terminals of the large high-voltage secondary. This secondary also has a center-tap connection that is used as the *negative terminal* of the rectifier output. The two terminals of the rectifier—positive and negative—provide an output for the uni-directional direct current. But, and this fact is highly important, these pulsations *must be filtered* out before the current is sufficiently smooth and quiet so it can be used in a radio circuit.

Chapter Fourteen

The Power Unit—Filter and Voltage Divider   In the preceding chapter we learned that alternating currents can be converted into direct currents by means of rectification. It was shown, however, that a rectified current, while possessing constant positive and negative terminals, consists of a rapid succession of tiny impulses of electric current.

These little pulsations cause fluctuations of voltage in the circuit through which they flow. Because of this action the "pulsating" current produces an audible vibration or hum in the sound reproducing unit. Such current is perfectly satisfactory for charging storage batteries or operating certain electrical devices, but it is of no use whatever in connection with

Figure 50

the direct-current plate circuits of a radio receiver. The current used in these circuits must be as smooth and steady as that obtained from a battery.

But it is possible to smooth out these tiny pulsations; fill in the gaps between the moments when they occur, and eliminate the voltage fluctuations that create hum and noise. A rectifier-tube circuit was shown in Fig. 48. From the output of the rectifier tube we can feed an uni-directional pulsating current into a *filter* system. The impulses will be smoothed out so as to provide a steady, non-fluctuating direct current for the plates of the tubes and the speaker of the receiver.

A Typical Filter   A typical filter circuit is shown at "A" Fig. 50. It is a part of the complete power unit. The input is connected to the output of the rectifier circuit mentioned above. This filter system is, in fact, quite simple
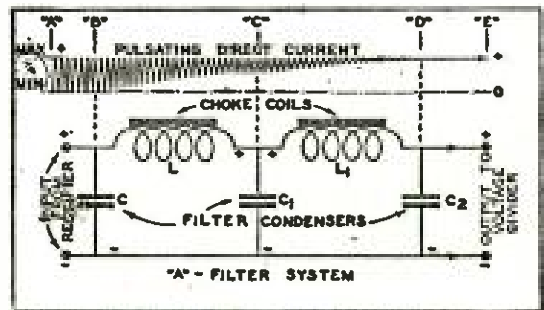
73

to understand, for it consists of but two units—fixed condensers and choke coils.

The wave forms of the current flowing through the filter are graphically pictured in Fig. 50. To the left, between points A and B, will be seen the characteristic undulations or voltage fluctuations of the rectified current flowing from the output of the rectifier circuit. Each of the undulations or curves, between points A and B, is a *maximum* rise in current or voltage fluctuation. The filter apparatus is utilized to smooth out and reduce entirely these rapid pulsations.

Fixed condensers and large inductances (iron-core choke coils) or *reactors* are connected in the filter circuit. The coils present high resistances to the passage of any currents that constantly fluctuate in voltage. This resistance is known as *impedance*.

How It Let us examine the action of the filter. When
Works one of the fluctuations of current reaches its full strength, as it does with each pulsation that is passed from the rectifier output, the iron core of the choke coil becomes an electro magnet. Its surrounding magnetic lines of force cut through the wires in the coil, and it is this self-inductance (explained in Chapter Five) that tends to oppose any further rise of current through the coil. A choke coil is always used to oppose current fluctuations.

Much of this opposed current will be thrown *back* into the input portion of the circuit where it is deflected to the condenser C, shown in Fig. 50. When the charging voltage of this surge decreases, as it does *between* every pulsation from the rectifier, the condenser *discharges* its accumulated voltage into the circuit. This occurs *between* peak voltage fluctuations. Thus the condenser C sends *new* voltage into the circuit and offsets the intervals between the rectified impulses of maximum voltage.

The condenser, then, works to maintain a constant voltage in the circuit. Really the condenser is a sort of reservoir. It takes in a charge when the line voltage increases (at the time of a pulsation) and releases this charge when the line voltage subsides (as it does between pulsations). The filter condenser *equalizes* the voltage fluctuations and provides a constant flow of current from the filter output.

The Entire A single condenser and choke coil, however,
Filter are not entirely sufficient completely to filter out all voltage fluctuations. The original impulses will be smoothed down to a considerable extent, as shown by the wavy line between points B and C, in Fig. 50. The current output, from L, however, will continue to show slight fluctuations. These will be heard as a purring or rippling sound in the loudspeaker.

In order further to smooth out the remaining fluctua-

tions a second combination of choke coil and filter condenser is added. The second condenser (C_1) and choke coil (L_1) are identical to C and L. A third condenser (C_2) is also added to the output of the filter system.

The graphic line between points B and C, at the top of Fig. 50, shows how the fluctuations are partially filtered out by the first choke and condenser. That portion of the line between C and D shows all remaining irregularities entirely smoothed out by the second condenser and choke coil (C_1 and L_1), and final condenser (C_2). The final section of the line, between D and E, shows a constant, non-fluctuating direct current, ready to be supplied to the plates of the tubes and speaker of the radio receiver.

Electrolytic Condensers Large fixed condensers are used for filtering. These are usually of the direct-current *electrolytic* type. Most condensers, as explained in Chapter Four, pass alternating currents but block direct currents. The electrolytic condenser passes a direct-current charge, but in one direction only; it really is a sort of electrolytic rectifier, as explained in Chapter Thirteen.

The electrolytic condenser, which usually has a capacity of four or more microfarads, must be able to receive the maximum charging current and voltage created by the reactor or choke coil. These condensers are either "wet" or "dry." The former type has a borax solution (*electrolyte*) in a sealed metallic container. The latter uses an electrolyte solution mixed with an absorbing material so as to form a paste.

The container is the negative contact of the condenser, as it must be connected in the circuit in but one way. A long strip of *aluminum* is coiled up in the container and solution. It is the positive contact of the condenser. When the aluminum is connected to a positive source of charging current a thin film of gas or oxide accumulates on the surface of the aluminum foil and acts as the dielectric to separate the two surfaces—foil and liquid. If the voltage is too high this film might break down at some point and a noisy discharge will be heard. Defective electrolytic condensers can be a source of annoying noises and static.

Sometimes several sheets of aluminum foil are wound in a single roll so as to construct two or more condensers in one concentrically wound condenser. A common negative terminal for all sections is used, but each positive sheet has its individual positive terminal. The use of a three-section combined condenser is illustrated in the completed power unit shown in "C," Fig. 52.

Several Voltages Required When the rectified current has been passed through the filter system, and all variations in voltage smoothed out, it is ready to be delivered from the filter output terminals—positive and negative. A potential difference will exist across these two ter-

minals, and the amount of voltage will depend upon the output of the power transformer. In most radio receivers this output is approximately 250 to 400 volts.

But a radio receiver demands several different voltages ranging from negative zero to 300 or more positive volts. In addition, certain negative potentials, ranging down to as much as 50 negative volts are required for grid and bias circuits. How can all these voltages be supplied by a power unit which has only two terminals—one negative and one positive—at its output?

The Voltage The system in a power unit whereby the sin-
Divider gle high voltage existing *across* the positive
and negative terminals of the filter output can be split up into any number of different voltages, between zero and the maximum, is called the *voltage divider* system.
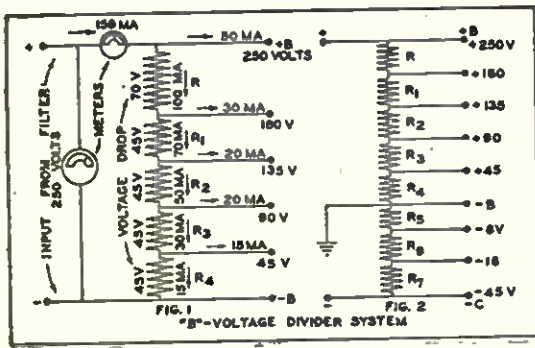

Figure 51

The design of this portion of the power circuit requires careful calculations, which, however, are not at all difficult to make. It is only necessary that we know the voltage and amperage (in milliamperes) required by the several different tube circuits of the receiver. A simple application of Ohm's Law, which anyone can work out in a few seconds, will give the values of the various resistances needed to make a voltage divider. This will be explained later.

A typical divider system is shown at "B," Fig. 51. In order that the reader may grasp how a divider is designed, it will be best for us to assume that we have a certain radio circuit which requires a number of different voltages for its operation. Let us assume, then, that this receiver has tubes that call for 250 volts, 180 volts, 135 volts, 90 volts and 45 volts. These are the positive "B" voltages. Also, a certain amount of current is required. This plate current is, of course, measured in *milliamperes*, or thousandths of an ampere.

The The power transformer, in this case, will de-
Resistors liver a maximum voltage of 250 volts. The
current rating must also be equal to or greater than the *total* plate current drawn by *all* the tubes of the receiver. This alternating current, from the transformer, is then rectified and filtered. The non-fluctuating direct-current output delivered from the filter to the voltage divider must be of the proper amount so the receiver will be sufficiently powered.

A large resistance coil is connected *across* the positive and negative terminals of the voltage divider input. It really

is a large *potentiometer*. Taps are taken off the resistance at different points between its two ends. Each tap will provide a different voltage, for the amount of voltage delivered by the taps depends upon the amount of resistance (in ohms) existing between the zero end of the resistance and the taps in question. The design of a voltage divider merely requires the finding of the proper resistance (in ohms) when the voltage and current drain at the tap in question is known.

The divider resistance is shown in Fig. 51. The taps and voltages to be taken off for the tubes in the receiver are indicated. And, generally speaking, the resistance in use is a fine coil of wire, wrapped around an asbestos covered copper wire. This resistance is then wound on a threaded fire-clay tube. Adjustable taps are clamped around the resistance tube at points where the proper "B" voltages will be supplied.

Dividing the Voltage Let us return to the divider circuit shown in Fig. 1, at "B." We see a *voltmeter* connected across the terminals. This is not done in practice, however, but simply for the purposes of explaining this text. It indicates 250 volts as the output of the rectifier and the filter systems. Also, a *milliammeter* is shown in series with the high-voltage output. It indicates a current of 150 milliamperes passing through the circuits of the receiver. The large resistor is separated into five sections—R, R_1, R_2, R_3 and R_4. The lower end of the resistor (R_4) is connected to the negative B lead which also is the ground terminal of the filter circuit. The upper end (R) is connected to the high-voltage terminal. Thus, a potential difference of 250 volts now exists across the two ends of the resistance unit.

The first section (R) of the divider must provide a voltage drop of 70 volts from 250 volts in order to obtain the 180 volts required for the first tap. Also, the top tap (250 volts) will require a current drain of 50 milliamperes (MA). Therefore, 100 milliamperes remain to supply the taps of lower voltages below the top 250-volt tap. So, in this case, a current of 100 milliamperes will flow *down* through R, which reduces the voltage from 250 to 180 for the second tap. This tap takes 30 of the 100 milliamperes now available.

Voltage Drop There now remains a current of 70 milliamperes which flows down through resistor R_1. But, as this section must have a voltage drop of 45 volts to reduce the 180 volts to 135 volts, it requires a certain resistance. Then, too, this third tap needs 20 milliamperes for its tube. There now remains a current of 50 milliamperes which flows on down through the section R_2. A voltage drop of 45 volts in this section will deliver 90 volts to the fourth tap. As 20 milliamperes are required by this tap, 30 milliamperes remain to flow down through section R_3. The voltage drop in this section is 45 volts, and, therefore the last or fifth tap provides 45 volts. The current drain at this tap is 15 milliam-

peres. There now remains only 15 milliamperes which has not been accounted for. The various taps of the divider have taken off a total of 135 milliamperes from the original current of 150 milliamperes. The remaining 15 milliamperes will be consumed by the last section of the resistance, R₄.

This final loss or consumption of current is called the *bleeder current*. It is a more or less constant load on the power unit, but is so low that it is far from being a short circuit. The bleeder current usually is rather high. It tends to act somewhat as a reservoir in case a tap should become overloaded and draw more current than normally needed.

Simple Calculations How can we determine how much resistance (in ohms) should be placed in the sections R, R₁, R₂, R₃, and R₄, in order to provide the proper potentials in volts and current in milliamperes to the various taps, and thence to the tubes of the receiver?

We must know the voltage and current supplied by the power unit, and also the voltages and currents to be delivered by all the taps individually to the various parts of the receiver. We wish to know the resistances of the various sections of the entire divider. By Ohm's Law, we find that resistance is equal to the voltage divided by the current. The calculations, therefore, are quite simple.

The resistance of section R, which has a voltage drop of 70 volts and carries a current of 100 milliamperes, is calculated by dividing the voltage by the current in amperes (70 divided by .100). It will be 700 ohms. Section R₁, by the same method (45 divided by .070), will have a resistance of 630 ohms. Section R₂, which will be 45 divided by .050, has a resistance of 900 ohms. Section R₃ (45 divided by .030) has a resistance of 1,500 ohms. Section R₄ (45 divided by .015) will have a resistance of 3,000 ohms. The total resistance of the entire divider, then, will be 6730 ohms.

Negative Voltages Radio circuits also require certain negative voltages, such as supplied by "C" batteries. It is possible to get negative voltages from a voltage-divider circuit. At Fig. 2, in "B," is shown a second series of resistors. Below —B will be seen three additional taps, marked C-6, C-16, and C-45 volts. Their total is -67 volts. But, before we can get 67 negative volts from the circuit shown in Fig. 1, at "B," we must provide a power transformer that will give 67 volts *in addition* to the 250 required for the positive "B" portion of the divider circuit. This transformer, then, must have an output of not less than 317 volts.

As shown at "B," Fig. 2, the negative B terminal is grounded. This is the zero potential point. Positive voltages exist *above* this point. This portion of the divider circuit is identical to that shown in Fig. 1, of "B." We will get the negative C voltages *below* the grounded or zero potential

point of the circuit. The arrangement of resistors is as follows:

To obtain a negative potential of -6 volts, we find, by dividing the voltage drop of 6 volts by the *total* amount of current carried in the divider circuit (6 divided by .150), that a resistance of 40 ohms will provide the negative voltage from the seventh tap. This resistor is section R_5, shown in "B," Fig. 2.

Resistor R_6, with its voltage drop of 10 volts to give -16 volts for the next or eighth tap, (10 divided by .150), has a resistance of 67 ohms. Resistor R_7, drops the voltage from -16 to -45. Therefore, its 29-volt drop divided by the total current (29 divided by .150), gives us a resistance of 193 ohms.

Complete Power Unit   This completes the voltage divider circuit. If the foregoing rules have been followed carefully it will not be difficult to design a voltage divider circuit for any receiver operating under all conditions of voltage and current demands. However, in order that the reader may see how the complete unit looks in the circuit, let us take the power transformer shown at "A," Fig. 46 page 68; the tube rectifier shown at "C," Fig. 48 page 72 in the same chapter; the filter system shown at "A," Fig. 50, and the voltage divider shown at "B." Fig. 51, and combine the *three systems* into a *single* complete power unit. The power unit, shown at "C,"
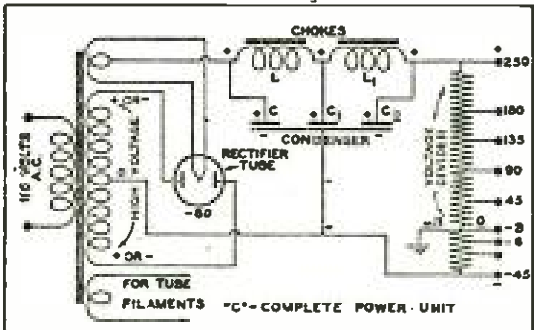

Figure 52

Fig. 52, will be recognized in any radio circuit diagram, with perhaps, just a few variations. The basic principles, however, will not be changed.

Chapter Fifteen

The Reproduction and Control of Sound Sound waves travel very slowly when compared to the swiftness of radio waves. The speed of a sound wave through the atmosphere is approximately 1,100 feet a second. Radio and light waves can travel nearly a million times that far during the same interval of time. A radio wave from a broadcast station that is thousands of miles distant will speed through space to your radio receiver in less time than it takes the resulting sound wave to pass from the loud speaker to your ears.

A striking comparison of the speeds of radio and sound waves frequently is demonstrated by a distant flash of lightning during a thunderstorm. Although the brilliant lightning discharge will be seen at the same instant its static crash is heard in the loud speaker, the sound of its thunder will not reach the listener until some seconds later. If you allow five seconds for each mile the sound of the thunder has to travel to the observer, after the static wave has been detected by the radio set, the spot where the lightning struck can be determined.

The rapid vibrations of a radio broadcast wave occur at radio frequencies. These are far beyond the audible limits of the human ear. It is the slower audio frequencies, which really are sound waves *unscrambled* from the r.f. carrier waves, that bring the *sounds* of the broadcast to our ears.

The Telephone Receiver But these audio-frequency waves must first be sent into a device that will communicate its mechanical vibrations to the air so as to set up sound waves that will affect the drums of our ears. The device that is used to create the mechanical motion which will set the air adjacent to the radio receiver in vibration is called a *telephone receiver*.

The telephone receiver, familiar to us all for many years, still hangs upon the arms of our desk and wall telephones. It is crude and has changed but little from its original. Its only purpose is to make the electric waves that travel along the wires from the mouthpiece or transmitter audible to us. The telephone receiver that is used for radio reception is a refinement of the well-known type, but its principle remains the same.

The average telephone receiver consists of a long bar magnet. A coil made of many turns of fine wire is wound around one end. A small disc of thin iron is centered over one end of the magnet, but its circumference is firmly clamped between the *shell* of the receiver and the screw cap. The center of the disc or *diaphragm* does not quite touch the end of the bar magnet and, therefore, bends inward under the pull of the magnet, but still is free to vibrate.

A Vibrating When an audio-frequency current, which
Diaphragm may come from either another telephone
(which corresponds to the microphone in the broadcasting
studio) or from the audio output of a radio set, passes
through the coil of wire that is wound around the magnet,
it creates a fluctuating electromagnetic field that alternately
strengthens and weakens the permanent *pull* exercised by
the bar magnet on the center of the diaphragm. This causes
the iron diaphragm to *vibrate* in exact unison with the
diaphragm in the transmitting microphone. The ear cap of
the receiver has a central opening so that the vibration of the
disc will be communicated to the air, and thus reproduce the
a.f. electric waves as actual sound waves.

The ordinary radio or wire-
less *head telephones* are not
single bar-magnet types of
receivers such as are used in
connection with our home
and office telephones. They
are small *watch-case* type
telephones. A typical receiver
is shown at "A," Fig. 53. This
type has a *bi-polar* perma-
nent magnet that is shaped
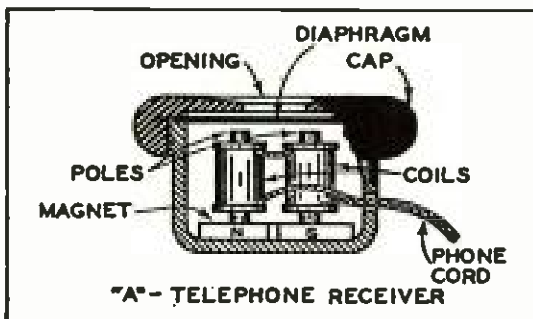like a letter U. The container

"A" – TELEPHONE RECEIVER

Figure 53

or case usually is made of aluminum; the cap is hard rubber
or composition. Two bobbins of fine wire are slipped over the
two soft-iron pole pieces of the permanent steel magnet.

How the When the a.f. current from the power output
Phone Works of the radio set passes through the two coils
it varies the constant pull of the magnetism in the perma-
nent magnet. This causes the diaphragm to bend in more or
spring farther out. Vibrations are developed when the dia-
phragm is irregularly displaced by the fluctuations of the a.f.
current. Thus sound is reproduced. A previous discussion of
the average current flowing through a telephone receiver will
be found in Chapter Eight.

The pull of the electro-magnet in the telephone receiver
tends to bend the diaphragm in proportion to the current
flowing through the coils. This force is controlled by the
strength of the a.f. current flowing through the turns of wire
in the two coils.

Ampere- A large wire will carry more current and,
Turns therefore, it is best to use as large a wire as
possible. But we also must have a great many turns of wire
to build up a strong magnetic field. The relationship between
the large number of turns and the current carrying capacity
of the wire is known as *ampere-turns*. We must get as many
ampere turns as possible in a small space. In practice, these
coils are wound with No. 36 to No. 40 wire. The windings
have considerable resistance, usually 1,000 ohms per unit.
As two units are connected in series and held to the ears by

means of an adjustable *head band,* the entire resistance of the *headset* will be 2,000 ohms, or more.

Distortion · The diaphragm of a telephone receiver, vibrating in *step* with the fluctuations of the audio current, sets the surrounding air into a wave motion. This action communicates sound to the ear. The average headset produces its greatest volume only when the audio frequencies range from about 300 to 1,000 cycles a second. Higher frequencies prevent a strong vibration at the center of the diaphragm because the metal does not have time properly to vibrate vigorously. Thus the *amplitude* of the sound waves that are produced will be considerably lessened. A telephone receiver, therefore, cannot reproduce sound faithfully over the entire range of audio frequencies.

When more power or voltage is used so that the higher frequencies (high notes) can be strengthened, the subsequent *super*-amplification of the lower frequencies (low notes) will cause *distortion.* A very thin diaphragm will bend more at the center and give more amplitude and greater volume on the rapidly vibrating high notes. But it will be a poor reproducer for low notes. A thick diaphragm will work well on low notes, but because of its inertia and rigidity will not vibrate rapidly and strongly enough to respond well to high notes.

The headset or telephone receiver, therefore, is not the best reproducer of sound having a good fidelity. It is subject to distortion and fails to give faithful tones. It does not have the proper tone to make it satisfactory for all radio reception. However, because of high sensitivity and the ability to place the pair of headphones close to the ears so as to shut out external sounds, the headset is without an equal when it comes to picking up weak and distant signals.

The Phone There are several methods of connecting
Adapter headsets to radio receivers. If telephones are to be used then certain circuit changes and alterations are required. These are more or less difficult for they are associated with mutilation and the danger of burning out portions of the radio set. High potentials are present in these circuits and there is some risk of electrical shock.

An *adapter* device now offers the opportunity to cut in a telephone headset at will to those who desire to quiet the loud speaker and use telephones with modern a.c. sets in order to experience the thrills of distant reception. It is all very simple and permits the phones simply to be plugged into the receiver without circuit alterations. This phone adapter is quickly installed in any all-wave or broadcast receiver. The power tubes are removed and then re-inserted into an adapter *plug* that is placed in the power socket from which the tube was removed. A *phone-jack* is attached to this adapter-plug by means of a flexible cord. A small box containing the jack is then placed at some convenient location in

the cabinet, and the headphones plugged in when desired. The speaker is instantly and completely silenced.

But the volume of sound from a telephone receiver is not sufficient to make listening possible for several persons. Early methods included the attaching of a large horn to the telephone receiver cap. This developed the horn type of *loud speaker* and made radio signals audible without the need for close fitting headsets. Undesirable features were present—distortion and lack of tone fidelity, and the volume was weak.

Magnetic Loud Speakers The first important loud speaker improvement came with the development of the *cone* type of diaphragm. The cone is a large-diameter flat cone made of stiff paper or parchment. It is lightly supported around its edge; not tightly clamped as is the case with the telephone diaphragm. The center or *apex* of the cone is attached to a pin or *driver*. This, in turn, is attached to an arm of soft iron that is balanced freely between the tips of the two poles of the electro-magnet. Audio-frequency current passing through the magnet's coils cause the armature to vibrate similar to the diaphragm of a telephone receiver. This vibration, however, is communicated to the cone by means of the driving pin at the apex.

The cone speaker, usually known as a *magnetic speaker*, has a higher fidelity of tone than the telephone receiver. It is used extensively with battery sets. At higher frequencies (high notes) the center of the cone vibrates; at the lower frequencies (low notes) the outer edges of the cone vibrate. Thus, various notes, from the lowest to the

Figure 54

highest, appear because of the vibration of different areas of the cone's surface, from the outer edge toward the center, respectively. A magnetic cone speaker is shown at "B" Fig. 54.
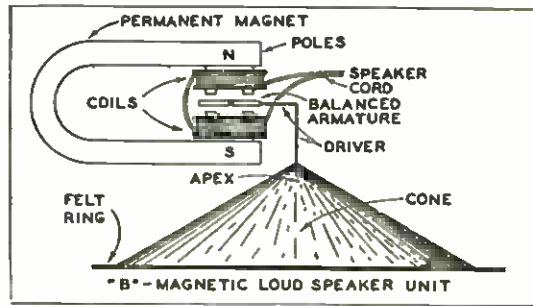
Dynamic Loud Speakers Power receivers, such as modern a.c. sets, have a strong signal output which requires large, responsive speakers. The *dynamic* type of speaker revolutionized the radio industry, and practically every radio receiver now uses the dynamic principle. These speakers are capable of the highest fidelity of tone reproduction. A dynamic speaker is shown at "C," Fig. 55.

Instead of using a driver pin to vibrate the apex of the cone, as shown at "B," the dynamic type employs a light coil of fine wire suspended between the two pole pieces of a powerful magnet. The magnetic field, instead of being created by a permanent magnet, is continuously and evenly excited by a powerful direct current that passes through a separate coil. This electro-magnet is the *field* magnet. Frequently this

coil is substituted for one of the chokes in the power unit. The exciting coil is known as the *field coil*.

The Voice Coil   The driving or vibrating coil, shown at "C," Fig. 55, is called the *voice coil*. It carries an audio-frequency current and, because its surrounding magnetic field tends to vary in strength according to the fluctuations of current it carries, it will be *displaced* from its normal position at rapid intervals. This displacement or swinging effect, in step with the a.f. current fluctuations, causes the coil to vibrate as if it were a diaphragm in a telephone receiver.
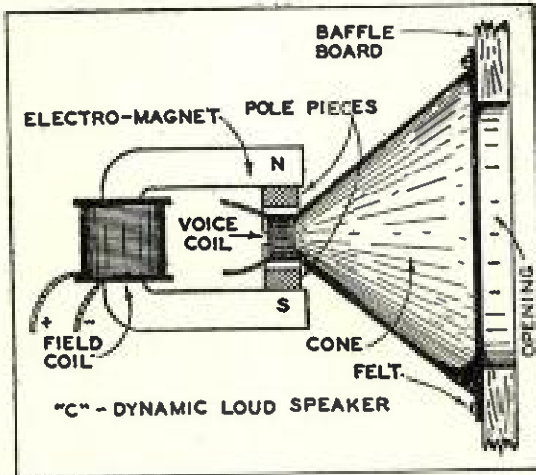

ELECTRO-MAGNET   POLE PIECES

BAFFLE BOARD

N

VOICE COIL

S

+ −

FIELD COIL

CONE

FELT

OPENING

"C" – DYNAMIC LOUD SPEAKER

Figure 55

The motion is transmitted to a cone to which the coil is permanently attached at the apex. The apex is a stiff paper *collar*. It is a part of the cone. The outer edge of the cone is glued to some soft material, such as wool or felt, and is then clamped by a metal ring to the housing of the speaker unit. The whole is then bolted to a large board or *baffle*. This gives additional vibrating surface and brings out the deep, low notes that appear in the frequencies below 300 cycles. Sometimes two dynamic speakers, of different diameters, are used simultaneously.

Volume Controls   Up to now we have made no provision for the control of volume. By this we mean the output of sound coming from a telephone receiver or a loud speaker. The intensity of sound can be varied from the lowest to the highest possible volume by means of a *volume control*.

An early form of volume control, now seldom employed, was a variable resistance placed in the "A" battery circuit. This *rheostat* varied the electronic emission within the tubes so the volume of sound could be controlled. Filament control methods have serious disadvantages because the tubes seldom operate under proper filament temperatures. Distortion and lack of sensitivity is the inevitable result. Such forms of control in old radio sets should be replaced with more modern means.

Perhaps the control of volume by varying the *grid bias* or negative "C" potential, to the tubes of the r.f. amplifier of any set is one of the most simple methods. The action of the control-grid in a tube has been explained in Chapter Six. We learned how the flow of plate current can be *decreased* if the negative condition of the grid is *increased*. Therefore the volume of sound will be *reduced* if we increase the nega-

tive bias on the grid of a tube. The volume control device used in this case is a *potentiometer*.

Other   Many receivers control volume by varying
Methods   the screen-grid potential applied to the screen-grid tubes. Frequently two or more of these tubes have their screens connected together, and the voltage is varied from as low as 10 to as high as 75 volts. The amplification will *decrease* as the screen-grid potential also is *decreased.*

It is possible to control volume at the audio amplifying end of the circuit. A potentiometer having a resistance of from 300,000 to 500,000 ohms is connected across the two terminals of the secondary of the audio-frequency power transformer. The variable arm of the resistance connects to the grid of the following power tube.

A volume control, which can be placed in the antenna circuit, consists of a high resistance connected across the antenna and ground. Changes in resistance will vary the strength of the antenna signals sent into the receiver. A potentiometer resistance of 10,000 or more ohms is used, and the variable arm will take off antenna current of any strength between minimum and maximum intensity.

Automatic   The greatest stride toward volume perfec-
Volume   tion has been the *automatic volume control.*
Control   All receivers, of course, are built with manual volume controls. This is necessary because it is desired that a pleasing volume of sound be selected by setting the control to suit the individual. Volume, unfortunately, has the bad habit of *fading* quickly *booming* forth, particularly the latter, when the dial tunes station after station.

Automatic volume control maintains this *selected* signal intensity at a constant sound level. Fading, as we know, causes signals intermittently to fall off in strength so they cannot be heard. Automatic volume control can not eliminate all fading for, should a radio signal become so weak that it can no longer affect the tubes of a receiver, the A. V. C. system cannot amplify a signal that does not exist in the antenna. But, in nearly all cases of fading, the A. V. C. system boosts up the fading signal and holds it at an even level as it returns to its normal intensity. As the incoming signal gets stronger, the A. V. C. does not permit the volume to get too loud. All signals can be held at a constant level because the volume cannot increase beyond that selected by the setting of the manual volume control device.

A. V. C.   Automatic volume control, in most cases, is
Operation   applied to the r.f. and i.f. amplifying tubes of a receiver. The A. V. C. circuit automatically regulates the negative voltage applied to the grids of the tubes in question. If we *increase* the negative bias impressed upon the grids of the tubes we shall then *decrease* the conductivity of the tubes; the plate current drops and, consequently, the volume is diminished.

The automatic change of grid bias applied to the amplifying tubes is brought about by an additional tube — the A. V. C. tube, or by a dual-purpose tube or by a system of resistances. Incoming radio signals, which fade and vary in intensity, are applied to the A. V. C. tube. They cause changes in its plate current. These changes, in turn, are made to vary the amount of potential applied to the control-grids of the r.f. or i.f. tubes, and tend to hold the amplification at a constant level. We find, then, that a *weak* radio signal automatically brings about a *decrease* in the grid bias applied to the r.f. or i.f. tubes. This, as a result, *increases* their amplification and thus boosts the signal *up* to its predetermined level. A *strong* signal to the A. V. C. tube has the opposite effect; it *increases* the grid bias and thus *decreases* the amplification action, and holds the signal *down* to its proper level.

Quiet A. V. C. Action   *Quiet* automatic volume control, known more briefly as *Q-A. V. C.,* is a recent achievement. When an amplifier circuit of a radio receiver steps up its amplification rate to maximum sensitivity there also will be an increase in *noise* amplification. The new, quiet system tends to give greater sensitivity to weak signals while at the same time it decreases the *noise-level* in the receiver. *Noise suppression* is a newcomer in the field of *high-fidelity* sound reproduction.

Noise suppression makes use of a new circuit known as the noise gate. The action of the noise gate is to *close* the audio-frequency amplifying circuit of a receiver to all incoming signals during periods when stations are being tuned in. The fault with A. V. C. was that, between station signals, amplification quickly stepped up static and tube noises. But, with the noise suppression system, all *inter-station noise* is eliminated, and the receiver will be silent while station signals are absent. The action of the noise gate is explained below.

Visual Tuning   *Visual tuning* is accomplished by means of a *meter* or a *glowing light*. The meter indicates the maximum volume of current flowing in a circuit *after* a radio signal has been correctly tuned in. A glowing tube, such as a *neon lamp,* is commonly used for visual tuning. Maximum resonance to a tuned signal is indicated by the *brilliancy* of the light, or the length of a ray of light projected from the lamp.

A visual tuning device depends entirely upon the development of a proper operating voltage within the neon tube. When no signal comes in from the antenna the voltage across the tube will be insufficient to create the characteristic glow that is developed by ionization of the inert gas. The greater this ionization the more brilliant will be the glow from the tube. Now, this changing intensity in brilliancy or in the length of a projected ray of light enables us to use a noise gate for the suppression of noise. As the glow be-

tween the elements in the neon tube increases to maximum when a station is tuned in there will be a discharge when a certain brilliancy is reached. This discharge, or flow between the tube elements is the switch effect that starts current to flowing in the audio amplification circuit. This sets the audible portion of the receiver in action. In other words, the noise gate is *opened* suddenly with the tuning in of a signal. The moment the signal is tuned out the neon-tube brilliancy fades away, and the conductivity of the tube ceases. The audio system is again locked.

Tone Control There are times when it is desirable to accentuate high or low notes coming from a speaker. *Tone control* enables us to fix the pitch of the tone to suit conditions. The most simple method is to connect two or three small bypass condensers in parallel between the audio-frequency output of the power transformer and the ground. These condensers are then connected—one, two or all three together—at will by means of a switch. The small capacity of one condenser will pass only the highest audio frequencies and thus eliminate them from the audio output and speaker circuit. A double capacity will pass slightly lower frequencies; and all the capacity (three condensers) in use will short the high notes or frequencies, and thus permit the deep, low notes or frequencies to become prominent.

Chapter Sixteen

Antenna and Ground The antenna or aerial — whichever you choose to call it—leads a rather uneventful existence. It is a simple device, and has only a single purpose in life. The antenna must intercept and collect energy from the radio waves that come its way. But it must perform this duty well, for, when the antenna fails properly to function, it is impossible to get the full measure of usefulness from our radio receivers.

Attach your radio set to a bed spring, bird cage, window screen, dishpan, wire fence, tin roof or automobile body, and the usual programs will be heard. Neither the nails in our homes are too small, nor miles of railroad track too long or heavy, to intercept radio signals. But there is a happy medium which provides the ideal antenna size, as the reader shall learn.

It is commonly known that, if a length of wire be moved quickly across the face of a steel magnet so as to pass through its magnetic field, a surge of electric current will be induced in the wire. This is the simple principle of electro-magnetic induction. Because of it the electric dynamo and magneto can generate an electric current as its armature, wound with many turns of wire, spins rapidly between the magnetic

poles of the machine. The action of an antenna was discussed and illustrated at considerable length in Chapter Seven.

Selecting the Signals The duty of a radio receiver is to select, or tune in, one at a time, the different radio-frequency currents flowing through the antenna. A highly selective set will separate the many different antenna currents, tuning out all unwanted signals, and permitting only the selected wave to enter the set for amplification. A non-selective set will make audible many of the different currents flowing in the antenna, and the result is interference and a jumble of meaningless sounds.

When an antenna is thoughtlessly constructed of any indefinite length of unsuitably sized wire, supported with little or no insulation between improper hangers, and connected to the receiver by poor contacts, it cannot be expected to give good results. Location, height above ground, length, insulation, arrangement of overhead wires and the design of its lead-in conductor, play important parts in making possible good radio reception on all wave lengths. The best antenna is never too good. And we must be on guard constantly to prevent energy losses. The amount of local static picked up from nearby sources must be held down to a minimum. Electric machines, light switches, power lines, street cars and automobiles, are the worst offenders in this respect.

"Skin Effect" Resistance Antennas of unusual length serve no practical purpose. The length of an antenna has a direct relationship to the wave lengths it will pick up. This tends to weaken or eliminate many of the waves that could otherwise be intercepted. Radio-frequency currents, because of the high rate of their alternations, travel on the surface of a wire. They do not penetrate into the solid interior. A copper tube is as good a conductor of high-frequency currents as a solid wire of the same diameter. In fact, an iron wire with a thin copper-plated surface is just as good for an antenna as a solid copper wire.

The wire presents a high surface-resistance to the flow of induced radio currents. This also is known as the "skin effect" of the wire. To overcome this, antenna wires are woven or *stranded* so as to present a larger area than a solid single wire. It must be remembered that the lead-in wire must also have a surface area equal to the wire or wires in the antenna top; otherwise it will introduce objectionable resistance in the down lead and partially nullify the conductivity of a good antenna top.

Antenna Insulation Insulation is of prime importance. The very high frequencies at which the induced currents in the antenna alternate back and forth, particularly on the short waves, permits the electricity accumulated in the antenna to leak off rapidly to the earth. Most readers know that it requires only a very small condenser capacity to pass high-frequency currents. The smallest capacity or con-

denser effect between the antenna wires and adjacent grounded surfaces carries a portion of these high frequencies off to the earth. Short-wave reception calls for careful consideration of the subject of antenna insulation. The higher the frequency of an electric current the more difficult it is to control and hold in place by means of insulation.

Antenna Height The effective height for the antenna still is a debated subject. The wire should be far enough above the surface of the earth, or the metal roof of a building (such a roof is considered an earth surface) to prevent condenser effects. The antenna should reach up into the unobstructed sweep of passing radio waves. Adjacent tall buildings, and other nearby obstructions, tend to throw an electrical shadow that prevents an otherwise good antenna from collecting a maximum amount of energy.

Location and Noise Location of the antenna is important under certain conditions. In the open, far removed from electrical machines, power lines and other local sources of "man-made" static noises, any antenna will work nicely. It is in the city, and congested areas, that we hear the annoying hums, buzzes, clicks, crashes, sputters and howls of local static impulses. Fortunately, however, this form of noisy disturbances does not carry very far, and will not be picked up by the antenna when it is from 50 to 100 feet from the source.

We are forced to accept natural static or "atmospherics." Such static is heard during hot, humid weather, and during the thunderstorm season. Lightning static is the worst type of static discharge there is. Clear, cold weather, such as winter nights, is always free of natural static. There is no antenna system that can check or prevent natural static. The only solution is to tune to powerful stations so the volume controls are at a minimum. This keeps the ratio of static noise to signal strength low enough to drown out much of the static.

FIG. 1 – OUTDOOR ANTENNA WITH ORDINARY UNPROTECTED LEAD-IN

Figure 56

But there is something we can do about man-made static. Let us look at Fig. 56. It shows a standard flat-top "L" antenna of the old Marconi style. The lead-in passes down through a field of local static impulses that do not carry very far. These tiny electric waves impinge on the antenna lead and the static surges are carried into the radio receiver. The antenna itself is removed from this static field and does not pick up the impulses.

Noise-Reducing Antennas Now we can place a metallic shield around the lead-in wire. It will prevent the static impulses from reaching the wire. This is shown in Fig. 57. This form of shielded lead-in is used on
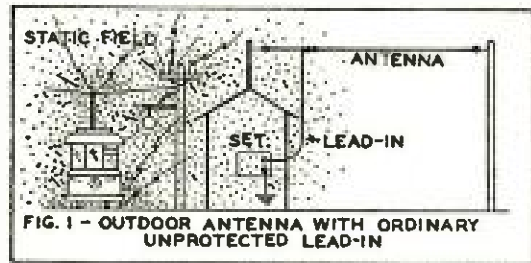
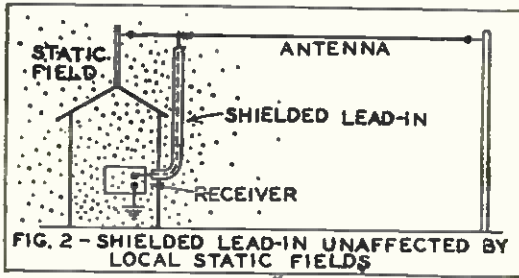standard antennas, such as the "L" and "T" types shown in Figure 58.

FIG. 2 – SHIELDED LEAD-IN UNAFFECTED BY LOCAL STATIC FIELDS

Figure 57

With the coming of interest in the short waves the question of noiseless short-wave, and all-wave, antennas, is being seriously considered. In all cases the noise-reducing antennas operate on the so-called Hertz principle. Hertz was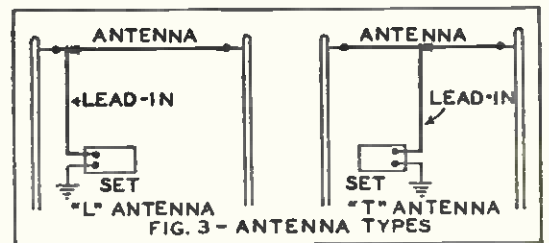 the discoverer of the method of sending and receiving electrical oscillations through the air for short distances. Marconi discovered the practical application of using these waves to send messages over long distances. The Hertz antenna is older than the Marconi antenna, such as the conventional "L" and "T" antennas shown in Figure 58, which use a ground connection.

The "Doublet" Antenna The Hertz antenna, simply stated, consists of two antennas or *horizontal* wires, with the radio receiver inserted in series in the center. There is no ground connection. This type is useful in short wave reception but can also be used for broadcast work. Thus it is an "all-wave" antenna. The single wire, and grounded, Marconi "L" or "T" top antennas are best only for

long and broadcast waves. However, we cannot place the receiver high up in the antenna, so we insert an insulator between the two halves of the antenna, as shown in Figure 59. The two sections are called "doublets," and the antenna becomes a doublet antenna.

FIG. 3 – ANTENNA TYPES

Figure 58

Some change must now be made so the lead-in will not pick up local static in the noise zone close to the ground.

The doublet antenna, which is very effective on short waves, can be turned into a noise-reducing antenna, by preventing its lead-in wires from being affected by the local static field. Some designs favor a twisted-wire transmission line or lead-in; others place the two wires within a metallic, flexible shield.

Shielded Leads The shield is grounded and tends to prevent local static impulses from reaching the receiver. Some makes of antennas use two lead-in wires, transposed and separated by insulating blocks, as shown in Figure 59. This is called a transposition lead.

When a metallic shield is placed over the lead-in from the antenna, as shown in Figures 56 and 57, it grounds

local static impulses before they get into the lead-in wire. The metal shield should extend only through the zone of static and not always entirely up to the antenna itself. Do not use more shielding than is necessary to get results. The shielding must be grounded directly, and *not* to the ground terminal of the receiver.
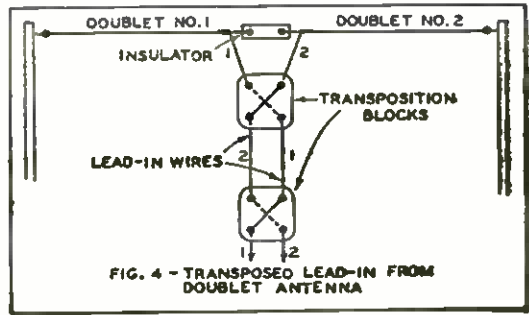

Figure 59

Transposed Leads   In order to bring the lead down from the flat top of the Hertz antenna, with its doublets outside the local static field, and eliminate the signal absorbing effects of a metallic shield, the transposed lead-in transmission line is used. The method of transposing the two leads is shown in Figures 59 and 60.
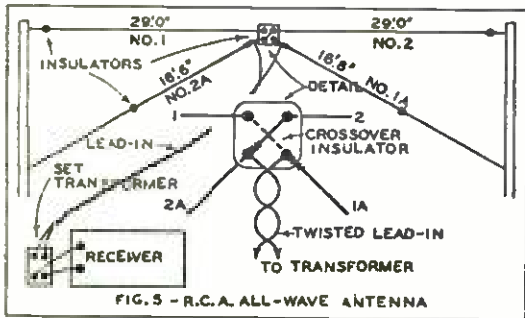

Figure 60

The two leads are transposed every 15 or so inches by means of the transposition blocks shown in Figure 59. The spacing must be carefully arranged throughout the construction. If a voltage is induced in the lead-in wires, as they pass down through the local static field (shown in Figures 56 and 57), the potential immediately will be canceled out. This cancellation effect is a rather complicated electrical phenomenon, but it is sufficient to state that it is caused by the fact that the voltage induced in one wire is not in phase with that induced in the adjoining wire. The antenna lead-in shown in Figure 60, uses a specially twisted pair of wires. Any static pickup in this transmission line as it passes down through the zone of man-made static between the double-doublets and the radio receiver, will be balanced and electrically neutralized.

Transformer Coupling   Shielding can also be applied to the twisted, double-wire lead from a doublet antenna. Some experimenters have found, however, that the losses are so severe that steps must be taken to overcome them. The transformer method of coupling the antenna to the receiver has become almost universal. In some cases a transformer is attached to the antenna top and another placed close to the receiver, and other cases use a single transformer at the radio receiver. This scheme is shown in Figure 61.

The two leads from the Hertz antenna really are part

of the antenna, for they permit the receiver to be placed in the center of the wires. Twisting of the lead-in wires eliminates signal pickup and does not add to the natural wave length of the antenna top.

Using Transformers A shielded lead-in introduces capacity action between the outer metallic shield and the inner wire or pair of wires. Such condenser effects cannot be prevented, but it is possible to lower the potential of the signal picked up by the antenna. A small *step-down* transformer or coupler is placed between the antenna-top and the lead-in, as shown in Figure 61. Lowering the signal voltage tends to reduce the capacity effect. It is then a simple matter to increase the potential again by means of a *step-up* transformer connected between the lead-in and the receiver. The coils of the transformers contain 12 turns and 5 turns of No. 22 wire wound on a tube about one inch in diameter, the whole being shielded in a can.

FIG. 6

TRANSFORMER COUPLED ANTENNA

Figure 61

All-Wave Antennas With the short waves beckoning, an antenna erected to bring in signals over a wide range, between five and 600 meters (60,000 to 500 kilocycles, respectively), is called an *all-wave* antenna. It can be used with any of the all-wave radio receivers now sold. In fact, some of the newer sets have separate all-wave doublet antenna terminals and built-in coupling transformers.

The shortest possible antenna is one that will just hold a *complete* rise and fall of current or half a wavelength. An antenna, with its length equal to a half-wavelength of the signal in question, will be resonant to that signal and pick it up with a maximum amount of energy. Assume the wave length of the signal to be 19 meters: A half-wave is 32 feet, and a quarter-wave is 16 feet. The shortest effective resonant length of a Marconi antenna, then, is 32 feet; and, if a doublet or Hertz type is used. each half should be a quarter-wave, or 16 feet, long.

Since we cannot build an elastic antenna so as to provide different lengths equal to half the wavelength of the signal being received, we must be contented with an antenna of a length that will be *approximately* one-half of the wavelengths of a good many stations.
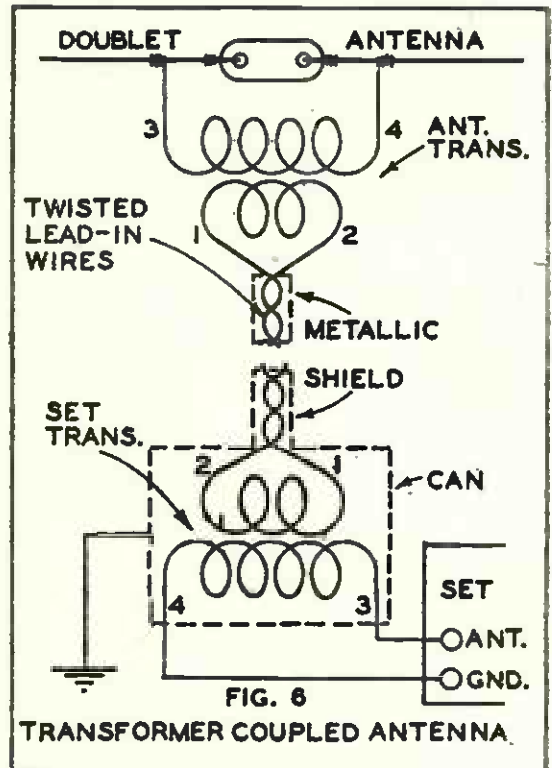
It has been found that a 41-foot antenna of the "L" or "T" type, or a doublet antenna with each half measuring 20½ feet in length, will work well on wave lengths of 13, 16, 19, 24, 31, 49 and 70 meters. These are the most commonly used short-wave bands to which we listen.

Directional Effects   A single-wire antenna, such as the Marconi inverted "L" type, has definite directional qualities. It tends to pick up signals best from stations toward which its *heel* or lead-in end points. Sometimes the "L" antenna receives best if it is *tilted* by raising its open or free end higher than the lead-in end. This slant may vary from 15 to 35 degrees from the horizontal.

The doublet antenna, however, should be erected *horizontally* in all cases. It receives best when placed at right angles to the direction in which the station lies. This must be remembered when erecting a doublet for short-wave reception only.

The Loop Antenna   A directional antenna can be made by building it in the form of a diamond-shaped *loop*. The frame should be mounted so it can be rotated. The loop antenna will receive best when its vertical plane lies in the line that points toward the location of the stations to be received.

On shipboard, the loop antenna is valuable as an efficient direction finder. The loop can be rotated so that land stations can be heard. From the angular positions of the stations noted, by means of intersecting lines drawn on a chart, the position of the vessel can be determined.

A support, 5 feet high, fastened to a base so it can revolve, and with a cross arm four feet long, is used for the loop. A single No. 14 copper wire is strung around the frame. The two ends connect to the receiver, as shown in Figure 62. This loop, of course, is limited in its pickup of distant stations, but is valuable as a means to cut through interference from nearby stations that lie in other directions.

The "Double Doublet"   The *double doublet* system is a radical departure from the usual doublet type. We know that a doublet antenna is an efficient collector of short-wave signals. A doublet antenna, each section of which is a quarter-wave long, is more efficient at or near the point at which it is resonant to the incoming wave. An antenna 33 feet long, therefore, works best when receiving signals of 20 meters in length, or the harmonics of higher wave lengths. This means, then, that the antenna also will pick up signals of 40, 60, 80 or 100 meters, of which the fundamental length of the antenna is the second, third, fourth and fifth harmonics, respectively. (See Fig. 60).

The antenna proper consists of *two* long, horizontal sections, each 29 feet long. Immediately below, and in the same vertical plane, are two short sections, each 16½ feet long. They are *tilted* down from the center of the top doublet at
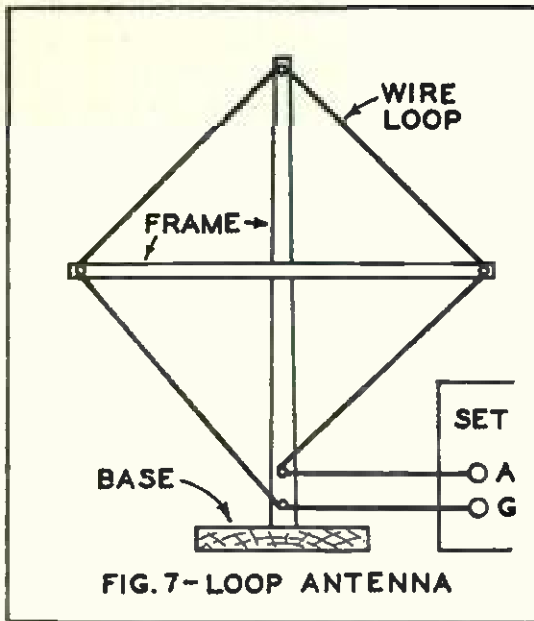
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FIG. 7 – LOOP ANTENNA

Figure 62

an angle of about 35 degrees. The left, long section connects to the same lead-in wire as the right, lower short doublet; and the right, long section, to make one unequal section goes to the same lead as the left, lower short section to make the second unequal doublet. A special insulating crossover block is used for these connections.

Any type of doublet antenna will be greatly improved if a coupler is used. It can be used with the types of antennas shown in Figures 59, 60, 61 and 63. Only one coupler is required. It should be connected directly to the radio set, and tuned by the pin jacks which are plugged into several holes so that the impedance of the coupler can be made to match the impedance of the receiver.

The "Simplex" Antenna   The "Simplex" system is shown in Figure 63. It is not a doublet antenna, in the sense that we have been discussing doublets. The lead-in cable is taken from one end instead of from the center. The antenna, too, is long, being 114 feet. It need not be erected in a straight line if space is limited, but can be zig-zagged about in order to place the entire length in a short space. The short section of the doublet is only two feet in length.

Another new doublet antenna utilizes a *parallel* pair of lead-in transmission wires instead of the shielded, twisted and transposed lines. It is said this untuned antenna does not require any definite length either for the doublet top or the lead-in wires, as is the case with all other doublet systems. The

FIG. 8 – LYNCH 'SIMPLEX' DOUBLET ANTENNA SYSTEM

Figure 63

transmission line is a pair of heavy rubber-covered wires spaced two inches apart with insulating separators.

Length is not an essential matter when this system is used. Both sections of the doublet, however, must be equal in length; if one section is 20 feet long the other must be the same. If the two sections are 30 feet in length the antenna will give best results.

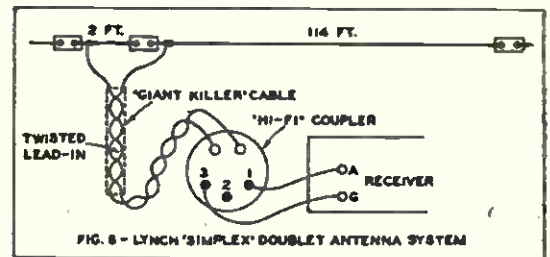For older receivers, which are not provided with doublet

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antenna connections, it is necessary to use a doublet transformer. Connection is made to the two parallel leads from the doublet, and then to the antenna and ground terminals of the receiver. The usual ground wire may be left in place. The transformer has two switch contacts; one is for short-wave reception and the other for broadcast reception. The coupling transformer is designed especially so that any interference picked up by the parallel transmission line is balanced out in the transformer instead of relying upon a twisted or transposed transmission line to perform this essential action.

The Ground   An electric current cannot flow unless a circuit can be completed. This circuit consists of two wires—one *from* the battery and another *to* the battery. As long as the circuit is closed a current will flow, but as soon as it is opened the current ceases.

Electric cars use a circuit composed of a trolley wire and the grounded *rails* upon which the cars run. Some power, telegraph or telephone lines use a single wire and the conductivity of the ground in place of two separate wires for their circuits. So it is with radio. To complete a radio circuit two conductors are necessary—either the *ground* and a single-wire antenna, or the two wires or halves of a doublet antenna.

A Counterpoise   No ground is required when a doublet antenna is used; the two halves of the doublet lead-in go to the two terminals of the receiver. This is comparable to the older type of antenna and *counterpoise* system. The counterpoise is an additional wire stretched parallel beneath the antenna. It is used with "L" or "T" Marconi type antennas when good, moist ground connections are not available. An effective counterpoise is composed of wires laid out on the surface of the ground and spread out radially in all directions. This increases the capacity effect between the antenna and the ground beneath. Dry soil is a poor ground, and serious losses of power will result.

The fundamental purpose of the ground wire is to provide a short path for the flow of the antenna current into the ground. The resistance of the soil is a question of great importance. A dry, sandy soil has many hundreds of times the resistance of wet, salty earth. The value of a good ground cannot be stressed too emphatically.

Water Pipes   Water pipes offer the best possible ground contact. They extend for miles underground and make ultimate contact with water. Any *cold-water pipe,* running within close proximity of the radio receiver, will make a satisfactory ground if it is scraped bright and clean. A low-resistance electrical contact should be made by means of a securely attached *ground clamp* or carefully soldered joint. Hot-water pipes are a second choice; steam and hot-

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water radiators and pipes come third; and gas pipes are a poor final.

However, water pipes, because of their ideal contact with the earth, may also be the source of much noise and electrical induction. In some localities power and commercial industries use single-wire power lines and favor the economical conductivity offered by the earth. This grounded electric power, during its return through the earth, will seek the path of least resistance. This, quite naturally, happens to be some convenient water main. The constant flow of heavy currents through the earth-return causes a condition known as *electrolysis*. Such action is one of the principle reasons why static noises are annoyingly present in radio receivers that are grounded to water pipes. Other electrical devices, grounded to the pipes, also reflect their static discharges through the pipes. But, out in the rural regions, where private and small water systems are used, the pipes are free from this trouble and do not prove to be a source of noisy clicks and sputters.

Making a Ground   When practicable, separate and individual grounds are best, provided, of course, they can make an earth contact equally as good as a cold-water pipe. But, when water systems are not available, other grounding methods must be designed.

The easiest method of making a ground is to drive one or more iron *pipes* into the earth. If four new, clean pipes, each from six to eight feet in length, are driven into the earth at intervals of about six feet apart and then connected together, they will provide a very efficient ground contact. Flatten the driving ends of the pipes, standard ¾-inch size, galvanized iron, to wedge points; drill a number of small holes cross-wise through the pipes at moderate intervals from top to bottom; and place a cross bolt through the top of each for connection to the single, heavy copper wire used to connect all together.

Selecting the Spot   Select a moist spot, along the edge of the house and under the eaves of the roof, and drive the pipes down to within two inches of their tops. If a salt solution is poured down the pipes it will leak through the holes and improve the moist, earth contact. This moistening operation can be repeated at infrequent intervals.

One or more metal plates (preferably copper), with heavy, copper wires soldered to them, may be buried about six feet deep in permanently moist soil. Each plate should be imbedded in a soft mud of clay, salt and water, firmly tamped in place, and then buried beneath heavy, moist earth. Other forms of grounds are but variations from the above and offer little or no improvement. The main purpose it to bring as large a surface area as possible in perfect contact with permanently wet and compact clay soil.