EDUCATION MANUAL **EM 415**

Radio for Beginners

A SELF-TEACHING COURSE

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EDUCATION MANUAL EM 415

Radio for Beginners

A Self-teaching Course, Based on Elements of Radio

Abraham Marcus,

William Marcus, and Ralph E. Horton

REPRINTED FOR

THE UNITED STATES ARMED FORCES INSTITUTE

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How to Use This Book

Prefaces to books are often not very interesting. Few people read them. But we have some things we want to tell you that will help you use this book to your best advantage in learning radio.

First of all, many of you may find it a little hard to get back into the habit of study. Most people do find it hard because it's easy to become rusty mentally. Probably the main difficulty lies in becoming accustomed to the kind of reading you have to do. Obviously, a scientific textbook is not a story magazine. You've got to read thoroughly and thoughtfully. You've got to be sure you really understand what you are reading. Even when you understand all the *words*, you may have to go back over the text two or three times to get the over-all idea. But the more you study, the easier it is to study efficiently.

Of course, it will be a big help to you if other people in your organization are taking this course. Getting together with them and talking things over will clear up a lot of difficulties. You may also be able to find someone who knows radio and who will be glad to give you a lift.

There is one problem we can't solve for you: We can't hand you a complete radio laboratory full of capacitors, coils, transformers, tubes, and what have you. We wish we could. But you can do a lot to solve this problem yourself. There are few military organizations that do not have a radio crew with them. Talk with these radio operators and maintenance men. Take a look at the apparatus. Ask questions. You may get thrown out, but probably you won't. It is your chance to obtain a first-hand working knowledge of what this book is telling you.

How much do you know about electricity? Some of you probably know quite a lot. In order not to complicate this story of radio, we have omitted any lengthy discussion of the nature of electricity and of electrical circuits. If you want to know more about these things, ask the United States Armed Forces Institute for *Electricity For Beginners, EM 416*. That course will answer all your questions about electricity and will be a valuable companion for this radio course.

Now for a few words about how the book is organized. Look through the table of contents to see what topics the chapters cover. Turn to the back of the book and find out what is there. The Appendix contains a lot of valuable material. The Glossary gives you definitions of all the technical words and phrases. It is a kind of radio dictionary for your use as you study.

You will notice that this book is *Radio for Beginners*. It is written for people who know nothing about radio. Therefore, we have tried to write very simply. We have also tried to hand out the new ideas slowly, one at a time, so that you can nail each idea down before you go on to the next one. You must get every idea in its turn, because this book is a continuous story. There are no parts that stand alone. Each idea builds on the ideas that precede it. Each idea that you learn you will need over and over again as you go on with your study.

To help you see the important ideas quickly and easily, we have done two things: we have divided the book up into short chapters--twenty-six of them. Each chapter discusses one major part of radio. Furthermore, we have carefully labeled the sections of each chapter with boldface numbered headings. Most of these headings are questions, thus: **11. What are wave frequency and wave amplitude.** These headings show you exactly what you are supposed to learn from that part of the chapter. Half of learning is knowing what it is you are supposed to learn.

As you study the book, you will want to know whether you have really learned what you are studying. You can check yourself, for we have inserted a test at the end of each chapter. These tests cover the material of the chapter and nothing else. At regular intervals in the book are longer tests that cover the material in a number of chapters. Answers to all these tests are at the back of the book.

Nobody is going to grade you on these tests. They are put in so that you can find out for yourself whether you have learned what you want to learn. Be fair with yourself. Answer every question thoughtfully, and don't look up the answers until you have decided on your answer. Above all else, if your answer is wrong, go back to the text, find the right answer, and be sure you understand why it is the right answer.

The sample examination given at the end of this book provides a review of all the important ideas that you have studied. If this sample examination shows you that you are not sure of some of these ideas, restudy the chapters in which they are explained.

And finally, feel free to write to the Armed Forces Institute, Madison 3, Wisconsin, on any point that bothers you. When you write, be sure to give the exact topic that bothers you, and the page on which it occurs.

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CHAPTER 1

Wave Motion

QUESTIONS THIS CHAPTER ANSWERS

1. *How does a wave travel?*
2. *How is wave length measured?*
3. *What is the frequency of a wave?*
4. *What is the amplitude of a wave?*

1. How does a wave travel? Radio communication, we are told, travels in *waves*. Therefore, to understand radio we must first try to understand what a wave is. If you drop a pebble into a pond of still water, *ripples* or *waves* are created, and these

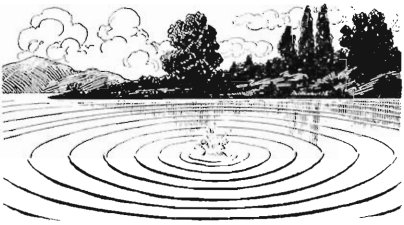


Fig. 1. Ripples caused by a stone thrown into a still pond travel in ever widening circles from the point of disturbance.

travel away from the splash in ever widening circles. If you examine these waves, you can see how they are formed and how they travel. The falling pebble, when it strikes the water, displaces, or pushes away, some water from its path, forming a sort of cavity or hollow in the pond. The displaced water is piled up all around the cavity and is forced above the normal level of the pond in a circular wall.

The weight of the water causes this circular wall to collapse to fall—and when it falls, it goes past and below the original level of the pond. This falling water, like the falling pebble, in turn

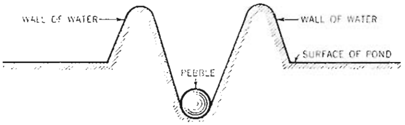


Fig. 2. Sectional view of the pond showing the crater and wall of water formed by the falling pebble.

displaces some more water, causing another circular wall to be built up a little distance away from the original cavity. This rising and falling continues on and on. The building up and collapsing of the walls of water cause the wave to travel away from the original hollow made by the pebble. Because of the resistance of the water, each wall is a little lower than the one before it,

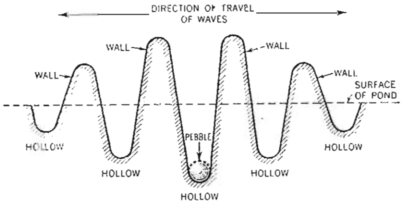


Fig. 3. Sectional view of the pond showing the series of circular walls and hollows formed by the falling pebble.

and when the wall falls, it descends a little less below the surface of the pond.

Place a small piece of cork on the surface of the pond a little distance away from where you drop the pebble. As the ripples reach the cork, it bobs up and down but does not travel on with the wave. This bobbing shows that each *particle* of water moves up and down but does not travel across the pond as the wave does.

You can better understand this behavior, perhaps, if you set up a row of dominoes. Tip the first one against the one alongside it. It will push its neighbor against the next one, and so on. The *motion* (or wave) will pass through the whole row, but each domino will travel only a short distance.

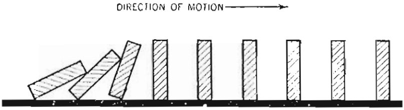


Fig. 4. A row of dominoes illustrating wave motion.

It is the *energy* caused by the weight of the falling domino that travels, not the dominoes. Similarly, in the case of the water wave, the particles of water do not travel across the pond; the energy alone does the traveling.

Obtain a fairly heavy rope about fifteen feet long. Fasten one end to a post. Now move the free end up and down. The rope

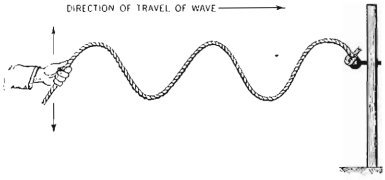


Fig. 5. Illustrating wave motion with a rope.

seems to travel towards the post. But the rope itself is not traveling—the free end gets no nearer the post. Each particle of rope is merely moving up and down. It is the *wave of energy* that is traveling through the rope from the end in your hand to the end fixed to the post.

In these examples, the water, the dominoes, and the rope are each called the *medium*. The particles of the medium move a very short distance. *It is the energy or motion traveling through the medium from particle to particle that we call the wave.*

2. What is wave length? Let us look more closely at the ripples in the pond. Recall that the pebble forms a hollow in the pond and builds up a wall of water next to that hollow; when this

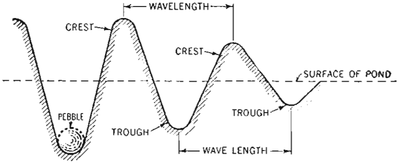


Fig. 6. Sectional view of the pond showing what is meant by wave length.

wall falls, it makes a hollow next to it; and so on. Note that the walls and hollows alternate; that is, first there is a wall, then a hollow, then a wall, and so on. The top of the wall is called the *crest* of the wave. The bottom of the hollow is called the *trough*.

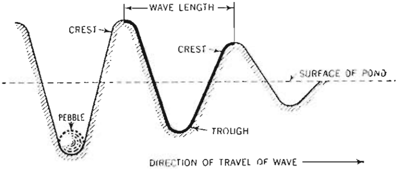


Fig. 7. Sectional view of the pond. The heavy line shows the path of the wave going through one cycle.

The distance between one crest of a wave and the next crest (or between one trough and the next trough) is called the *wave length*. At the seashore you may see waves whose wave lengths vary from a few feet up to about a half mile. You may set up rope waves whose wave lengths vary from several inches to several feet.

The *path* that the wave travels in going one wave length is called a *cycle.* This path may be from one crest through the trough and up to the next crest.

3. What are wave frequency and wave amplitude? The number of *cycles* in a given unit of *time* is called the *frequency*. Thus, an ocean wave may have a frequency of about two cycles per minute. This expression means that the wave will travel through two cycles in one minute.

If you examine water ripples again, you may notice another interesting thing about them. The larger the pebble you drop, or, the more force with which you throw it, the deeper is the

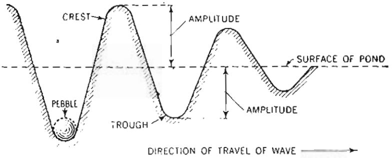


Fig. 8. Sectional view of the pond illustrating what is meant by amplitude. Notice that in this kind of wave the amplitude decreases the further the wave travels away from the point of disturbance.

hollow produced and the higher the wall of water set up. The depth of the trough beneath the normal level of the pond or the height of the crest above it is called the *amplitude* of the wave. Note that the amplitude of a wave depends upon the force producing it.

Another interesting thing is the *speed* with which a wave passes through a medium. *Since the wave travels from particle to particle in the medium, the type of medium makes a difference in the speed with which a given kind of wave will pass through it.* Thus, sound waves travel 1090 feet per second in air at 32° Fahrenheit, 4708 feet per second in water, and 15,422.5 feet per second in steel.

SUMMARY

Now let us see what we have learned so far.

A **wave** is energy traveling through a medium by means of vibrations from particle to particle.

The **amplitude** (of a water wave) is the height of the crest of a wave above the surface of the medium at rest.

The **wave length** is the distance between one crest of a wave and the next crest.

A **cycle** is the path that the wave travels in going one wave length.

The **frequency** is the number of cycles in a given unit of time.

The **speed** with which the wave travels depends upon the nature of the **medium.**

CHECK-UP

If a statement is true, encircle or check the T. If a statement is false, encircle or check the F.

T F **1.** Energy, not matter, travels through a material by means of waves.

T F **2.** The medium is the material that moves from the center of the disturbance outward to the limits of the wave.

T F **3.** For a water wave, a wave length is the distance between a crest and the next trough.

T F **4.** The path that the wave travels in going one wave length is called a cycle.

T F **5.** The number of cycles in a given unit of time is called the frequency.

T F **6.** For a water wave, the amplitude is the distance from a crest to the adjoining trough.

T F **7.** The amplitude of a wave depends on the force producing it.

T F **8.** The speed of travel of a wave through any given medium depends on the force producing it.

T F **9.** A given kind of wave, as for example a sound wave, travels through all kinds of mediums at the same speed.

Answers to this test are on page 299. Don't be satisfied with merely looking up the answers. If your answer is wrong, turn back to the text discussion and find out why it is wrong and why the correct answer is the correct answer.

CHAPTER 2

Waves in Ether

QUESTIONS THIS CHAPTER ANSWERS

1. *What is "ether"?*
2. *How do heat and light energy travel?*
3. *What is the metric system of measurement?*
4. *How does electrical energy create radio waves?*

4. What is "ether"? The first electric light bulbs were made by sealing a slender filament of wire in a glass bulb from which almost all the air had been pumped out. In other words, the inside of the bulb was almost a complete vacuum. Between the filament and the glass there was nothing but empty space. Yet, when the electricity was turned on and the wire began to glow, somehow or other light traveled across the empty space inside the bulb, through the glass, and through the air to people's eyes. But how did the light get across the empty space? Scientists tell us that light is a form of energy, and that it travels in waves; it was waves of light energy, therefore, that traveled from the glowing filament across the empty space within the bulb.

Now: since a vacuum surrounded the hot filament, what was the medium that carried the light waves? Scientists say that the space between the earth and sun is empty, or in other words, a vacuum. What medium carries light waves from the sun to the earth?

To get around the difficulty, scientists were forced to assume a medium through which the waves of light energy could pass. They called this medium *ether*. (Note that this ether is not the same as the gas the doctor gives you when he wants to put you to sleep.) Ether, as scientists use the word, is what remains in space when all substance or matter, as we know it, has been taken away. There is no proof that ether does or does not exist. Some scientists prefer to ignore it. However, since "ether" is a convenient label for the idea of a medium by which all forms of radiant energy (heat, light, radio) are transmitted, it will be used in this text. This so-called ether is the medium that transmits the light waves across a vacuum; hence it is called *luminiferous* (that is, light-carrying) *ether*.

By experimentation, scientists have learned that the light wave travels through ether at the enormous *speed* of 186,000 miles (300,000,000 meters) per second. The *frequency* of light waves (that is, the number of cycles per second) varies from 375 million millions to 750 million millions of cycles, while their *wave lengths* vary from about 15 to 30 millionths of an inch (0.000015 in. to 0.000030 in.). To find the wave length we divide the speed (186,000 miles or 300,000,000 meters) by the frequency (number of cycles per second).

5. What are heat waves? If you touch the outside of a lighted vacuum-type electric-light bulb, you quickly find that it is hot. How did *heat*, another type of wave energy, get across the vacuum in the bulb? How do the heat waves sent out by the sun reach the earth? The heat wave, like the light wave, travels through the so-called ether. Like the light wave, its *speed* is 186,000 miles per second. The *frequency* of heat waves varies from 750,000 millions to 375 million millions of cycles per second; hence their *wave lengths* vary from about one hundredth to 30 millionths of an inch (0.01 in. to 0.000030 in.).

Waves of energy which move in the so-called ether as a medium are known as *ether waves*. Light and heat are two forms of energy which travel by ether waves.

6. What is the metric system of measurement? At this point it should be explained that scientists prefer the *metric system* to the *English system* for the measurement of length. Under the English system you know that

12 inches = 1 foot
3 feet = 1 yard
1760 yards = 1 mile

In the metric system the unit of length is the *meter*, which is slightly more than a yard long (39.37 inches). In this system of measurement the prefix *deka-* means ten, *hecto-* means hundred, *kilo-* means thousand, and *mega-* means million. Similarly, *deci-* means a tenth (1/10), *centi-* means a hundredth (1/100), *milli-* means a thousandth (1/1000) and *micro-* means a millionth (1/1,000,000). Thus a *kilometer* means 1000 meters, and a *millimeter* means 1/1000 meter.

The following table may help to make clear the relationships among the various units of the metric system:

10 millimeters (mm)	=	1 centimeter (cm.)
10 centimeters	=	1 decimeter (dm.)
10 decimeters	=	1 meter (m.)
10 meters	=	1 dekameter (dkm.)
10 dekameters	=	1 hectometer (hm.)
10 hectometers	=	1 kilometer (km.)

The relationship between the metric and English systems can be seen from the following table:

1 inch	=	2.54 centimeters
39.37 inches	=	1 meter
0.62 mile	=	1 kilometer

The prefixes used in the metric system for length are also used to measure other values; thus, 1000 cycles becomes a *kilocycle* (kc.), and 1,000,000 cycles a *megacycle* (mc.). When we say that the frequency of light waves varies from 375 million millions (375,000,000,000,000) to 750 million millions (750,000,000,000,000) of cycles, we may express these numbers as from 375,000,000 megacycles (mc.) to 750,000,000 megacycles.

We have taken time out to explain the metric system because you will constantly come across this system of measurement in your scientific studies. As a matter of fact, the frequencies of the radio waves from the various broadcasting stations are usually listed in kilocycles (1000 cycles). Thus the frequency of a station may be 710 kc. (710,000 cycles) per second.

7. How does the energy of magnetism travel? For the light and heat types of ether waves, special organs of our bodies, such as eyes and other sense organs, act as *receivers*. However, other forms of energy are transmitted through the ether; we cannot detect these with any of our unaided senses. We must therefore devise special instruments that can change such forms of energy to types which our senses can perceive.

To see the effect of one such type of energy, balance a magnetic needle on a pivot (a magnetic compass will do) and near it suspend a coil of about 25 turns of No. 18 insulated copper wire. Then pass the current from a dry cell through the coil, and observe that the magnetic needle is sharply deflected. *Energy from the coil of wire passes to the magnetic needle.* In a science laboratory

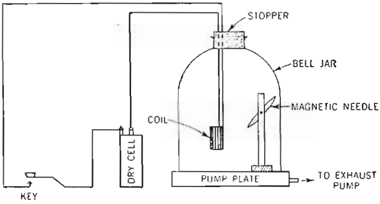


Fig. 9. Apparatus to show that electric current, flowing through a coil of wire, will set up a magnetic field around that coil. This field is created even though the coil is surrounded by a vacuum.

you could prove that it is not the air which transmits the energy, by placing the coil and needle under a bell jar (Figure 9) and pumping out the air. When the current of electricity is again passed through the coil, again the magnetic needle is deflected. The energy is transmitted across the vacuum.

For want of a better explanation, we again fall back upon the ether and assume that the ether is the medium which transmits the energy. We say that when an electric current passes through a wire, it sets up a *magnetic field* of force in the ether around that wire. Note that this magnetic field, unlike the light and heat waves, cannot be received by our senses. Accordingly, we use the magnetic needle to detect this field, and thus to change its energy to a form which our senses can receive. The energy of the magnetic field is changed to the *motion* of the needle; we can see motion.

All these ether waves are "wireless" waves; they do not depend upon metallic wires to transmit their energy. Because of this fact, these waves may be used to communicate between places where it is not possible to string wires, as between an airplane and the ground. Light waves, as we well know, have been used for communications. To a lesser degree, so have heat waves and magnetic fields.

8. What are radio waves? Light waves travel in straight lines and cannot penetrate many kinds of materials. Materials through which light cannot pass are called *opaque*. Because light cannot pass through certain materials and cannot bend, the curvature of the earth and such intervening objects as houses, trees, hills, and the like, limit the range of this method of communication. As for heat waves, they are too readily absorbed by surrounding objects to permit them a large range.

The magnetic field is effective for only a very short distance. If, however, the key in Figure 9 is opened and closed very rapidly (ten thousand or more times a second), a type of ether wave new to us, a *radio* wave, is created. This wave can travel great distances and can penetrate non-metallic objects. It travels at the speed of light, namely 186,000 miles per second, and its frequency, wave length, and amplitude can be controlled by the apparatus used to create it. Radio waves vary in length from about 18 miles down to $\frac{1}{250}$ inch. Those used in ordinary broadcasting are from 656 ft. to 1968 ft. (approximately 200 m. to 600 m.) in length.

SUMMARY

The following principles have been discussed in this chapter:

1. Certain forms of radiant energy are transmitted by means of ether waves. These forms are light, heat, and radio waves.

2. The idea of a medium called "ether" has been postulated (assumed for practical reasons, although not proven).

3. Radiant energy travels through the ether with a speed of 186,000 miles or 300,000,000 meters per second.

4. The length of an ether wave is found by dividing 300,000,000 meters by the number of vibrations (or cycles) per second.

5. Radio waves may be created by the rapid opening and closing of an electric circuit.

CHECK-UP

In the blank spaces write the words or numbers needed to complete the statements correctly. (Answers to this test are on page 299.)

1. In the metric system the unit of measure that most nearly equals a yard is the ....

2. The number of cycles in a kilocycle is ....

3. The number of cycles in a megacycle is ....

4. Radio, radiant heat, and light waves differ in their .... and ....

5. Radio waves have a velocity equal to .... miles per second or .... meters per second.

6. The only ether waves for which our bodies are receivers are .... and ....

7. Waves used in ordinary broadcast radio transmission vary in wave length from .... to .... meters, approximately.

8. The word that means one one-thousandth of a meter is ....

9. The word that means one million cycles is ....

10. To find wave length you divide the .... of the wave by the .... of the wave.

11. When an electric current passes through a wire, it sets up a .... in the space around the wire.

12. To create a radio wave a .... must be started and stopped at a rate of at least 10,000 times per second.

CHAPTER 3

A Simple Radio Receiving Set

QUESTIONS THIS CHAPTER ANSWERS

1. *How does a radio receiver collect radio waves?*

2. *How does a radio receiver select a radio wave of a certain wave length and reject those of other wave lengths?*

3. *How does a radio receiver change the energy of radio waves into signals that we can hear?*

4. *How is the electrical current in a radio set changed so that it can operate a loudspeaker or earphone?*

---

9. What are the four major parts of all radio receiving sets? It will be helpful in your study of the principles of radio to learn at the start that every radio receiver, no matter how complex or involved, consists of only four essential parts. They are:

1. The *aerial-ground system*, which collects the radio waves.
2. The *tuner*, which selects the radio wave (or station) to be received and rejects all others.
3. The *reproducer*, the device which changes the energy of the radio wave to a form which our senses can perceive.
4. The *detector*, which changes the energy of the radio wave to a form whereby it can operate the reproducer.

This holds true for all receiving sets from the simplest crystal set to the most complex television receiver. Everything else in the receiver is merely a refinement of these four essentials.

10. What is the purpose of the aerial-ground system? Suppose we string a copper wire so that one end is up in the air and the other end is connected to the ground. Radio waves, sent out by a broadcasting station, striking this wire, will set up an *electrical pressure* or *voltage* along the wire. This pressure will cause a small electrical current to flow up and down the wire. We now have the beginning of our radio receiver, the *aerial-ground system*. With it we collect the radio waves. All receivers must have an aerial-ground system. It may be external and connected to the set by wires, or it may be contained in the set itself in the form of a number of loops of wire.

To prove that this aerial-ground system is necessary to the receiver, connect up a regular broadcast receiver with an external aerial and ground. Tune in a station and then disconnect the aerial and ground. The station dies away. (It may be faintly received even after the aerial and ground are disconnected. This reception occurs because the wires in the set itself act as a very inefficient sort of aerial and ground.)

11. What is the meaning of radio tuning? All radio receivers must have some method of separating the station desired from all other stations broadcasting at the same time. The apparatus which does this is called the *tuner*. Since each station sends out radio waves of a different frequency, the tuner must select the frequency desired and reject all others. To understand how this is done you must first learn about *resonance*.

Place a number of drinking glasses of different size, shape, and thickness upon a table. Strike each with a pencil. Observe that each glass gives off a different tone. The vibrating glasses set up air waves which reach our ears and are interpreted as sound. The different tones are caused by the different frequencies of these air waves. This tone difference means that the glasses, too, are vibrating at different frequencies. The frequency at which an object will vibrate when struck depends upon the material of which it is made, its size, its shape, and its thickness. This frequency is called the *natural frequency* of the object.

Suspend a small weight at the end of a string about a yard long. You now have a pendulum. Start the pendulum swinging gently. You will note that it swings a certain number of times per minute. That number is the natural frequency of that particular pendulum. Wait till it is swinging gently. Now, every time the pendulum reaches the end of its swing, give it a very light tap in the direction of its return swing. You will soon have your pendulum swinging violently to and fro. To increase the swing of the pendulum, you must tap "in step" with its swing. The increased energy of the swing came from the tapping. Therefore, to obtain the maximum transfer of energy from the tapping to the pendulum, the *frequency of the tapping must be equal to the natural frequency of the pendulum.* We say the tapping is in *resonance* with the swing of the pendulum.

Here is another experiment you may perform if you can obtain two tuning blocks or tuning forks of similar frequency, say, 256 vibrations per second, which corresponds to the note we call middle C on the piano. A tuning block is a bar of steel so designed that it will vibrate at a certain frequency when struck. This bar is mounted on a hollow wooden block which amplifies the note produced.

Place these blocks about 10 feet apart. Now strike one of them vigorously. It will give off its note, middle C. Place your hand on the block you struck to stop its vibrations. You will continue to hear the note, although a good deal fainter. Bring your ear near the second block. The sound will be coming from it, although you did not strike it. Place your hand on the second block. The sound stops.

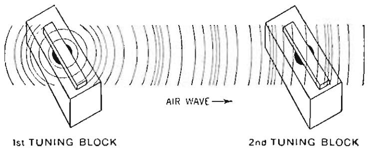


Fig. 10. Set of two tuning blocks showing how air waves sent out by the first block strike the second one and set it vibrating.

Let us see what happened. When you struck the first block, it was set vibrating at its natural frequency of 256 vibrations per second. The vibrating bar set up air waves at that same frequency. These air waves struck the second block. Since the frequency of the air waves was the same as the natural frequency of this second block, the energy of the air waves was transferred to the block and it was set in vibratory motion. The second block thereupon set up air waves of its own, and it was these waves you heard when you stopped the vibrations of the first block. We say that the two blocks are in *resonance* with each other.

Repeat this experiment, using two tuning blocks of different frequency, say, one at 256 or middle C and the other at 288 or D. This time you get no sound from the second block because the air waves are not vibrating at the natural frequency of the second block; therefore there is no transfer of energy. These blocks are *not in resonance* with each other.

So you see that you have here a means of selecting only a certain frequency and rejecting all others. All you have to do is to construct your receiving block so that it is in *resonance* with the frequency you wish to receive. It will vibrate only when air waves of that frequency hit it but not at any other frequency.

In our radio receiver we use the same principle that was shown by the tuning blocks. Assume that three stations A, B, and C are broadcasting simultaneously at frequencies of *a*, *b*, and *c* respectively. If you wish to receive station A, you adjust your tuner so that the natural frequency of your receiver is the same as the frequency *a* of the radio waves sent out by station A. The receiver now is in resonance with the radio wave from station A, and the energy of the radio wave is transferred to the receiver. Since stations B and C are not in resonance with the receiver, the energy of the radio waves sent out by these stations is rejected, and we do not hear them.

12. What is the function of the reproducer? So far, we have been able to catch or collect the radio waves by means of the aerial-ground system and to select the station (or frequency) we desire by means of the tuner. But we still cannot hear nor see the electric currents which have been set up in our receiver. What we now need is some device which will change this electric current to a form of energy which we can hear or see. This device is called the *reproducer*.

Using copper wire, hook up a telephone transmitter, a telephone receiver, and some dry cells as shown in Figure 11. The electric current flows from the dry cells through the copper wire, through the telephone transmitter, then from the transmitter through the copper wire, through the telephone receiver, and then through the copper wire back again to the dry cells. We call this hookup an electrical circuit. It is a complete path along which the electric current can travel from the cells, through the wires and telephone instruments, and back to the cells again.

When you speak into the telephone transmitter, the sound waves hitting it cause it to act like a gate, allowing more or less electric current to flow into the circuit. We say of the electric current thus set flowing in the circuit that it fluctuates (becomes stronger and weaker). At the other end of the line, in the telephone receiver, this fluctuating electric current causes a metal diaphragm to fluctuate (move back and forth) in step with the current. This movement of the diaphragm causes the air next to the diaphragm to move back and forth, setting up air waves; we hear these air waves as sound. Since the air waves that hit the transmitter move the same way as the air waves set up by the diaphragm of the receiver, you hear the same sound as was spoken into the transmitter. We call the telephone receiver a *reproducer*.

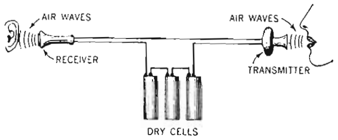


Fig. 11. Hookup of a telephone transmitter, telephone receiver, and dry cells, showing how air waves, striking the transmitter, are heard as sound coming from the receiver.

Now, remember that radio waves set up an electric current in an aerial-ground system, as we discovered earlier. Hence it might seem that all you have to do to hear a radio message from a distant station is to lead this electric current through the tuner and into some type of telephone receiver.

But not so fast. There are some electric currents that cannot operate the telephone receiver. The current that the radio wave sets up in your aerial-ground system is a current of this type. So it is necessary to change it to current of a type that will operate the reproducer.

13. What is the function of the detector? There are a number of ways of accomplishing the change of current from one type to another. The simplest, perhaps, is to compel the current to pass through a certain type of mineral such as *galena.* This passage changes the aerial-ground current into current of a type that will operate the telephone receiver and make it possible to hear the radio wave as sound. Such a device, which changes the electric current set up by the radio wave into a form that will operate the reproducer, is called a *detector.*

SUMMARY

Here, then, is your complete radio receiver. First of all is the **aerial-ground system,** which collects the radio waves. Next comes the **tuner,** which selects the station or radio wave desired and rejects all the rest. Then comes the **detector,** which changes the form of the electric current set up by the radio wave into a form that will operate the **reproducer,** which in turn produces the sound that we can hear.

CHECK-UP

In the blank spaces write the words needed to complete the statements correctly. (Answers are on page 299.)

1. The four essential parts of all radio receivers are the ...., ..., ..., and ....

2. When a radio wave sweeps across an aerial-ground system, it sets up a .... or .... across it.

3. The device in the radio receiver which enables us to receive one station and reject others is known as the ....

4. The frequency at which a body will vibrate when struck, which is dependent on the material and mass of the body, is known as its ....

5. A radio receiver, as a rule, will receive the signal from a broadcasting station when the two are in a condition known as ....

6. Because we cannot hear electrical currents, we must use a .... to change the electrical energy into sound energy.

7. The simplest type of detector is ...., a mineral.

CHAPTER 4

The Aerial-ground System

QUESTIONS THIS CHAPTER ANSWERS

1. *How is a simple antenna set up?*
2. *How is the aerial connected to the receiving set?*
3. *How is the aerial connected to the ground?*

Before we continue our study, let us have clearly in mind what we are trying to do. The plan of this book proposes to take up the problems of radio in the following order:

1. **What** are the parts of a radio receiving set?
2. **How** are these parts connected and how do they work?
3. **Why** do the parts function as they do?

We have learned that the radio wave, striking the aerial, sets up an electric pressure, called an electromotive force (abbreviated E.M.F.) which causes a small electric current to flow up and down the aerial-ground system. Because this current is extremely small, it is necessary to construct your aerial-ground system as efficiently as possible, and you must be sure that you do not waste this current once it is set flowing.

14. How is a simple antenna set up? First of all, there is the aerial or antenna. For ordinary broadcast reception, the simplest type of aerial consists of a single strand of wire about 75 ft. long. This wire should be of copper, of No. 12 or No. 14 gauge, and may either be insulated or bare. It should be raised as high above ground as is practical and should be kept clear of all obstructions, metal especially. *Insulators* should be attached to both ends to prevent the small currents from leaking off. Insulators are substances that do not conduct electricity. Common examples are glass, porcelain, bakelite, and hard rubber. If a power line or a trolley wire runs nearby, your aerial should run at right angles to that line or wire.

15. How is a lead-in set up? After the *aerial* comes the *lead-in*. This is a piece of wire similar to the aerial. It is connected at one end to the antenna and at the other end to the receiving set. If possible, the aerial and lead-in should be made of one piece of wire. But if you should have to join one piece of lead-in wire to another, be sure to scrape the two pieces clean with a knife or sandpaper. Then twist one wire securely around the other. For best results this joint should be soldered. Finally, wrap friction tape around the joint to prevent the air from corroding it.

The lead-in should be kept at least 6 in. away from all walls and other surrounding objects. It is usually brought in through a window, and, to avoid the necessity of drilling a hole in the frame, the lead-in is cut and a flexible window strip is inserted. This window strip lies flat under the window frame and permits the window to be opened and closed without disturbing the installation.

From the inside end of the window strip, connect an insulated copper wire to the post on your radio set marked ANT or AERIAL. For best results, the lead-in should be about 25 ft. in length, from the aerial to your radio set.

16. How is the ground connection made? Finally, there is the *ground* connection. Ground is a technical term used in electrical work. It refers to a part of an electrical circuit which is directly connected either to the earth or to the metallic base of some device to make a complete circuit. In an automobile one terminal of the battery is connected to the steel frame of the car; this frame is a *ground*. Hence, in the automobile there is only one wire leading to a lamp or other fixture, the circuit being completed by connecting it through the frame.

The best connection for a ground, if one is available, is a cold-water pipe. Next best is a radiator or any other pipe which goes to the ground. Gas pipes should *never* be used as grounds. Scrape the paint off the pipe where you plan to make the connection. Then wrap a number of turns of bare copper wire tightly around the cleaned part of the pipe. Better yet, get a ground clamp designed for this purpose and attach it to the pipe at the point selected. Then run a piece of insulated copper wire from your ground connection to the post marked GROUND or GND on your radio set. This wire should be about No. 18 gauge and should be as short as possible.

When we draw a diagram of our radio set we use symbols to signify the various parts. The symbol used for the aerial is

 and that used to signify a ground is: .

It should be understood that the aerial-ground system just described is a very simple type. In a later chapter some other types will be discussed, types better adapted to certain purposes.

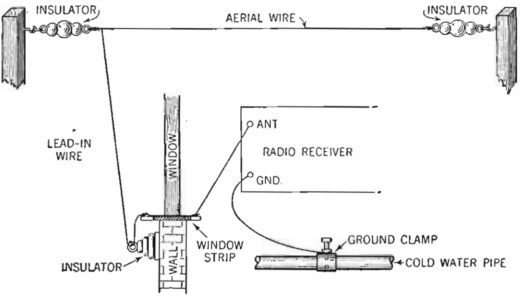


Fig. 12. Diagram illustrating the installation of the aerial-ground system.

SUMMARY

1. The **aerial-ground system** consists of three parts: the **antenna or aerial,** the **lead-in** wire, and the **ground.**

2. The function of this system is to receive and capture some of the radio waves being sent out by broadcasting stations.

SYMBOLS

 Aerial.

 Ground.

CHECK-UP

In the parentheses opposite each item in column *A*, place the letter of the item in column *B* that best describes or applies to it. (Answers to this test are on page 299.)

Column A		*Column B*
1. Aerial.............	( )	(a) About 75 feet long for ordinary receiving sets.
2. Conductor.........	( )	(b) Symbol for "aerial."
3. Ground connection.	( )	(c) Connects aerial to receiver.
4. Insulator..........	( )	(d) Allows easy passage of electrical currents.
5. Lead-in...........	( )	(e) Types of insulators.
6. Rubber or porcelain	( )	(f) Symbol for "ground."
7. 	( )	(g) Runs from lead-in into house.
8. 	( )	(h) Does not allow easy passage of electrical currents.
9. Window strip......	( )	(i) A water pipe.
		(j) Produces a voltage.
		(k) Connects aerial to ground.

CHAPTER 5

The Tuner

QUESTIONS THIS CHAPTER ANSWERS

1. *What are the principles of a tuning system?*
2. *What electrical device takes care of inductance?*
3. *What electrical device takes care of capacitance?*
4. *How is a tuning system constructed?*

You have already learned that the tuner selects the desired radio station by adjusting the natural frequency of the receiver so that it is in *resonance* with the transmitter frequency. Let us see what determines the natural frequency of the receiver.

Examination of the tuner shows that it consists of two parts—a coil of wire and a capacitor. This coil and capacitor produce certain electrical effects upon the current flowing through them. We call the electrical effect of the coil *inductance* and that of the capacitor *capacitance*. We will discuss these effects later in the book, but for the present it will be enough to say that the values of inductance and capacitance determine the natural frequency of the tuner, even as the size and weight of a tuning block determine its natural frequency.

17. How is inductance taken care of? The device that takes care of the *inductance* consists of a coil of wire wound around a tube usually made of cardboard or bakelite. Its electrical value depends on:

1. The number of turns or loops of wire.
2. The length of the coil of wire.
3. The diameter of the tube on which it is wound.
4. The core of the coil. This is the material inside the tube. The two most common materials for the core are air and iron. Air-core coils are usually used for the tuner.

The unit for measurement of inductance is the *henry* (h.) or the *millihenry* (mh.). The millihenry is one one-thousandth of a henry. The symbols for inductance devices or *inductors* having cores of air or iron are:

AIR CORE IRON CORE

We can vary the value of our inductance by changing one or more of the four factors listed above. It is most convenient to change the number of turns or loops of the coil. The symbol for a variable inductor is either of the following:

Whenever we desire to represent inductance in an electrical formula or equation, we use the letter L.

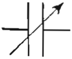
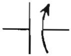
18. **How is the capacitance of a tuner provided?** The capacitance in a tuner is provided by a device called a *capacitor*. This capacitor is made of two or more metal plates facing each other and separated by some substance which will not conduct electricity. This substance is called a *dielectric* and usually consists of air, paper, mica, oil, or glass. The plates are usually made of brass, tinfoil, or aluminum. The electrical value of a capacitor depends on:

1. The total area of the plates facing each other.
2. The material of the dielectric.
3. The thickness of the dielectric (or distance between plates).

The unit of measure of capacitance is the *farad* (f.). For radio purposes we usually use the *microfarad* (μfd.), which is one one-millionth of a farad, and the *micromicrofarad* ($\mu\mu$fd.), which is one one-millionth of a microfarad.

Sometimes, when the typesetter does not have the character for *mu* (μ), the small letter *m* is used instead. Thus, *microfarad* may appear as *mfd.* and *micromicrofarad* as *mmfd.* The symbol for the capacitor is:

We can vary the value of our capacitor by changing one or more of the three factors listed above, that is, total area of plates facing each other, material of dielectric, or thickness of dielectric. The most convenient method is to change the area of the plates facing each other. We do so by making one plate, or set of plates, rotary, and the other plate, or set of plates, stationary. All the stationary plates are joined together, giving the effect of one large stationary plate. The same is done with the rotary plates. The rotary plates move in and out between the stationary plates. Thus, the more the rotary plates are moved in between the stationary plates, the greater the area of the plates facing each other and the greater the capacitance of the capacitor. The symbol for a variable capacitor is:

 or 

Whenever we desire to represent capacitance in an electrical formula or equation, we use the letter C.

19. How is a tuning circuit set up? If, by means of wire, you connect a coil and condenser as shown in Figure 13, you create a tuning circuit. When you apply a voltage (electrical pressure) across this circuit, you will cause an electrical current to flow back and forth through it. We speak of such back-and-forth flow of current as *oscillations.* These oscillations are more fully discussed in Chapter 11. The natural frequency of the oscillations in this circuit is determined by the product of the values L and C ($L \times C$ or LC).

The transmitting station may use a capacitor and coil hookup similar to the one we have just described to generate the radio wave it sends out. The frequency of its wave is determined by the $L \times C$ of the transmitting set. Should the $L \times C$ of the transmitting station equal the $L \times C$ of your receiver, your set will be in resonance (in tune) with the frequency of the radio wave from the transmitter. You will then receive that station only and no other.

Note that it is not necessary to have the same L and the same C in your receiving set as is in the transmitting station. It is enough that the product of L and C ($L \times C$) of your set be equal to the $L \times C$ of the transmitter. So if we arbitrarily give a value of 4 to the L and 4 to the C of the transmitting station, the $L \times C$ of that station is 16. To bring your receiver in resonance with the transmitter (that is, to *tune* your set for reception) you may choose an L whose value is 2 and a C whose value is 8. Or

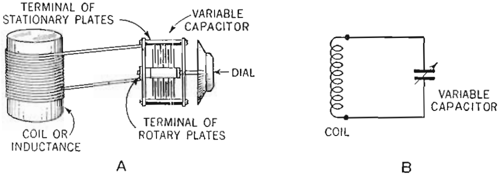


Fig. 13. Hookup showing how coil and variable capacitor are connected to form the tuning circuit. The circuits in Figures A and B are identical, A being the pictorial method of showing the circuit while B is the schematic method using symbols.

else you may choose an L of 8 and a C of 2. Or an L of 4 and a C of 4. In other words, you may choose any value of L and C whose product is equal to 16, the same as the $L \times C$ value of the transmitter.

Now all this is very well if you wish to build a receiver which will receive only one station. But if you wish to receive another station, you must be able to vary the L or C (or both), of your receiver so that the new $L \times C$ will be equal to the $L \times C$ of the new station.

Although the natural frequency of the tuner may be varied by changing the L or C (or both), in most radio sets this adjustment is accomplished by varying the C only, using a variable capacitor for that purpose.

20. Construction of a tuner. Now you are ready to build your tuner. If you can do so, obtain a cardboard mailing tube about 2 in. in diameter and about 6 in. long. Upon this tube wind 90 turns of No. 28 gauge insulated copper wire so that the turns lie next to each other and form a single layer. This assembly is your inductor.

Now obtain a variable capacitor whose maximum value is 0.00035 microfarad (μfd.). Such a capacitor usually has from 17 to 21 plates, half rotary and half stationary. Connect one end of the coil to the rotary-plate terminal of the capacitor and the other end of the coil to the stationary-plate terminal, as shown in Figure 13. You now have constructed your tuner.

SUMMARY

1. The **tuning system** consists of two essential parts: a **coil** of wire and a **capacitor.**

2. The coil provides the electrical effect known as **inductance.**

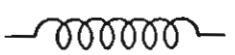
3. The capacitor provides the electrical effect known as **capacitance.**

4. The mutual action of the inductance and the capacitance determines the natural frequency of the tuner.

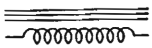
5. The oscillations of electric current flowing in the tuner may be put in **resonance** with those of a broadcasting station by making the values of L (inductance) and C (capacitance) such that the product $L \times C$ is identical with the product $L \times C$ of the desired station.

6. Tuning is achieved by using a variable capacitor by which capacitance (C) can be given any desired value.

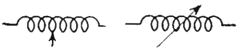
SYMBOLS



Coil wound on nonmetallic core.

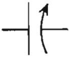


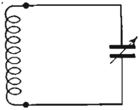
Coil wound on iron core.



Variable inductance coil.

 Fixed capacitor.

 or  Variable capacitor.

 Tuner circuit.

CHECK-UP

Part A

In the blank spaces write the words or numbers needed to complete the statements correctly. (Answers to this test are on page 299.)

1. The two properties that determine the natural frequency of the tuner of a receiver are the .... of the coil and the .... of the capacitor.

2. The four factors that determine the inductance of a coil are:

(a) ....

(b) ....

(c) ....

(d) ....

3. The unit for inductance is the ....

4. Fundamentally, every capacitor consists of two .... separated by a ....

5. The capacitance of a capacitor depends upon the:

(a) ....

(b) ....

(c) ....

6. The fundamental unit for capacitance is the ....

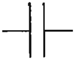
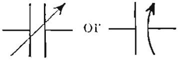
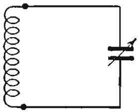
7. The back-and-forth surges of current through a capacitor and coil connected together are known as ....

8. The natural frequency of oscillations in a tuning circuit is determined by the product of .... and ....

9. The natural frequency of oscillations of the output tuning circuit of a transmitter must be .... the natural frequency of the oscillations of the receiver if we are to receive that station.

Part B

In the brackets opposite each item in column *A*, place the letter of the item in column *B* that best describes or applies to it.

Column A		*Column B*
1. 	( )	(a) $\frac{1}{100}$.
		(b) Coil wound on iron core.
2. 	( )	(c) 1/1,000
		(d) Fixed resistance.
3. Micro-............	( )	(e) Fixed capacitor.
4. Micromicro-.......	( )	(f) Variable capacitor.
5. Milli-.............	( )	(g) Variable coil.
		(h) 1/1,000,000,000,000.
		(i) 1/1,000,000.
6.  ...	( )	(j) Tuning circuit.
7.  ...	( )	

CHAPTER 6

The Reproducer

QUESTIONS THIS CHAPTER ANSWERS

1. *How does an electromagnet work?*
2. *How are electromagnets used to produce sound waves?*
3. *What is a magnetic loudspeaker?*

---

21. What is magnetism? To understand how the reproducer works, you must learn a few facts about magnetism and electromagnetism. Cut a circular disk of thin iron about 2 in. in diameter. Obtain a bar magnet and hold it near your iron disk. The magnet is surrounded by an invisible magnetic field of force which acts on the disk and pulls it towards the magnet. Such a magnet is called a *permanent* magnet.

Obtain a piece of soft iron rod or bar stock about 1 in. in diameter and 2 in. long. Be sure it is not magnetized. Now wind upon it a coil of about 25 turns of No. 18 gauge insulated copper wire. Connect the ends of the coil to the posts of a dry cell. When the current flows through the coil, the bar becomes a magnet. It has a magnetic field which will attract the iron disk just as did the bar magnet. When the current ceases to flow through the coil, the bar loses its magnetism. Such a combination of a bar in a coil that is carrying current is called an *electromagnet*.

22. How does a varying current affect an electromagnet? Mount the bar magnet upright on a board. Remove the soft iron bar from the coil and slip the coil over the bar magnet. Above the magnet, and separated from it by about an inch, suspend your disk from a spring balance. This balance will show how much pull is being exerted on the disk. Measure the pull which the bar magnet exerts on the disk. Connect the coil to the posts of a dry cell. The pull should increase because you now have the double pull of the bar magnet and the electromagnet. (Should the pull decrease, reverse the connections to the dry cell.)

Now connect another dry cell *in series* with the coil. To connect them properly, disconnect the end of the coil from the outer post of the first dry cell. Connect this outer post to the center post of the second dry cell and connect the wire from the coil to the outer post of the second dry cell. Cells connected in this manner are *in series.*

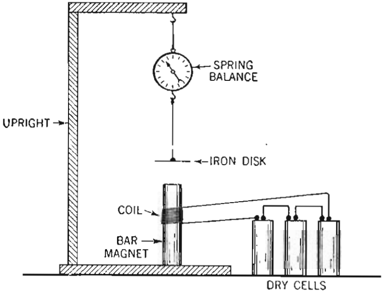


Fig. 14. Apparatus used to show that a varying electric current passing through an electromagnet will exert a varying pull on an iron disk.

You will observe that the pull is greater. This increased pull is to be expected, because using two dry cells in series increases the current and makes the electromagnet stronger. Repeat, using three or more dry cells. As you add cells, the pull becomes greater because more current is flowing through the coil of the electromagnet. Reducing the number of dry cells reduces the current in the electromagnet coil, and the pull on the disk becomes weaker. If you pass a varying or fluctuating current through the coil, the pull on the disk will fluctuate in step with the current. Note that a steady current will not cause the disk to move. It will be pulled to a certain position and then will remain stationary as long as the current is steady.

23. How is a telephone receiver constructed? Now, if possible, get a telephone receiver and unscrew the cap. You will see a thin iron disk; this disk is called the diaphragm. Remove the diaphragm and you will see a coil of wire (the electromagnet coil)

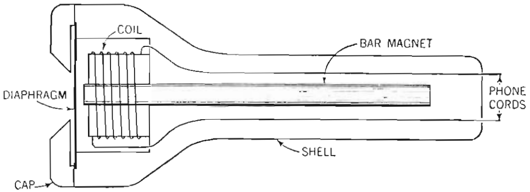


Fig. 15. Construction of a telephone receiver.

which is wound over the end of a bar magnet. The ends of the wires connecting the electromagnet pass out through the opposite end of the telephone receiver.

The bar magnet exerts a constant pull on the diaphragm. Since the diaphragm is held fast at its rim, it can only move

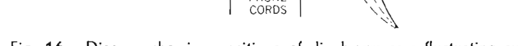


Fig. 16. Diagram showing positions of diaphragm as a fluctuating current flows through the electromagnet of the phones. The bending of the diaphragm is greatly exaggerated in this drawing.

inward toward the magnet at its center. The springiness of the diaphragm constantly tends to pull it back. When we add the pull of the electromagnet, the diaphragm bends inward much or little, depending upon the current flowing through the coil. You see, then, that a fluctuating current flowing through the coil causes the diaphragm to fluctuate in step with it.

Now look back to Figure 11. You will remember that the sound waves striking the telephone transmitter cause a fluctu-

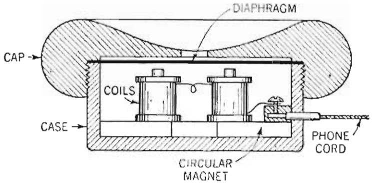


Fig. 17. Diagram showing a sectional view of an earphone of the type used in radio receivers. Note how flat it is as compared to the telephone receiver. The permanent magnet is here made either circular or horsehoe shaped.

ating current to flow through the circuit. This current fluctuates in step with the sound waves. This current is sent through the electromagnet coil of the telephone receiver, and the diaphragm is thus made to fluctuate in step with the original sound waves. The moving diaphragm sets the air next to it in motion, and

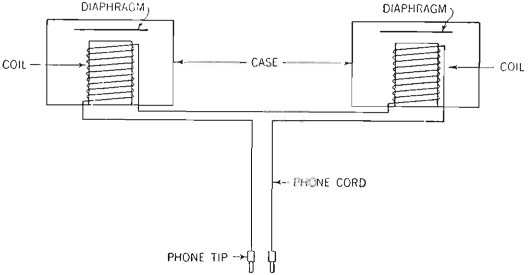


Fig. 18. Diagram showing how a pair of phones is connected in series.

it is these air waves which hit our ear. Thus we hear a sound which is the same as that which was spoken into the telephone transmitter.

For the sake of convenience, the earphones used for radio reception (called simply *phones* or *headphones*) are made flat. This flattening is accomplished by using a circular magnet instead of the long straight one used in the telephone receiver. Usually two of these phones are connected together in series, one for

Murdock Manufacturing Co.

Headphone set.

each ear, and held in place with a metal band or spring that fits over the head.

The symbol for earphones is: 

24. **What is a magnetic loudspeaker?** You have seen that the moving diaphragms of the earphones set the air next to them in motion and thus produce the sound you hear. If this sound were

loud enough, you could lay the phones on the table and would not need to bother wearing them on your head.

If you were to make one of the diaphragms larger, it would move a greater quantity of air and thus produce a louder sound. For practical reasons a diaphragm cannot be made very large, and so another scheme was developed. One end of a stiff wire is fastened to the center of the diaphragm. This wire now moves toward the magnet and away from it in step with the diaphragm. To the other end of the wire a large paper cone is fastened. The

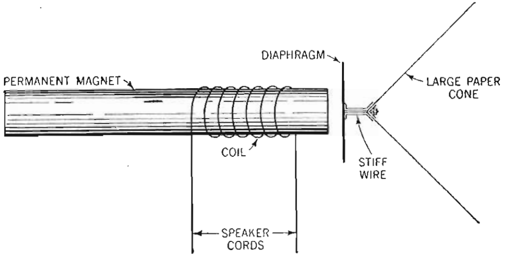


Fig. 19. Diagram showing how an earphone is converted to a loud-speaker.

fluctuating diaphragm moves the wire; the wire in turn moves the paper cone. This cone in turn sets a large amount of air in motion, creating a loud sound. By this means we are able to do away with earphones. The device is called the *magnetic loudspeaker*.

SUMMARY

1. A coil of wire surrounding a core of soft iron becomes an **electromagnet** when an electric current passes through the coil.

2. The strength of the **magnetic field** (that is, its attractive force) increases when the current increases and decreases when the current decreases.

3. The **telephone receiver** is an application of the electromagnet. Variations in the electric current caused by the sounds in the transmitter are reproduced in the receiver and cause fluctuating magnetic strength. A metal **diaphragm** is pulled in and out as the current is stronger or weaker. This diaphragm produces sound waves in the air.

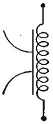
4. **Earphones** are telephone receivers with flat electromagnets.

5. **Loudspeakers** are comparable to telephone receivers in which the diaphragm is attached to a large cone. The cone sets in motion a larger amount of air and hence gives a louder sound.

SYMBOLS

Earphones or phones.

or



Loudspeaker.

CHECK-UP

Part A

In each statement below there are three words or three phrases in parentheses. Only one of these correctly completes the statement. Underscore the word or phrase that you think is correct. (Answers are on pages 299–300.)

1. When you pass an electric current through insulated wire wound on a soft iron core, you have (*an electromagnet*) (*a permanent magnet*) (*a magnetic loudspeaker*).

2. Cells are connected to each other in series when (*center binding posts are connected to each other*) (*the center post of one cell is connected to the side post of another cell*) (*side posts are connected to each other*).

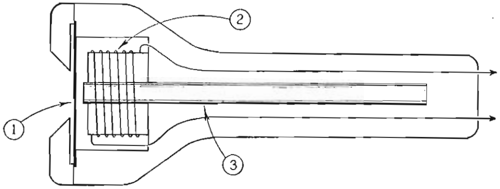
3. For a telephone receiver to produce sound, the strength of the electric current (*must be steady*) (*must vary*) (*may be either steady or varying*).

4. The part of an earphone or telephone receiver that actually sets the air in vibration to make sound is the (*diaphragm*) (*electromagnet*) (*paper cone*).

5. The paper cone of a magnetic loudspeaker produces louder sounds because it (*is larger and thus moves more air*) (*vibrates more violently*) (*vibrates more rapidly*) than a diaphragm.

Part B

In the blank spaces below the diagram of a telephone receiver, name the three numbered parts.



1. ....

2. ....

3. ....

CHAPTER 7

The Detector

QUESTIONS THIS CHAPTER ANSWERS

1. *What is the electron theory of electricity?*
2. *What is a radio-frequency alternating current?*
3. *What is a pulsating direct current?*
4. *Why must a radio reproducer use a pulsating direct current?*
5. *What is the purpose of a detector?*
6. *How does a crystal detector work?*

25. What is the electron theory of electricity? In studying the aerial and tuner you have learned that the radio wave striking the aerial sets up a voltage or electrical pressure in the aerial. This electrical pressure causes a small current to flow in the receiver. But if you connect your phones to this circuit, you will hear nothing.

To understand why the electrical current flowing in the receiver fails to operate the phones, we must first consider the theory of electricity. Although scientists have succeeded in putting electricity to a great many uses, they do not know just what electricity is. It is one of the many forms of energy and may be changed into other forms such as heat, light, and motion. From a study of the behavior of an electric current and from a study of the methods of obtaining electrical effects, scientists have arrived at some theories about its nature.

When a scientist tries to explain one of nature's mysteries, he carefully examines all the facts he can obtain. He makes experiments to obtain more facts and then makes a guess that tries to explain all the facts. This guess is at first called a *hypothesis*. When more evidence is found to support it, and other scientists generally accept it, the explanation is called a *theory*. After a time, someone may come along with proof which shows the theory to be true. We then call the explanation a *law*. Or someone else may come along with facts to show that the theory cannot be true. In the latter case the theory may be modified to take the new facts into account or discarded entirely in favor of a new theory which tends to explain the new facts.

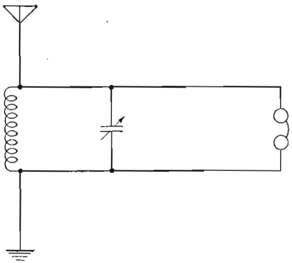


Fig. 20. Diagram showing the aerial-ground system and the tuner connected to a set of phones. This circuit will not work.

So it is with the electric current. Although we do not know what it is, we have a theory which tries to explain it. It is called the *electron theory*.

According to the electron theory an electric current consists of the movement of minute particles, negatively charged. These particles are called *electrons*. While some of these electrons will drift through a conductor like water flowing through a pipe, the main movement of these electrons consists in hitting their neighbors and by that means passing along the impulse of energy which we call an electric current. The action is somewhat similar to that of the dominoes of Figure 4.

This impulse of energy travels at the rate of nearly 186,000 miles per second, or nearly the same as the speed of the light wave. When the electric current flows in one direction through the conductor, we say it is *direct current* (D.C.). If the current flows first in one direction and then reverses itself and flows back in the opposite direction, we say it is *alternating current* (A.C.). When an alternating current flows in one direction, stops, and then flows in the opposite direction we say the current has gone through one *cycle*. The number of cycles per second is called the *frequency*.

26. **What is a radio-frequency alternating current?** The electricity used to light your house may be alternating current and have a frequency of 60 cycles per second. The current set flowing in your aerial-ground system by the action of the radio wave also is alternating current; its frequency is the same as the frequency of the radio wave; that is, it may vary from 10 kilocycles (kc.) per second to 3,000,000 megacycles (mc.) per second. Electric current whose frequency falls within that range is said to be *radio-frequency alternating current*.

Now let us go back to our radio receiver. Let us assume that a broadcasting station sends out a radio wave whose frequency is 500 kc. (500,000 cycles) per second. This frequency we call *radio frequency* (R.F.). The radio wave hits our aerial and sets a current flowing in our aerial-ground system. It is an alternating current whose frequency is the same as that of the radio wave, namely, 500 kc. per second. (The statement that a current has a frequency of 500 kc. per second means that the current will change its direction of flow one million times per second.) This new current, in turn, starts an alternating current of the same frequency flowing in the tuner. It is this current which you have applied to the phones in Figure 20.

Let us see what happens in the phones. For one one-millionth of a second the current flows in one direction through the electromagnet of the phones. This flow causes the pull of the electromagnet to be added to that of the bar or permanent magnet. The diaphragm is therefore pulled a little closer to the magnet.

For the next one one-millionth of a second the current reverses itself and is now flowing through the electromagnet coil in the opposite direction. Now the magnetism of the electromagnet is subtracted from that of the permanent magnet and the total magnetic pull is less than before. The diaphragm starts to spring back. This process occurs every time the current reverses itself, which is once every millionth of a second.

Now, one one-millionth of a second is a very small interval of time, and there is no diaphragm that is so sensitive that it can follow these changes. Every time the diaphragm begins to be pulled towards the magnet, the current reverses itself, and the pull is released. As a result the diaphragm stands still, and you hear no sound.

27. Why must a pulsating direct current be used to operate a reproducer? To overcome this difficulty, someone had a brilliant idea. Suppose we put into the circuit a gate which permits an electric current to flow only in one direction and not in the other. Now let us see what happens to the radio-frequency alternating current in the circuit. For one one-millionth of a second the current will flow through the gate. During the next one one-millionth of a second the gate will block the current and there will be no flow. Then a flow in the same direction as the first. Then no flow. And so on. The effect of the gate will be to permit a series of pulses of current to flow, all going in the same direction. These pulses of current will be separated by intervals when there is no flow. Each pulse and each interval will last only one one-millionth of a second.

Since the current now flows only in one direction, we call it *direct current.* Since it is not a steady flow, but consists of a series of pulses, we call it *pulsating direct current.*

Let us see what happens when the pulsating direct current flows into our phones. For one one-millionth of a second the pull of the electromagnet is added to that of the permanent magnet, and the diaphragm starts to bend in. For the next millionth of a second the electromagnet will exert no pull and the diaphragm will start to spring back. Before it can move back, however, the next pulse enters the electromagnet coil, and the diaphragm is pulled a little closer. This continues, and as a result of these streams of pulses the diaphragm is set vibrating, and we can hear a sound.

28. What is a detector for? The device used in radio which serves as a one-way gate is called a *detector.* Scientists have discovered that certain crystals like *carborundum* and the mineral *galena* have this peculiar property of permitting electric current to flow through them in one direction but not in the other. We do not know precisely how this control is accomplished, but we have theories. It would not help our understanding of modern radio receivers, however, to enter at this point into a discussion of those theories.

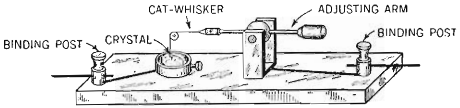
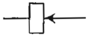


Fig. 21. A crystal detector.

29. How does a crystal detector work? The crystal most commonly used for detectors is galena, a mineral compound consisting of lead and sulphur. Not every spot on the crystal, however, has this remarkable property of making the one-directional current. We must, therefore, use a fine wire to find the spots that will work. The symbol for the crystal detector is:  .

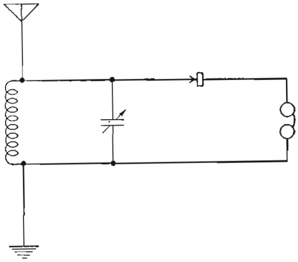


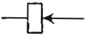
Fig. 22. The complete crystal receiver. It makes no difference whether the catwhisker or crystal side of the detector is connected to the phones. This circuit will work.

When you have hooked up your receiver with the crystal detector in series with the phones, you must move your fine wire (which is called a *catwhisker*) from spot to spot. When you find a spot where you hear a sound in the phones, leave the wire at that spot, and adjust the tuning control to produce maximum loudness. You should avoid handling the crystal as the grease from your fingers will interfere with its sensitivity. If your crystal becomes dirty, wash it in carbon tetrachloride to remove any grease.

SUMMARY

Your complete radio receiving set, in its simplest terms, then, must have these parts which we have discussed: an **aerial and ground,** a **tuner** (an **inductor** and a **capacitor**), a **detector,** and a **reproducer** (phones). In Figure 22 is the diagram of these parts arranged in the proper relationship to each other. If you understand the symbols and connect the parts of your set according to this arrangement, you should be able to hear speech and music through the earphones.

SYMBOL

 Crystal detector.

CHECK-UP

In the blank spaces write the words, phrases, symbols, or numbers needed to complete the statements correctly. (Answers are on page 300.)

1. Scientists explain an electric current as being a stream of ...., each of which has a .... charge.

2. A direct current is one in which the current flows continually .... through the circuit.

3. An alternating current is one in which the current flows .... through the circuit.

4. To operate the earphones the type of current set flowing in the aerial by the radio wave must be changed to a .... type of current.

5. The number of cycles per second is what we mean when we refer to the .... of the current.

6. The radio wave produces the .... type of current when it sweeps across the aerial-ground system.

7. Alternating currents of very high frequency are known as .... currents.

8. The diaphragms of a set of earphones cannot follow the variations of the .... type of current.

9. The simplest device used in the radio receiver which serves as a one-way gate for alternating current is called a ....

10. Two examples of minerals used as detectors are .... and ....

11. The symbol for a crystal detector is

CHAPTER 8

Wave Form

QUESTIONS THIS CHAPTER ANSWERS

1. *How is the type of electric current shown by a graph?*
2. *What is meant by the "sine wave"?*
3. *What is a modulated radio wave?*
4. *In what form is the modulated carrier wave passed through the tuner, detector, and reproducer?*

30. What is a graph? Did you ever visit a sick friend in a hospital? Did he, perhaps, point to the chart hung at the foot of

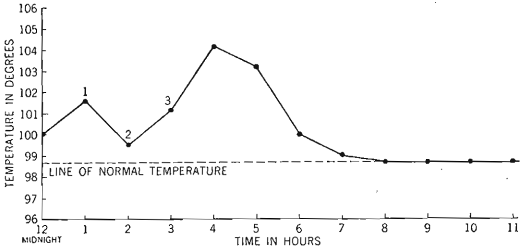


Fig. 23. Temperature graph for your sick friend. Note that the vertical part shows the degrees of temperature while the horizontal part shows the time. By this means we can see what the temperature was at any particular time.

his bed and say, "This is my temperature chart"? You examined the chart and saw on it a wavy line going up and down several times and finally—we hope—leveling out to a horizontal line. You know, of course, that the temperature did not travel over this scenic-railway type of path. This chart was merely a picture or diagram which showed how high your friend's temperature was at any given time of the day. We call such a chart a *graph.*

The word *graph* means a drawing or a picture. Many kinds of graphs are used in science, mathematics, and economics. The most common kind of graph attempts to show, by a line called a *curve,* the course of events when two different conditions are changing. In the graph, Figure 23, the two conditions are time and temperature. The hours are marked from left to right on the horizontal line in equal spaces. The degrees of temperature are marked on the vertical line with the lowest temperature at the bottom.

The nurse reads the temperature of the patient each hour and makes a dot on the vertical line over the hour where the horizontal line from the observed temperature crosses it. For example, the chart shows that at 1 A.M. the patient's temperature was 101.8° (dot 1); at 2 A.M. the temperature was 99.5° (dot 2). Thus each dot is the temperature at a certain hour. When the points or dots are connected by a continuous line, the course of the fever is pictured. This line or curve is called here the temperature curve.

31. How does a steady direct current flow? We can draw such a chart or graph to show how electric current flows. First we draw a horizontal line and call it the *line of no current flow.* When electric current flows in one direction, we call it *positive* and picture its path above the line of no current flow. When it reverses itself and flows in the opposite direction, we call it *negative* and picture its path below the line of no current flow. Thus, the path of a direct current is entirely above that line.

If the current is a steady direct current, the picture of its flow starts at the line of no current flow and very quickly rises above it to the maximum strength of the current (see Figure 24). It then continues to flow at the same rate, and we picture it as a straight horizontal line until the instant when the current is cut off. At that point the line drops down to zero, the line of no flow.

The line we draw picturing that flow of current is called the *curve* or *wave form.*

The strength of the current at any one instant of time is shown by the distance of the curve away from the line of no current flow at that instant. We call this distance from the curve to the line of no current flow the *instantaneous amplitude.*

32. What is the wave form or curve of a fluctuating direct current? A direct current may either be steady or fluctuating. If it is

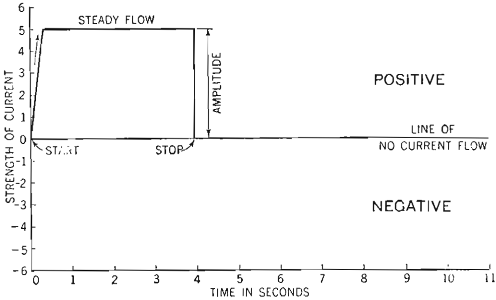


Fig. 24. Graph showing curve or wave form of a steady direct current.

steady, the amplitude is constant while the current is flowing, as shown in Figure 24. In the case of a fluctuating direct current, the instantaneous amplitude is different at different intervals of time, as shown in Figure 25. Notice that in both Figures 24 and 25 the current is direct current; that is, it flows in only one direction. You can see this fact from the graphs by observing that in both cases the curves lie entirely above the line of no current flow.

33. What is the sine curve of an alternating current? We can also picture the flow of an alternating current by means of such a graph. The current starts from zero and rises to a maximum flow in one direction. Still flowing in that direction, it starts to decrease until it again reaches the line of no current flow. Then it flows to a maximum in the opposite direction (below the line), and then decreases again until the zero line is reached. As you already know, the flow of current has gone through one cycle (see §25). Then it starts all over again.

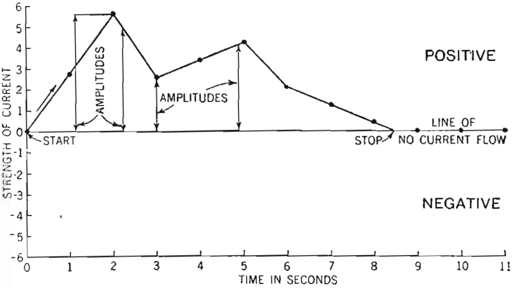


Fig. 25. Graph showing curve or wave form of a fluctuating direct current. Note that the instantaneous amplitude may assume different values at different times.

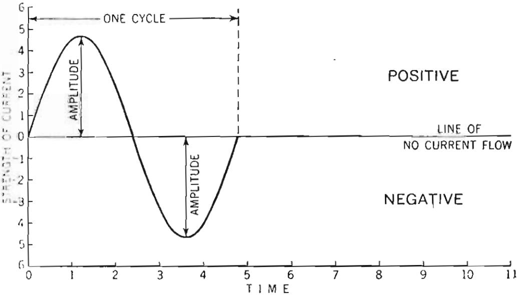


Fig. 26. Graph showing curve or wave form of an alternating current. A curve whose instantaneous amplitudes rise and fall in the smooth, even, and regular glide pictured here is called a sine curve.

Note that during the first half of the cycle the instantaneous amplitude increases from zero to maximum in a smooth, regular glide and then decreases to zero in that same, even way. The same thing occurs during the second half of the cycle (the bottom loop of the curve). A curve having this form is called a *sine curve* (Figure 26). In discussing alternating current, we call the *maximum* distance from the curve to the line of no current flow the *amplitude* (as distinguished from *instantaneous amplitude*).

The flow of alternating current does not always describe a smooth sine curve. The rise from zero to maximum may be

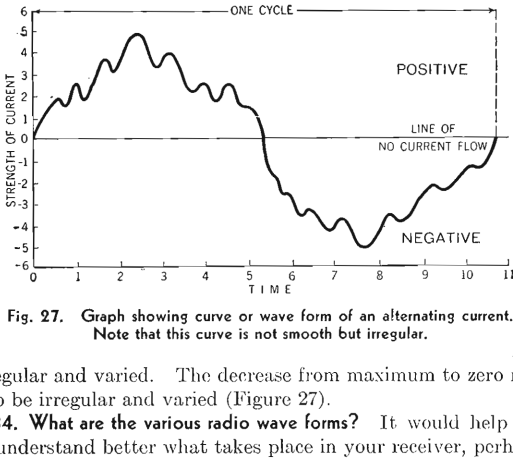


Fig. 27. Graph showing curve or wave form of an alternating current. Note that this curve is not smooth but irregular.

irregular and varied. The decrease from maximum to zero may also be irregular and varied (Figure 27).

34. What are the various radio wave forms? It would help you to understand better what takes place in your receiver, perhaps, if you were to examine the wave forms of the electrical currents flowing in the various parts.

Consider the wave form of the radio wave. It is the same as that of an alternating current; that is, the wave flows first in one direction and then in the other. Its range of frequency is from 10 kc. to 3,000,000 mc. per second. In the United States, standard broadcasting stations send out radio waves whose frequencies lie between 550 kc. and 1600 kc. per second. This range is fixed by law, and each station is given a definite frequency to which it must always keep its station tuned.

The radio wave may take several different forms. For the moment, we are interested in three of them. *First,* there is the wave whose form is that of a smooth sine wave and whose amplitude is constant throughout the entire wave. Such a wave is called a *continuous wave*—also known as a *carrier wave.*

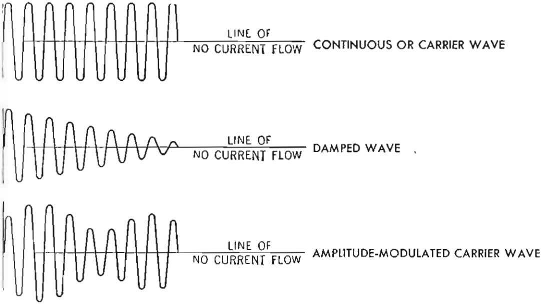


Fig. 28. Graphs showing the wave forms of a continuous radio wave, a damped radio wave, and a modulated radio wave. Note that in all three waves shown here the frequencies are the same. It is only the amplitudes that vary.

Second, there is the wave whose form is that of a smooth sine wave but with the amplitudes of successive cycles decreasing gradually. Such a wave is called a *damped wave.*

Third, there is the wave whose form is that of a smooth sine wave but with the amplitudes of successive cycles varying irregularly. This wave form is obtained by combining a continuous wave with a fluctuating or varying direct current at the broadcasting station. We call such a wave an *amplitude-modulated carrier wave.* We say that the continuous or carrier wave is modulated by the fluctuating direct current. The radio waves which carry speech and music through the ether are modulated carrier waves.

35. How is the modulated wave produced? To understand the method by which a fluctuating direct current modulates the carrier wave, examine Figure 29. First of all, sound striking the microphone at the broadcasting station sets up a fluctuating direct current. Meanwhile, in another part of the transmitting set, a continuous or carrier wave has been generated. Assume that the frequency of this carrier is 500 kc. per second. The

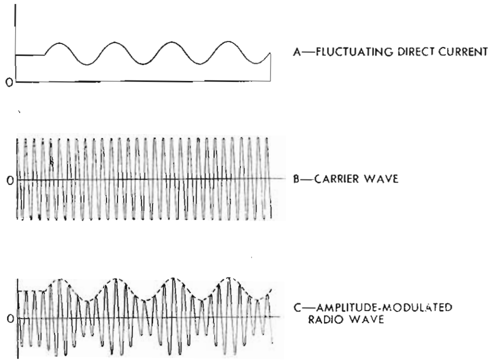


Fig. 29. Graph showing how a fluctuating direct current from the microphone modulates the carrier wave to produce the modulated radio wave which is broadcast by the transmitting station.

fluctuating direct current is now mixed with the carrier wave. The result is the modulated radio wave whose frequency is 500 kc. per second, but whose amplitude variations correspond to the form of the fluctuating direct current.

In this way, we modulate the carrier wave by the electric currents set up by sound waves hitting the microphone at the transmitting station. The modulated radio wave is broadcast by the transmitter. It is the task of the radio receiver to collect this modulated radio wave and to separate the carrier wave from the electric currents impressed on it by the microphone. These impressed currents are the currents that operate our phones, and through their action we reproduce the original sound waves.

36. What is the current wave form in the aerial-ground system? You have already learned (§10) that when the modulated radio wave passes across the aerial of your receiving set, it sets up in the aerial-ground system an electrical pressure or voltage that causes an electric current to flow in that system. The greater the pressure, the greater the flow of current. This flow of current, therefore, conforms to the electrical pressure, which in turn conforms to the modulated radio wave. You can see, there-

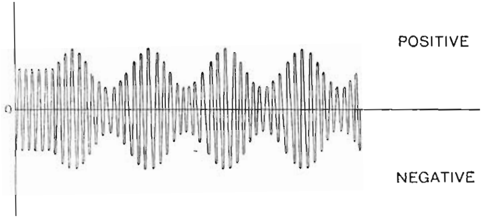


Fig. 30. Wave form of alternating current set flowing in the aerial-ground system when the modulated radio wave shown in Figure 29-C passes across the aerial of the receiving set.

fore, that the flow of current in the aerial-ground system will correspond to the wave form of the modulated radio wave. The current that flows in the aerial-ground system, then, is alternating current whose frequency is the same as that of the modulated radio wave. The amplitude variations of this current, too, will correspond to the amplitude variations of the modulated radio wave.

37. What is the current wave form in the tuner? Electric current flowing in the aerial-ground system, you will recall, sets an electric current flowing in the tuning circuit of your receiver. This current takes the same wave form as that in the aerial-ground system, which, in turn, has taken the same wave form as that of the modulated radio wave. The current flowing in the tuner, then, is alternating current having the same frequency and amplitude variations as the current flowing in the aerial-ground system.

38. How does the current flow in the detector? The crystal detector, you will remember, permits electric current to flow through it only in one direction. See if you can picture what happens to an alternating current as it attempts to flow through such a crystal.

First, the positive half of the cycle approaches the crystal and finds the "gate" wide open; that is, the positive part of the cycle

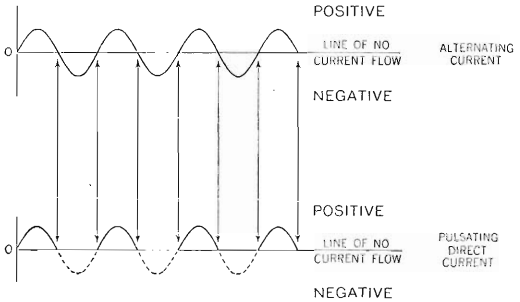


Fig. 31. Graph showing how the crystal detector changes alternating current into pulsating direct current. The negative halves of the cycles which were stopped by the crystal detector are shown by the dotted lines.

can pass through the crystal. When the current reverses itself, the gate is shut, and no current can flow through. The current thus flows through with all its variations as long as it is going in one direction—as long, that is, as it does not go below the line of no current flow of our graph (see Figure 31). Everything in the graph below the line of no current flow is wiped out. Our current now consists of a series of direct-current pulses, separated by gaps of no current flow that represent the negative halves of the cycles which were stopped by the crystal. This wave form is what is meant by a pulsating direct current.

We can now see what will happen to the alternating current of our tuner when it reaches the crystal detector. The current is changed from an alternating to a pulsating direct current, and the bottom halves of the cycles in the curve are wiped out. This, then, is what we mean by detection. The wave-form picture is the same as that for the tuner, except that the half below the line of no current flow is eliminated (see Figure 32).

39. How does the current flow in the reproducer? The current flowing out of the crystal detector is now a series of direct-current pulses of varying amplitude. These variations of amplitude

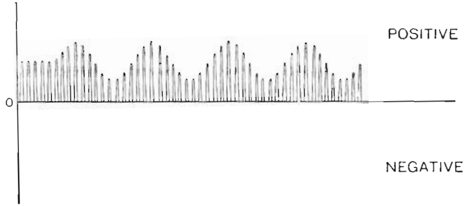


Fig. 32. Graph showing flow of pulsating direct current through the crystal detector. Note the action of the detector.

correspond to the curve described by the current that was set flowing by sound waves striking the microphone at the broadcasting station. If we again take our hypothetical radio station broadcasting at a frequency of 500 kc. per second, each such direct-current pulse lasts for one one-millionth of a second and is separated from its neighbor by an interval of one one-millionth of a second when no current flows.

As you already know, the diaphragms of the phones cannot respond to a pulse of such short duration, but since each pulse is flowing in the same direction, a series or train of such pulses makes its effect felt. The result on the phones, then, is the same as if a continuous, but varying, direct current, equal to the average of all these pulses, were to pass through the coils. This effect can be shown on the graph by joining the peaks of these pulses with a continuous line. We call such a line the *envelope* of the wave (see Figure 33). You will notice that this envelope has the same shape as the current set up by the microphone at the broadcasting station. We have now succeeded in making the carrier wave take the form of the modulating current; and it is this modulating

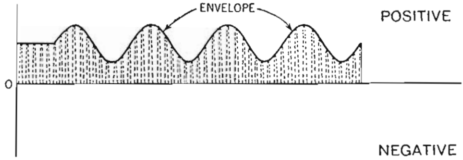


Fig. 33. Graph showing flow of fluctuating direct current through the phones. This current flow is indicated by the envelope. Note that the envelope has the same shape as the fluctuating direct current from the microphone in Figure 29-A.

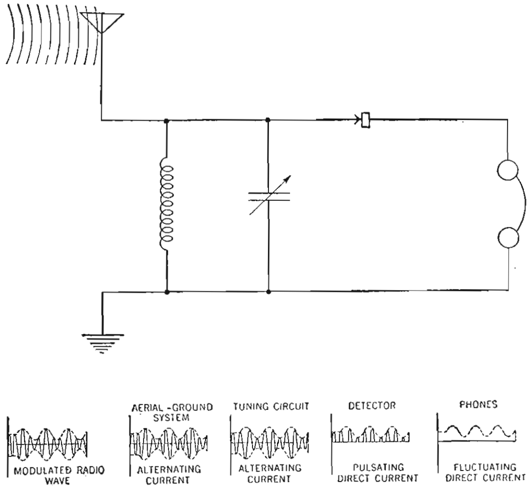


Fig. 34. Hookup of complete crystal receiver showing wave forms of electric currents flowing in the various parts.

current acting through our phones, that reproduces the sound originally created at the broadcasting station.

SUMMARY

1. A **graph** is a picture of values or quantities, usually shown by lines or dots.

2. Graphs in scientific work usually show relations between two or more **variable** quantities.

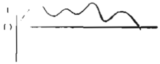
3. The line which pictures the course of any event in a graph is called a **curve.**

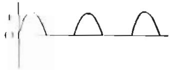
4. The **sine curve** is the graph which shows the wave form of a simple alternating current.

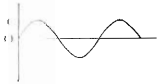
5. Three forms of radio waves must be distinguished; **carrier** or **continuous** wave, **damped** wave, and **amplitude-modulated** carrier wave.

SYMBOLS


Graph showing a steady direct current.

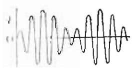

Graph showing a fluctuating direct current.


Graph showing a pulsating direct current.


Graph of a sine curve (alternating current).


Graph of a carrier wave.


Graph of a damped wave.


Graph of an amplitude-modulated carrier wave.

CHECK-UP

Part A

Underscore the words or phrases that make correct statements. (Answers are on page 300.)

1. The picture showing the relation between conditions as the conditions change is known as a (*wave form*) (*curve*) (*graph*).

2. In any curve showing current variation, the (*frequency*) (*strength*) (*direction*) of the current at any one instant is indicated by the distance from the line of no current flow.

3. A wave whose form is that of a smooth sine curve and whose maximum amplitude is constant is called a (*carrier*) (*damped*) (*modulated*) wave.

4. A wave whose form is that of a smooth sine curve but with the maximum amplitudes of successive cycles decreasing gradually is called a (*continuous*) (*damped*) (*positive*) wave.

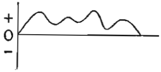
5. A fluctuating direct current produced by a microphone, when mixed with a radio-frequency carrier wave, produces a (*modulated radio*) (*continuous*) (*fluctuating*) wave.

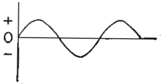
6. The (*amplitude*) (*envelope*) (*sine curve*) of an amplitude-modulated wave is the line joining the peak amplitudes of the radio-frequency alternating current and has wave form that is (*the opposite of*) (*the same as*) (*somewhat like*) the current set up by the microphone at the broadcasting station.

Part B

In the parentheses opposite each item in column A, place the letter of the drawing in column B that the item best describes or applies to.

Column A — *Column B*

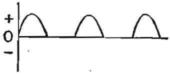
1. Carrier wave. ( ) (a) 

2. Damped wave. ( ) (b) 

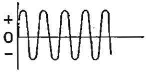
Column A | *Column B*

3. Amplitude-modulated carrier wave. ( ) (c)

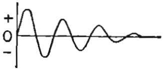
4. Sine curve of low frequency. ( ) (d)



5. Pulsating direct current. ( ) (e)



6. Fluctuating direct current. ( ) (f)



7. Steady direct current. ( ) (g)

CHAPTER 9

The Antenna Coupler

QUESTIONS THIS CHAPTER ANSWERS

1. *What are the faults of a tuner having but one coil?*
2. *What are the principles of a transformer?*
3. *How do we use a transformer to make a receiver tune more sharply?*

40. Why do we sometimes hear two stations at once? In continuing our study of radio, we shall follow the plan of pointing out certain faults and shortcomings of our simple sets. Then we shall explain the various methods of correcting these faults.

Let us study the tuner. The function of the tuning circuit is to select the wave of desired frequency and reject all others. While the tuner you built does this job fairly well, it occasionally fails to separate two stations completely, especially if these stations are quite powerful, close to your home, and not much different in frequency. You then hear a fairly loud broadcast from one station and in the background, although a good deal weaker, the *signal* or program from another station.

Theoretically, the tuning circuit should pass only a narrow band of frequencies. But because some resistance to the flow of current is always present in the circuit, other frequencies creep in. When this resistance becomes too great, two stations may be heard at the same time.

We can draw a picture to represent this situation. In Figure 35, we have assumed that the station desired has a frequency of 1000 kc. Let us assume also that there is no difference in the distance or power of the stations. Along the horizontal line we have indicated successive frequencies from 960 kc. to 1040 kc. Along the vertical line we have indicated the loudness of the signal received. The amplitude of the curve at any point then represents the loudness with which a signal of that particular frequency will be heard when your tuner is set for 1000 kc. If the amplitude at that frequency rises above the line marked "audibility level," the signal will be heard in the earphones. If it does not reach that level, the signal will not be heard and therefore will not interfere.

You will notice from the graph in Figure 35 that this particular tuner will permit three stations to be heard simultaneously, the

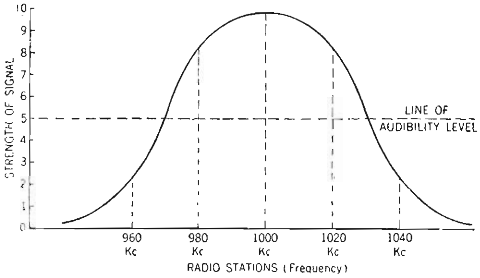


Fig. 35. Graph or tuning curve showing what happens when a receiver tunes broadly. Note that unwanted radio stations at 980 kc. and 1020 kc. come in well above the line of audibility level. This condition means that three stations may be heard at the same time.

one we want at 1000 kc. and two unwanted ones at 980 kc. and 1020 kc. We say that such a set *tunes broadly*. We can remedy this fault by redesigning our tuner so it will have a tuning curve that will correspond to Figure 36. Note that now the amplitude of every station except the one desired falls below the line of audibility level. Such a set, we say, *tunes sharply*.

41. How can we reduce the resistance in the tuner? In practice, we accomplish the desired change by reducing the resistance of the tuning circuit. Examine again the circuit diagram of your crystal receiver in Figure 22. You will notice that the aerial-ground system is connected directly across the tuning circuit;

that is, the aerial is connected to one end, and the ground is connected to the other end. Thus, the aerial-ground connection increases the resistance in the tuner. This increased resistance means that the tuned circuit will have less effect and will tune broadly.

The tuned circuit will tune very sharply if the aerial-ground connection is removed because then the resistance is very small in the tuned circuit. It would be ideal if we were able to transfer to the tuner the electrical currents flowing in the aerial-ground

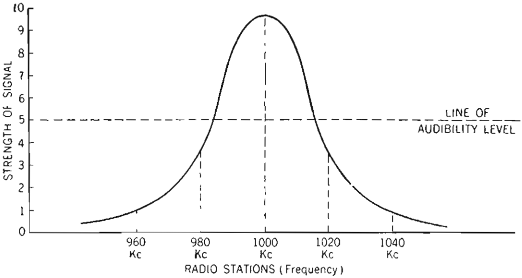


Fig. 36. Graph or tuning curve for a sharply tuning receiver. Note that all unwanted radio stations fall below the line of audibility level.

system, and yet not increase the resistance in the tuner. Our receiver then would tune sharply and make it possible to select only the desired radio station. It is possible to reduce the resistance of the tuning circuit to a very low value. This improvement can be accomplished by the use of a *transformer*.

42. What is a transformer? To see how this undesirable resistance is kept out, you must first learn what we mean by a *transformer*. You already know that when an electric current flows through a coil of wire, it sets up a magnetic field around this coil. When this magnetic field cuts across a conductor, it sets up an electrical pressure or voltage which in turn sets a current flowing, if there is a path through which it can flow.

We can have this magnetic field cut across a conductor in two ways: we can either have a stationary magnetic field set up by a steady direct current flowing through the coil and use a moving conductor, or we may have a moving magnetic field and a stationary conductor. This moving magnetic field can be produced when either a fluctuating direct current or an alternating current passes through the coil. The magnetic field is built up and collapsed in step with the variations of current in the coil.

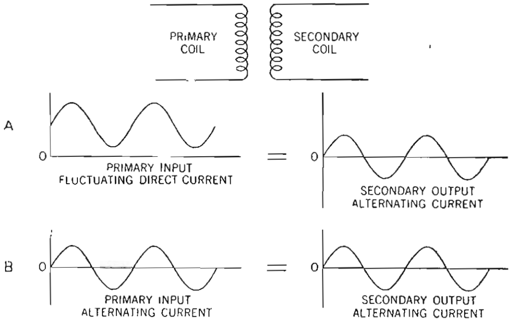


Fig. 37. Diagram showing that if a fluctuating direct current (A) or an alternating current (B) is sent into the primary of a transformer, the output from the secondary coil is always an alternating current.

In the transformer we have two stationary coils. We call one the *primary* and the other the *secondary*. We pass a fluctuating direct current or an alternating current through the primary coil. This current causes the magnetic field around the primary to fluctuate in step with it. This fluctuating magnetic field, cutting across the turns of the secondary coil, sets up a fluctuating electrical pressure that in turn causes an alternating current to flow in the secondary when there is a closed circuit. This alternating current corresponds in form to the fluctuating part of the direct current or the alternating current in the primary.

43. What are step-up and step-down transformers? Here is another interesting thing about a transformer. As you know, the fluctuating magnetic field cutting across the turns or loops of wire of the secondary coil sets up an electrical pressure or voltage in those loops. For low-frequency currents (up to about 15,000 cycles per second) an iron core, called a *magnetic circuit*, is placed so that it passes through both the primary and secondary coils. A magnetic field tends to pass through iron rather than through air. Thus, practically all the magnetic field is concentrated in the iron core. Since this iron core passes through both the primary and secondary coils, the same magnetic field surrounds both the primary coil and the secondary coil. Hence, if

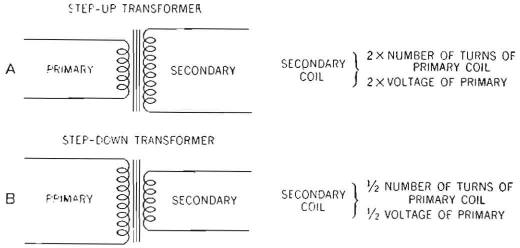


Fig. 38. (A) Step-up transformer. (B) Step-down transformer.

we have more loops in the secondary coil than in the primary coil, we have a greater total voltage in the secondary. If we have fewer loops in the secondary than in the primary, we have a smaller total voltage in the secondary.

Thus by varying the ratio between the number of turns of wire in the primary and secondary coils we can get a greater or smaller voltage in the secondary coil. For example, if the secondary coil has twice the number of turns that are in the primary coil, the voltage in the secondary will be twice that in the primary coil. We call such a transformer a *step-up transformer*. If, however, the secondary winding has half the number of turns that are in the primary winding, the voltage set up in the secondary winding will be half the voltage in the primary. We call such a transformer a *step-down transformer*.

44. **What is an antenna coupler?** In dealing with radio-frequency currents (that is, alternating currents whose frequencies are the same as the radio waves), iron-core magnetic circuits are seldom used because of the high loss of energy in the iron core. Hence an air core must be used, with the result that a very small amount of the primary field will cut across the turns of the secondary coil. The step-up or step-down effect of an iron-core transformer cannot be used. Fortunately, there is another way to obtain this effect at radio frequencies.

You will recall that we were seeking a method for transferring the electrical current from the aerial-ground system to the tuning circuit and, at the same time, permitting the tuning circuit to operate freely. The air-core transformer is the answer. If we make the tuning coil of the receiver the secondary of our transformer and hook the primary into the aerial-ground system, we have solved our problem (Figure 39).

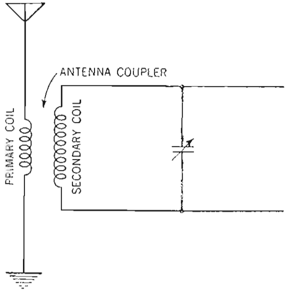


Fig. 39. Diagram showing how an antenna coupler or transformer is connected in the radio receiver. Note that the path of the aerial-ground system no longer passes directly through the tuning circuit.

Now the current in the primary (set flowing by the radio wave passing across the aerial) causes a little of its magnetic field to cut across the turns or loops of the secondary coil. This movement of the magnetic field produces a small electrical pressure or voltage in those loops. When the secondary circuit is tuned, this small voltage in the loops of the secondary coil produces a much larger voltage across the tuned circuit. This arrangement, in effect, is a step-up transformer. The step-up in this case depends upon the resistance in the tuned circuit and not on the turns ratio. Since the tuned circuit is coupled magnetically (that is, linked by the magnetic field rather than by wire connections) to the aerial-ground circuit, it receives the desired electrical energy without appreciably increasing the resistance in the tuned circuit.

Such a transformer used at this point is called an *antenna coupler* or transformer. Through its use we obtain sharper tuning, that is, we are able to keep out unwanted stations, since we have reduced the resistance of our tuning circuit. To make such an antenna coupler, all you have to do is to wind upon the same tube that has your tuner coil an additional winding of about 15 turns of wire (the primary winding). Separate the two windings about $\frac{1}{8}$ in. Connect the lead-in from the aerial to one end of the primary winding and the ground to the other. Try reversing the aerial and ground connections to this winding to obtain best results. Your improved crystal receiver will now appear as in Figure 40.

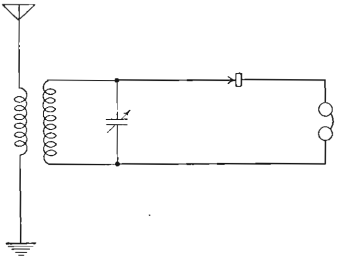


Fig. 40. Improved crystal receiver, using an antenna coupler. This set will tune sharper than that of Figure 22.

SUMMARY

1. One of the faults of the **tuner** consisting of a single coil is that it does not sharply separate different stations.

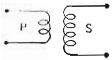
2. This fault may be partially corrected by a **transformer.**

3. The transformer consists of two coils unconnected but wound upon the same core. In such a device, the magnetic field created by a current in one coil transfers the energy to the other coil. In the second coil the fluctuation in the current induced therein will follow the pattern of the current in the first coil.

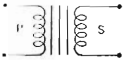
4. In an iron-core transformer the voltages in the primary and secondary coils are in direct ratio to the number of turns of wire in the coils.

5. An **antenna coupler** is an air-core transformer having the primary in the antenna circuit and the secondary in the tuner circuit.

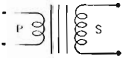
SYMBOLS



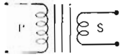
Transformer with air for a core, such as the antenna coupler.



Transformer wound on an iron core.



Step-up iron-core transformer.



Step-down iron-core transformer.

CHECK-UP

If a statement is true, encircle the T. If a statement is false, encircle the F. (Answers are on page 300.)

T F **1.** A set is said to "tune broadly" when it can tune in many stations at once.

T F **2.** The use of an antenna coupler broadens the tuning of a receiver.

T F **3.** A set can be made to "tune more sharply" by reducing the resistance of the tuning circuit.

T F **4.** The wave form of the voltage output of the secondary of a transformer corresponds to that of the primary.

T F **5.** A step-down transformer is one which has a lower voltage impressed across the primary than the voltage induced in the secondary.

T F **6.** We may use a varying direct current in the primary of a transformer to get an alternating current in the secondary.

CHAPTER 10

Electron Flow in the Aerial-ground System

QUESTIONS THIS CHAPTER ANSWERS

1. *How does a dry cell produce an electromotive force?*
2. *What are two kinds of alternating-current generators?*
3. *What kinds of currents are produced in the aerial-ground system by radio waves?*

45. How is a dry cell an electron "pump"? You have learned that an electric current consists of a flow of electrons through a conductor that forms a complete circuit or path for the current.

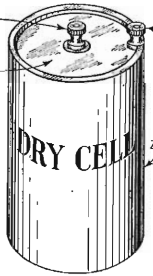


Fig. 41. The dry cell.

Let us see if this theory can give us some new light upon what happens in a radio receiver.

Look at a dry cell. You will notice that it is a can made of zinc, closed at one end. The other end is sealed with some insulator such as sealing wax or pitch. In the center of the sealing wax you will notice a binding post on a carbon rod. This post may be marked POSITIVE or +. At the same end of the cell, but fastened to the zinc, is a second binding post which may be marked NEGATIVE or −. The inside of the can is filled with certain chemicals. The carbon rod in a dry cell is called the *positive pole* and the zinc is called the *negative pole*. It is customary to name the pole from which electrons leave the cell the negative pole. In general the terminals of a battery or cell are called *poles* or *electrodes*.

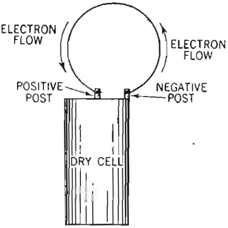


Fig. 42. The dry cell is a sort of pump sending electrons streaming from the negative post to the positive post when a path is furnished.

You may not have heard it, but a dry cell is sometimes called an electron "pump." The chemical action inside the cell builds up a pressure of electrons. This pressure exists, even when no electrons are flowing. You can understand this if you think of a water faucet. The water behind the faucet is under a pressure even when the faucet is closed and no water is flowing. When the faucet is opened, the water flows out.

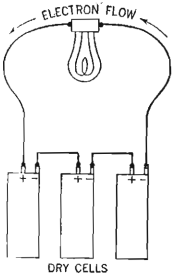


Fig. 43. Three dry cells connected in series.

So it is with the electrons in the dry cell. They accumulate at the negative pole and thus produce a pressure. When a path is furnished them by connecting a conductor between the negative and positive posts of the dry cell, electrons will flow out of the negative post of the cell, through the conductor, and back into the positive post of the cell.

46. What is electromotive force (E.M.F.)?

The dry cell piles up electrons at the negative post and creates a deficiency of electrons at the positive post. *When electrons are given a path to travel, they will always move from the place where they have been piled up* *to a place where there is a deficiency.* When electrons are in excess at a point, we say that point has a *negative charge.* If given a path, then, electrons will flow from a point with a negative charge to a point with a positive charge. In other words, *electromotive force* (E.M.F.) is the tendency of electrons to move from a place where there are many electrons to a place where there are fewer electrons.

If two or more dry cells are connected in *series,* that is, with the positive post of one connected to the negative post of the other, the effect is as if two or more pumps were connected together. The E.M.F. (or voltage) of the two cells is equal to the sum of their voltages. This increased E.M.F. causes more electrons to flow through any given circuit than does one cell.

Another thing to remember about electrons is that they repel each other. So while electrons will be attracted to a point with a positive charge (a deficiency of electrons), they will be repelled from a point with a negative charge (an excess of electrons).

47. How are alternating currents produced? Since a dry cell can generate only a direct current, we have been considering the flow of electrons in one direction only, that is, *direct current (D.C.).* But if a pump could be devised that would cause electrons to flow first in one direction and then in the other, the current then would be called *alternating current (A.C.).*

We have no such battery, but we have another kind of "pump" to make current flow first in one direction and then in the other. It is called an *alternating-current (A.C.) generator.* One form is the tremendous generator at the power house that supplies the current for our electric lights and electrical implements. The current is usually produced by passing conductors through magnetic fields; that is, an armature made of thousands of turns of wire on an iron core whirls between the poles of strong magnets. Each complete movement of a conductor through a magnetic field is called a cycle, and in each cycle the direction of the current changes twice. The stream of electrons pumped out by most A.C. generators changes its direction of flow 120 times in a second. Hence we call the electric current from such a generator a *60-cycle alternating current.*

Another modern pump to produce alternating current is the marvelous device called the *radio tube.* At the broadcasting station one of these radio tubes sends a stream of electrons which changes its direction of flow millions of times a second into the aerial system of the transmitter! As you have already

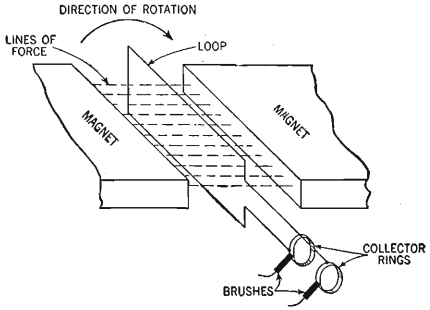


Fig. 44. **A simple alternating-current generator: a single loop of wire rotating in the magnetic field between two poles of a magnet.**

learned, we call such an electric current a *radio-frequency alternating current.*

48. How do alternating currents flow in the aerial-ground system? By this time you know that the radio wave passing across your aerial causes an alternating current to flow up and down the aerial-ground system. The radio wave sets up an electrical pressure that causes the electrons to flow through the circuit. When electrons move back and forth through a circuit, we say that they *oscillate.* See if you can picture how this oscillation takes place, by referring to Figure 45.

Here is the explanation. The radio wave, moving across the aerial-ground system, sets up for an instant a negative charge on the aerial and a positive charge on the ground of the system. The electrons, *which are present in the system at all times,* are set flowing *down* the aerial-ground system. These electrons move through the aerial wire, then through the lead-in wire, then through the primary of the antenna coupler and into the ground. We show this flow on the graph in Figure 45-B.

The curve starts from point *A* on the line where the electrons are at a standstill. It gradually increases its instantaneous amplitude (the rate of electron flow), until at *B* the electrons are flowing at their maximum rate. Then these electrons start to slow down, still flowing down the aerial system, until they reach a standstill at point *C*.

The radio wave has now reversed the direction of its electrical pressure. There is a positive charge on the aerial and a negative

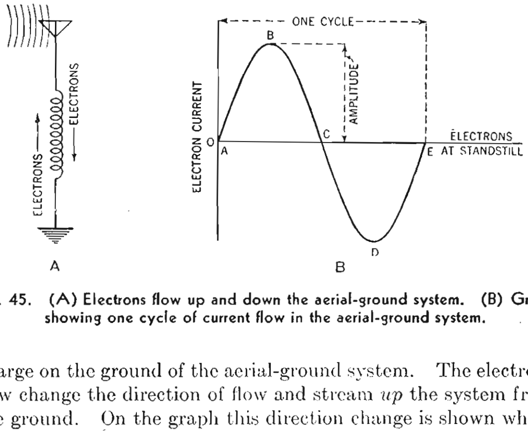


Fig. 45. (A) Electrons flow up and down the aerial-ground system. (B) Graph showing one cycle of current flow in the aerial-ground system.

charge on the ground of the aerial-ground system. The electrons now change the direction of flow and stream *up* the system from the ground. On the graph this direction change is shown where the curve starts its bottom loop. The electrons, moving in the reversed direction, now increase their rate of flow until the rate reaches its maximum at point *D* on the curve and then slows down to a standstill at point *E*.

The electron flow has gone through one cycle. In one second there may be millions of such cycles, corresponding to the frequency of the radio waves. We cannot show more than a few in a graph, but we plan the graph so that it shows the frequency by the time intervals along the horizontal line. The instantaneous amplitude of each of the graph loops, too, corresponds to the instantaneous amplitude of each loop in the current generated by the radio wave, as you have learned in Chapter 8.

SUMMARY

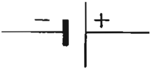
1. The dry cell may be considered an electron pump. It consists of a zinc can, which is the **negative** pole or electrode, and a carbon rod, which is the **positive** pole or electrode. The inside of the zinc can contains certain chemicals which, together with the zinc and carbon, act to place an excess of electrons on the zinc and a deficiency of electrons on the carbon, thus creating an electrical pressure or **electromotive force** between these two electrodes. If given an external path between these two electrodes, the electrons will always travel in one direction—from the point of excess (negative electrode) to the point of deficiency (positive electrode). We call this type of electron flow **direct current.**

2. Another type of **electron pump** which causes electrons to flow first in one direction and then in the other direction through a conductor is the **alternating-current generator.** This type of electron flow is called **alternating current.** As the electrons flow first in one direction and then reverse and flow in the other, we say that the alternating current has gone through one cycle. The number of cycles per second is called the **frequency.** Generators used to supply alternating current to our house lines usually have a frequency of 60 cycles per second.

3. Another type of alternating-current generator is the **radio tube.** This device is capable of generating alternating currents whose frequencies may be as high as millions of cycles per second. These radio tubes are used in radio broadcasting stations.

4. As the radio wave moves across the aerial of the receiver, it sets a high-frequency alternating current flowing in the aerial-ground system.

SYMBOLS



A cell.

Several cells in series.

CHECK-UP

In the blank spaces write the words, phrases, or numbers needed to complete the statements correctly. (Answers are on page 300.)

1. The positive pole of a dry cell is made of ....; the negative pole is made of ....

2. Electrons in a circuit connected across a dry cell will always move from the .... pole to the .... pole.

3. When two dry cells of 1.5 volts each are connected in series, the voltage is ....

4. Electrons tend to .... each other.

5. A cell or battery will give only a .... type of current.

6. Alternating currents can be produced by an .... or by an ....

7. A 60-cycle alternating current has .... reversals of direction of electron flow per second.

8. The type of current set flowing in the aerial-ground system by a radio wave is .... type of current.

9. Another name for voltage is ....

10. When there is a deficiency or shortage of electrons at any given point in a circuit, we say that that point has a .... charge.

11. In each cycle of an alternating current, the current changes direction .... times.

12. The instant of greatest rate of flow of electrons in a cycle is called the .... of the cycle.

CHAPTER 11

Electron Flow in the Tuning Circuit

QUESTIONS THIS CHAPTER ANSWERS

1. *How are currents induced in conductors?*

2. *What is the explanation of "charging" and "discharging" a capacitor?*

3. *What is meant by self-induction?*

4. *How are the oscillations of the tuning circuit produced?*

49. What is an induced current? You have just learned that the radio wave sets electrons moving up and down the aerial-ground system. Now let us see the effects of this alternating current upon the other parts of our receiver. First of all you should know that every electric current is accompanied by a magnetic field; that is, if a current of electricity is passing along a wire, there is a magnetic field of force around the wire. You should also know that when this magnetic field cuts through a conductor or is cut through by a moving conductor, or even when there is any fluctuation in a magnetic field near a conductor, the result is an *induced voltage* across the conductor.

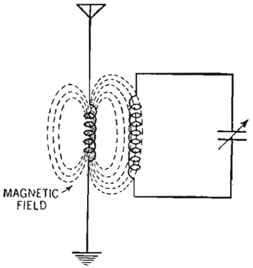


Fig. 46. Diagram showing how a magnetic field around the primary of the antenna coupler cuts across the turns of the secondary.

Our antenna coupler is a combination of two unconnected coils so related that any alternating or fluctuating current in either one will set up, by induction, an alternating current in the other.

The relationship of electromotive force, current, and rate of change, in one such induction coil, is known as *inductance*, or in the case of two coils coupled, as *mutual inductance.*

Here we have an explanation of how the electrical energy of the aerial-ground system is transferred to the tuning circuit through the antenna coupler. The sequence of events is: (1) The radio wave sets up an alternating current in the aerial-ground system, and especially in the primary coil of the antenna coupler. (2) This alternating current is accompanied by an alternating magnetic field around the primary coil. (3) This magnetic field cuts through the conductors in the secondary coil of the antenna coupler. (4) Alternating currents in step with the radio waves are induced in the secondary coil. (5) These alternating currents, of radio frequency, are transmitted through all parts of the tuning circuit. The frequency of the current set flowing in the tuning circuit is the same as that in the aerial-ground system. The variations in amplitude of each cycle likewise follow the variations in amplitude of the current in the aerial-ground system.

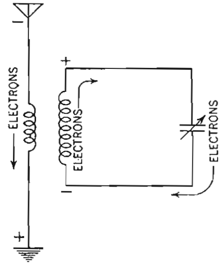


Fig. 47. Diagram showing electrical charges and direction of electron flow in the aerial-ground system and tuning circuit during a half-cycle of current flow. During the next half-cycle, the charges and flow of electrons are reversed.

Now let us examine the electron flow in the tuning circuit. You will recall that this circuit consists of a capacitor and inductance connected together. We will examine each part separately, with special attention to the behavior of the electrons.

THE CAPACITOR

50. How is a capacitor charged and discharged? As you know, a capacitor consists of two or more metal plates (or conductors) separated by a dielectric (or insulator). A conductor is a substance that permits electrons to flow through it quite easily.

An insulator is a substance that does not permit electrons to flow through it readily.

Now, if you can do so, obtain a capacitor whose capacity is about 1 microfarad (1 μfd.) and connect it to a 45-volt battery for a few seconds. Disconnect the battery. By means of a piece of wire, connect one plate of the capacitor to the other. You will notice a spark jump from the end of the wire to the second plate of the capacitor just as you are about to touch them together.

This phenomenon is explained as follows: When you connected the battery to the capacitor as in Figure 48-A, electrons were

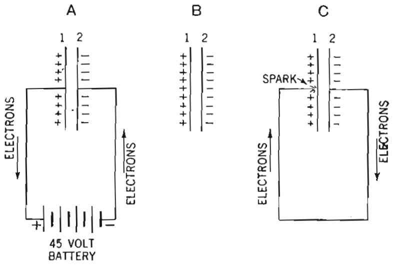


Fig. 48. (A) Charging a capacitor. (B) A charged capacitor. (C) Discharging a capacitor.

pumped onto plate 2 of the capacitor from the negative post of the battery; that is to say, plate 2 received a *negative charge.* This negative charge tended to repel electrons from plate 1. At the same time the positive post of the battery drew away some of the electrons from plate 1 to satisfy its deficiency. Thus, a deficiency was created on plate 1, which means that a *positive charge* was placed there. The dielectric prevented the flow of electrons through the capacitor from plate 2 to plate 1. We call this process *charging* a capacitor.

When you removed the battery and wires, as in Figure 48-B, the charges remained on the plates of the capacitor because there was no path over which the electrons could flow from the negative to the positive plate. Then you attached a wire to plate 2 of the capacitor, as in Figure 48-C. So great was the tendency of the electrons piled up on that plate to get over to plate 1 (where there was a deficiency of electrons), that they could not wait for the circuit to be closed, but actually jumped across the small gap just before you touched the end of the wire to plate 1. That was the spark you saw. This process is called *discharging* a capacitor.

51. What is an oscillatory discharge? But in their surge to get to plate 1, a good many more electrons rushed across than were

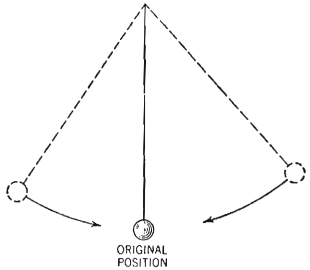


Fig. 49. Diagram of pendulum illustrating electrons rushing from one plate of the capacitor to the other during discharge.

necessary to make up for the deficiency. As a result, plate 1 had an excess of electrons, and plate 2 a deficiency of them. The charges were thus reversed. The electrons thereupon surged from plate 1 to plate 2. Again too many rushed across, and again the charges were reversed. These oscillations continued to become gradually weaker and finally stopped.

You may understand this better by comparing the motion of the electrons to the behavior of a pendulum. First consider a pendulum at rest. The weight points straight down. Now raise the weight to one side. You have created a stress in this case due to the force of gravity which tends to bring the weight to its original position. Now release the weight. It rushes back to its original position but overshoots the mark and swings on to the other side. The stress thereupon pulls it down again. It rushes back toward the lowest point but again overshoots its mark. It makes many such swings, each one of less amplitude, before it finally comes to rest.

The electrons in the capacitor, when discharging across a gap or conductor, surge back and forth many times before they come to rest. All this happens in a very small part of a second. We call this swinging of electrons back and forth an *oscillatory discharge*. The capacitance of the capacitor is a factor which determines the frequency or rate of these oscillations.

SELF-INDUCTION

52. What is back electromotive force? Our study of induction up to this point has been limited to showing how an electrical

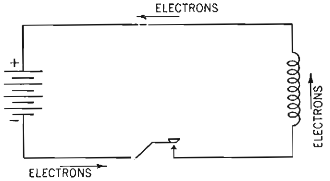


Fig. 50. Hookup of coil, key, and battery to illustrate self-induction.

current, flowing in one coil, sets up a magnetic field that cuts across the turns of a second coil and causes a current to flow in the second coil. Now let us see what happens in the original coil.

Suppose you were to hook up a coil (such as your original tuner coil of 90 turns), a battery, and a key as shown in Figure 50. At the instant the key is closed, electrons start flowing from the negative post of the battery through the circuit in a counterclockwise direction, as shown by the arrows. The current flow causes a magnetic field to be built up around the coil. This magnetic field, at the instant it is formed, cuts across the turns of the coil and sets up an electrical pressure (E.M.F.) in the coil which will start a second stream of electrons flowing in the coil. This second stream of electrons is only momentary and always is in a direction which *opposes* the original flow of electrons sent out by the battery. The effect, however, is to slow down the speed with which the battery can send electrons through the coil.

After the key has been closed for a while, a steady direct current will flow through the coil. The magnetic field is now stationary. The backward-flowing second stream of electrons lasted only an instant, when the magnetic field was first formed. Now the original flow of electrons from the battery will pass through unhampered.

53. What is self-induction? As the key is opened, the magnetic field collapses. Again a changing magnetic field will cut across the turns of the coil, and again it will set a second momentary stream of electrons flowing through the coil. This time the second electron stream will be in the original direction of electron flow, that is, counterclockwise. This momentary pressure now acts to oppose the stopping of the electron stream from the battery; thus it tends to keep the electrons flowing through the coil for a short interval of time after the key is opened.

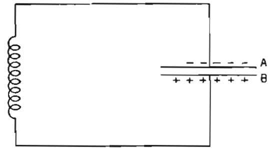


Fig. 51. Tuning circuit, showing charged capacitor.

In summary, the motion of electrons set up in the coil by a change in the magnetic field, at the moment the key is closed or opened, will always oppose the action of the battery. The phenomenon described above is known as *self-induction*. Both the diameter and the number of turns in a coil (that is, its "electrical size") affect its properties of self-induction.

54. What determines the natural frequency or rate of oscillation in the tuning circuit? Now connect your capacitor to the coil. This is the tuning circuit. Let us study the diagram of this circuit in Figure 51. Assume that a negative charge has been placed upon plate A of the capacitor and a positive charge upon plate B. Now the capacitor starts to discharge through the coil. The electrons surge back and forth (*oscillate*) from plate A, through the coil, onto plate B and back again, many times a second. The speed with which these electrons rush from one plate to the other (or oscillate in the tuning circuit) depends upon the electrical size of the capacitor.

But as this alternating current flows through the coil, the self-induction in that coil slows down this flow of electrons. So you see that it is really the electrical sizes of the capacitor and coil

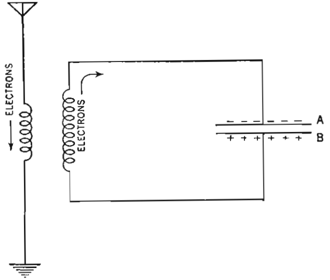


Fig. 52. Diagram showing how the capacitor got its charge.

that determine the rate at which the electrons oscillate in the tuning circuit. Another way of saying this is that the electrical sizes of the capacitor and coil determine the *natural frequency* of the tuning circuit.

The question now arises, where does the capacitor get its charge? Examine Figure 52. You will notice that when electrons are flowing *down* the primary of the antenna coupler, they induce a voltage in the secondary which causes electrons to flow in the tuning circuit in a clockwise direction. This flow causes electrons to pile up on capacitor plate A, and a deficiency of electrons results on plate B. Then, for an instant before reversing their direction, the electrons will cease moving in the primary of the antenna coupler. Nevertheless, at this instant self-induction in the secondary of the coupler continues to pile up electrons on capacitor plate A.

When the electron flow in the primary reverses itself, electrons begin to be piled up on plate B of the capacitor. So you see that the flow of electrons in the primary of the antenna coupler sets a stream of electrons oscillating in the tuning circuit. The frequency of this oscillation depends upon the frequency with which the electron flow in the primary reverses itself. This frequency in turn depends upon the frequency of the radio wave.

55. How are aerial and tuning-circuit oscillations placed in resonance? But we must not forget the other stream of electrons set flowing in the tuning circuit by the discharging of the capacitor (see §54). The frequency of this second oscillation depends, as you have seen, upon the electrical values of the coil and capacitor. Now if these two sets of oscillations are in step, all is well and they will work together. But should they be out of step, they will interfere with each other and quickly destroy all flow of electrons. If they are in step, we say that they are in *resonance*. We therefore select the proper values of inductance and capacitance to place our tuning circuit in resonance with the radio station we desire. Then oscillations caused by that station's wave are built up in our tuning circuit. Signals from stations of different frequencies cause oscillations that are out of step and they die away.

In practice, we usually keep the electrical size of the inductance constant and vary the capacitance of the capacitor to place our tuning circuit in resonance with the radio station we wish to receive.

SUMMARY

1. The radio wave passing across the aerial starts an alternating current flowing in the aerial-ground system.

2. This alternating current causes a fluctuating magnetic field to be built up around the primary of the antenna coupler.

3. This magnetic field cuts across the loops of the secondary of the antenna coupler and sets flowing in the tuning circuit an alternating current that is in step with the variations of the current flowing in the aerial-ground system.

4. Tuning is accomplished by the **inductance** of the secondary of the antenna coupler and the **capacitance** of the variable tuning capacitor. When the **natural frequency** of the tuning circuit is the same as the frequency of the alternating currents that the radio wave sets flowing in the aerial-ground system, maximum transfer of electrical energy from the aerial-ground system to the tuning circuit takes place, and the oscillations of electrons in the tuning circuit are built up.

CHECK-UP

Underscore the words or phrases that correctly complete the statements. (Answers are on page 300.)

1. An example of (*mutual inductance*) (*oscillatory discharge*) (*direct-current pulsations*) is found in the antenna coupler.

2. When a fluctuating magnetic field cuts across a conductor in a separate circuit, (*a pulsating direct*) (*an alternating*) (*a high-frequency direct*) current is induced in the separate circuit.

3. The frequency of the current set flowing in the tuning circuit is (*lower than*) (*greater than*) (*the same as*) that in the aerial-ground system for any one station.

4. A capacitor usually consists of two (*coils*) (*metal plates*) (*insulators*) separated by (*a dielectric*) (*a switch*) (*a transformer*).

5. A capacitor discharging through a conductor gives a type of discharge which is said to be (*alternating*) (*oscillatory*) (*high-frequency*).

6. (*a*) When the switch is closed and current begins to flow through a coil, a voltage is induced in the coil which (*opposes*) (*helps*) (*does not affect*) the original impressed current.

(*b*) When the switch is opened, a voltage is induced which tends to (*keep the current flowing*) (*stop the current*) (*make the current pulsate*).

(*c*) These results happen because of the condition known as (*oscillation*) (*self-inductance*) (*E.M.F.*) in the coil.

7. In a tuning circuit, the electrical sizes of the (*wire*) (*E.M.F.*) (*coil*) and of the (*back E.M.F.*) (*battery*) (*capacitor*) determine the natural frequency of the circuit.

8. In usual practice, to tune for a station with our tuning circuit, we keep the electrical size of our (*inductor*) (*battery*) (*capacitor*) constant and vary the electrical size of the (*inductor*) (*capacitor*) (*battery*).

CHAPTER 12

Electron Flow in the Crystal Detector and Phones

QUESTIONS THIS CHAPTER ANSWERS

1. *What are parallel circuits?*
2. *How are the detector and phones connected to the tuning circuit?*
3. *What kind of current flows through the phones?*
4. *Why is a fixed capacitor needed to make the phone diaphragms vibrate?*

---

56. How are detector and phones connected in the tuning circuit? Up to now you have seen a stream of electrons oscillating through the tuning circuit many times each second. Now for the next step. Let us see what happens in the detector and the phones.

Across the capacitor of the tuning circuit connect a loop of wire, which will have some resistance, as shown in Figure 53. When a stream of electrons starts to flow up the primary of the antenna coupler (Figure 53-A), another stream of electrons flows down through the secondary winding of the antenna coupler. The electrons are piled up on plate 2 of the capacitor. As long as plate 2 of the capacitor has an excess of electrons point y is negative with respect to point x. Since point y is connected to x through the loop of wire some of these electrons flow around this parallel path. We say that the capacitor and loop of wire are two paths parallel to each other. A parallel circuit is also called a *shunt circuit.* In parallel circuits, the electrons have two or more parallel paths and flow at the same time through all of these paths.

Beginning at the instant the capacitor has no charge, the electrons start to pile up on plate 2 as shown in Figure 53-A. Figure 53-A covers the time from the instant the capacitor has no charge until the instant that the capacitor is fully charged.

Figure 53-B covers the time from the instant the capacitor is fully charged until the capacitor is completely discharged. During this period of time most of the electrons flow from plate 2

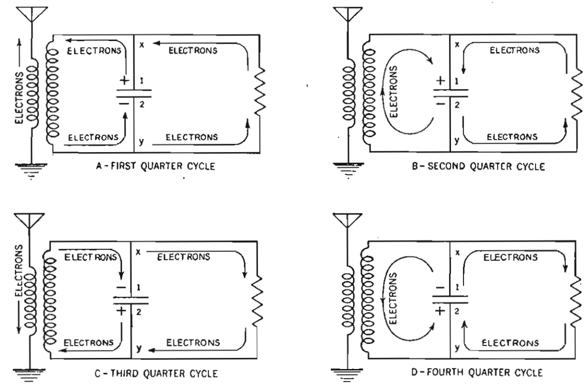


Fig. 53. Electron flow during one cycle.

to plate 1 through the coil but some of the electrons continue to flow through the loop of wire from point y to point x, for the reason that point y is connected to plate 2, which has an excess of electrons, and point x is connected to plate 1, which has a deficiency of electrons.

Now the capacitor is completely discharged, but the electron current in the coil is large and continues to flow owing to the inertia effect of the inductance. Figure 53-C shows how the electrons are piled on plate 1 of the capacitor during this quarter cycle. It will be noted that the electrons have also reversed in the primary and are now flowing from the antenna to the ground.

Now that plate 1 is building up an excess of electrons, the flow of electrons through the loop of wire reverses and some electrons flow from point x to point y through the loop of wire. The conditions in the circuit for this quarter cycle have all reversed to the conditions existing during the first quarter cycle illustrated in Figure 53-A. At the end of the quarter cycle illustrated in Figure 53-C the capacitor becomes completely charged.

At the beginning of the last quarter cycle, illustrated in Figure 53-D, the capacitor starts to discharge. The electrons flow through the coil and a few continue to leak off through the loop of wire connected between points x and y. This last quarter cycle is the reverse of the conditions in the second quarter cycle, illustrated in Figure 53-B. At the end of the last quarter cycle, illustrated in Figure 53-D, we are ready to repeat the first quarter cycle, as illustrated in Figure 53-A.

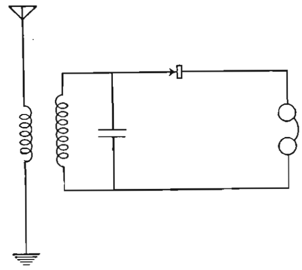


Fig. 54. Diagram showing crystal detector and phones substituted for the loop of wire.

Now substitute the crystal detector and the phones for the loop of wire containing resistance. Electrons then tend to flow through the detector and phones in step with the flow of electrons in the tuning circuit.

57. What kind of current flows through the phones? But hold on! You will remember that the crystal detector acts like an electrical gate, permitting electrons to flow through it only in one direction. Therefore, although the electrons flow back and forth in the tuning circuit, they can flow through the detector and phones in only one direction. In other words, because of the crystal detector, the current that flows through the phones is not an alternating current, but a pulsating direct current. (See Chapter 8, Figure 32.)

The pulses reaching the phones are a series of electron streams, each of very short duration, perhaps one one-millionth of a second or less. Also, the current is direct current; that is, the electrons always move in one direction. You already know that each such electron stream is of too short duration to move the diaphragm of the phones. But when a series or train of such electron streams push together, they can cause the diaphragm to fluctuate, and you can hear a sound. We will investigate how they do it.

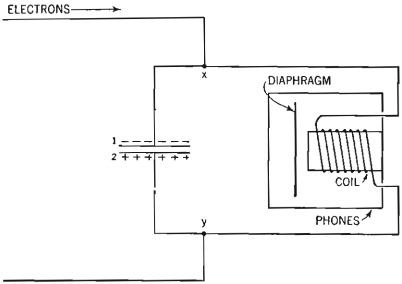


Fig. 55. Diagram showing how electrons flow through the phones.

58. Why is a fixed capacitor used across the phones? Across the phones (parallel to the phones) connect a fixed capacitor. The stream of electrons from the tuning circuit has already passed the detector and now approaches the phones, as indicated by the arrow in Figure 55. At point x this stream divides. One part attempts to pass through the coils of the phones, and the other part piles up electrons on plate 1 of the capacitor. The part attempting to pass through the phones encounters considerable difficulty because the many turns of thin wire in the coils in the phones present a good deal of resistance to the flow. Because of the very short duration of electron flow, only a few electrons find their way through. Most of the electrons, then, pile up on plate 1 of the capacitor.

When the next stream comes along the same thing happens. More and more electrons continue to pile up on plate 1 of the capacitor. The greater the negative charge on plate 1 the greater the positive charge that appears on plate 2 and the greater the tendency of the electrons on plate 1 to make up the deficiency on plate 2.

Since the only way the electrons on plate 1 can get to plate 2 is through the coils of the phones, they must wait until enough electrons have been piled up on plate 1 to overcome the impedance

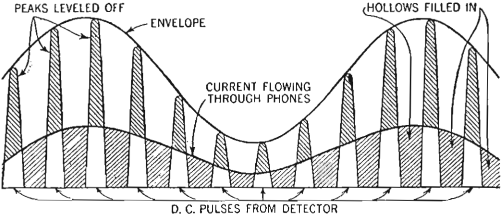


Fig. 56. Graph showing how the capacitor levels off the peaks and fills in the hollows between the pulses of direct current coming from the detector. Note that the resulting curve resembles the envelope quite closely.

offered by the coils. When that pile-up occurs, the flow through the coils of the phones increases, and the diaphragm is strongly attracted. It is these surges of electrons through the coils of the phones that cause the diaphragm to fluctuate and produce a sound.

You will recall that in Chapter 8 we said that the current flowing through the phones can be pictured by drawing a line through the peaks of all the direct-current pulses passing out of the detector; we called this line the envelope. Well, strictly speaking, this picture is not the true one. Actually, the effect of the capacitor is to level off the peaks of these pulses and fill in the hollows. The curve now presents a continuous line whose fluctuations resemble those of the envelope. Since it is these fluctuations that produce the to-and-fro motion of the diaphragm, the sound coming from the phones is very nearly like the sound first created at the broadcasting station.

59. Coils as capacitors. Let us now go back to that fixed capacitor across the phones. You will have noticed that in our circuit diagrams of the crystal receiver we have omitted it. Nevertheless, a fixed capacitor was always present. Here is why.

A capacitor, you know, consists of two metallic plates separated by an insulator. In the coils of the phones we have many turns of copper wire wound next to each other and separated by an insulator. So you see that if we consider two turns of wire next to each other and separated by an insulator, we really have a very small capacitor. Since there are hundreds of such small capacitors in the coils, the total effect is the same as though a large capacitor were connected across the phones. Thus a coil serves both as an electromagnet and a capacitor at the same time.

In practice, an external capacitor having a capacitance of about 0.006 μfd. is sometimes placed across the phones even though it is not absolutely necessary.

SUMMARY

1. Any electrical device is connected in **parallel** in a circuit when it is one of two or more paths through which some of the current can flow. Devices are said to be **in series** when all of the current must pass through all of the devices one after another.

2. A capacitor is usually connected in parallel with the phones.

3. In the graph of the current flow, the **envelope** is a fluctuating heavy line connecting the peaks of the pulses that produce the sounds in the phones.

CHECK-UP

If a statement is true, encircle the T. If a statement is false, encircle the F. (Answers are on page 301.)

T F **1.** In a series circuit the electrons have at least two paths to follow in flowing through the circuit.

T F **2.** In a crystal detector the current flowing through the crystal is, to all intents and purposes, a direct current.

T F **3.** In a crystal receiver, the crystal and phones form a parallel or shunt circuit with the tuning circuit.

T F **4.** Sometimes we may omit the capacitor across the phones because the turns of wire in the phones act as a small shunt capacitor.

T F **5.** In a series circuit, all of the current passes through each device in the circuit.

T F **6.** A shunt is a parallel circuit.

T F **7.** The current that actually moves the diaphragm of an earphone is an alternating pulsating current.

TEST 1—CHAPTERS 1–12

In the blank spaces write the words, phrases, or numbers needed to complete the statements correctly. (Answers are on page 301.)

1. A wave is .... traveling through a medium from particle to particle.

2. The number of cycles of change in a given unit of time is called the .... of a wave.

3. The hypothetical medium assumed by some scientists to carry the radio wave is the ....

4. Radio waves travel at a speed of about .... meters per second.

5. The four parts of any receiver are the ...., the ...., the ...., and the ....

6. When a radio wave sweeps across an aerial-ground system, an .... or .... is set up across it.

7. The tuner selects the desired station and eliminates all others by placing the receiver .... with the transmitter.

8. The .... changes the electrical currents flowing in the tuner into a form which the reproducer may change into sound.

9. The reproducer changes .... into sound.

10. The tuning circuit consists fundamentally of a .... and a ....

11. In common practice, we vary the setting of the .... in a tuning circuit when tuning in a station.

12. Radio-frequency alternating currents have a frequency range of about (*a*) .... kilocycles to (*b*) .... megacycles per second.

13. .... in the tuning circuit of a receiver makes it tune more broadly.

14. An antenna coupler is a .... which helps to make the receiver tune more sharply.

15. The electric current consists of a flow of .... through a conductor.

16. Electrons will always tend to move through a conductor from a point of (*a*) .... to a point of (*b*) ....

17. An electrical circuit in which the electrons have but one path from the negative to the positive pole is known as a .... circuit.

18. An electrical circuit in which the electrons have two or more paths from the negative to the positive poles is known as a .... circuit.

CHAPTER 13

The Vacuum-tube Detector—the Diode

QUESTIONS THIS CHAPTER ANSWERS

1. *What is meant by the "Edison effect"?*
2. *What are the principles of a Fleming valve?*
3. *What is the "diode" detector?*

60. What is the Edison effect? Having mastered the theory of the crystal receiver, we are now ready to go ahead. If you have constructed the receiver described here and "listened in" on it, you must be aware that the crystal detector has shortcomings. First of all, it is difficult to manipulate. Not every spot will work. You must move the catwhisker about for some time before you touch a spot that enables you to hear radio signals in your phones.

Even after you have found the proper spot, a slight jar may dislodge the fine wire and the hunt starts over again. Perhaps dirt, grease, or oxidation from the air may spoil the sensitive spot, and you have to start once again.

Oddly enough, the first hint as how to improve the detector came in 1883, long before the crystal detector was first used in a radio receiver. In that year Thomas A. Edison was experimenting with filaments for his new invention, the electric-light bulb. He placed a filament in a glass bulb and then exhausted the air, creating a vacuum. By means of an electric current, he heated the filament until it glowed brightly and produced light.

He soon observed an undesirable feature about his bulbs. After a short time, a black substance was deposited on the inside of the glass, interfering with the light given out. In an attempt to stop this deposit on the glass, he inserted a metal plate in the tube near the filament. Now this plate did not help much, but one day he connected a delicate electric meter between the plate and one end of the filament. To his amazement, the meter showed that a small electric current was flowing through the circuit. He did not know why this current should flow, and he merely jotted down this strange fact in his notebook and forgot about it.

Today, we know why this current flows. When a filament is heated to incandescence (when it becomes hot enough to give off

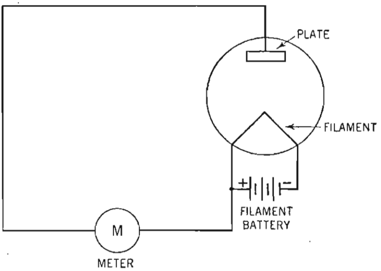


Fig. 57. Diagram showing Edison's experiment.

light), it shoots off streams of electrons. This behavior is known as the "Edison effect" or *thermionic effect* of a filament heated to incandescence. These electrons given off by the hot filament collect on the cool plate and, if a path is furnished them, they will flow along this path toward the filament. A meter in that path shows that electrons are flowing.

61. What is the Fleming "valve"? As we stated, this discovery of Edison's was made in 1883. At that time, the electron theory was not known. But in 1904, J. Ambrose Fleming, an Englishman, who understood the flow of the current in terms of electrons, decided to experiment a bit. To depend upon the electrons piling up on the cool plate, thought Fleming, is too slow. Suppose we were to create an actual deficiency of electrons on the plate by placing a positive charge on it. Wouldn't that charge attract still more electrons from the filament? Fleming connected a battery in the circuit from the plate to the filament, in such a way that the positive post of the battery was connected to the plate (see Figure 58). He also connected another battery to the filament to heat it to incandescence. Note that this filament battery is not in the plate circuit.

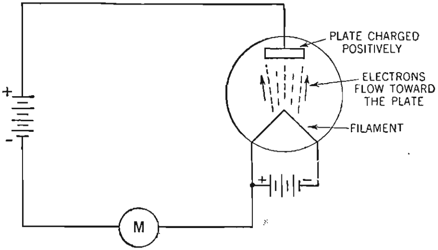


Fig. 58. Fleming's experiment with a positive charge on the plate of the tube. The meter showed that an electric current was flowing through it.

By this arrangement some of the electrons of the plate were pulled away to satisfy the deficiency at the positive post of the battery. This removal resulted in a deficiency of electrons on the plate, that is, a positive charge. Fleming now connected a meter in the circuit and, as he had expected, a much greater stream of electrons flowed through than before the battery was attached. He also discovered that the more powerful the battery, the greater the positive charge on the plate, the more electrons were attracted, and the greater the current flow through the meter.

Now Fleming reversed the connection to the battery and observed that the meter showed no current. The explanation is that this time the battery piled electrons onto the plate (gave it a negative charge). Electrons repel each other, hence the stream of electrons from the filament was repelled from the plate; therefore no current flowed through the meter (see Figure 59).

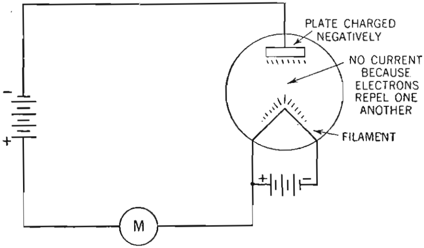
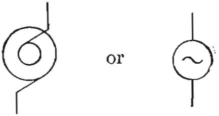


Fig. 59. Fleming's experiment with a negative charge on the plate of the tube. The meter showed that no electric current was flowing through it.

62. How does a Fleming valve affect an alternating current? By means of an alternating-current generator, Fleming now replaced the direct current of the battery with an alternating current. The symbol for the alternating-current generator is:



When the proper instruments were attached and the meter reading taken, Fleming now observed that the current flowing through the meter was direct, not alternating. The explanation (see Figure 60) is as follows: During the positive half of the alternating-current cycle the plate received a positive charge. This charge caused electrons from the heated filament to be attracted to the plate, and a current flowed in the circuit as registered on the meter. During the negative half of the alternating-current cycle the plate received a negative charge. This charge repelled the electrons from the filament, and the meter showed that no current was flowing. The effect of this action upon the graph of the wave form is shown in Figure 61. Only a pulsating direct current is passing through the meter.

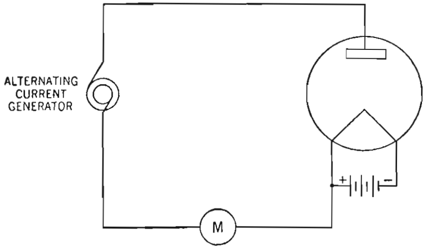


Fig. 60. Fleming's experiment with an alternating-current generator connected to the plate of the tube. Electric current flowed through the meter only during the positive half of the alternating-current cycle.

Here, then, is an electrical "gate" or "*valve*" that will permit current to flow only in one direction. As a matter of fact, the early radio tubes were all called valves and are still called by that name in England.

Doesn't this sound familiar? Of course! The crystal detector acted in just that way.

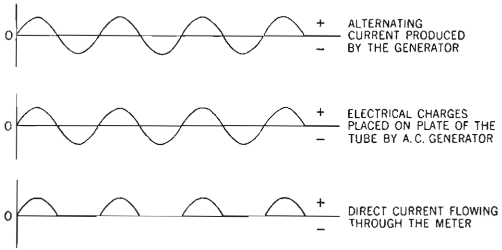


Fig. 61. Graph showing the effect of connecting an alternating-current generator to the plate of Fleming's tube.

63. The Fleming valve as a detector. Fleming went one step further. For the alternating-current generator he substituted a radio tuning circuit. Since alternating current flows out of the tuning circuit, it may be considered a sort of alternating-current generator. For the meter Fleming substituted a pair of phones, and now he had the same hookup as our old receiving set with a new kind of detector (the tube) to replace the crystal. (See Figure 62.)

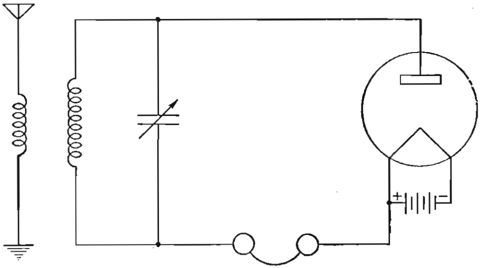
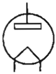


Fig. 62. Radio receiving set using a Fleming valve as a detector.

This type of detector is known as a *Fleming valve.* Because it has two electrodes, the filament and plate, it is also known as a *diode* (*di-* means two; *-ode* means pole). It is easier to operate than a crystal because there is no need to hunt for a sensitive spot. Further, you cannot disturb it by jarring; and no dirt, grease, or air can get inside the sealed glass tube. The symbol for the diode is:



or

SUMMARY

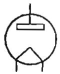
1. Thomas Edison, in 1883, discovered that in a vacuum tube an electric current passed from a hot filament through the vacuum to a plate sealed in the tube at some distance from the filament.

2. J. Ambrose Fleming in 1904 discovered that the current was increased in a vacuum tube when the plate was made positive and ceased when the plate was made negative.

3. The **diode** or **Fleming valve** depends upon the principle that alternating currents passed through the tube are changed to direct currents because only during the positive half of an alternating-current cycle are the electrons attracted from the filament to the plate.

SYMBOLS

 or  A.C. generator.

 or  Diode.

CHECK-UP

In the blank spaces write the words, phrases, symbols, or numbers needed to complete the statements correctly. (Answers are on page 301.)

1. When a filament is heated until it glows, it throws off .... This behavior is known as the .... effect or the .... effect.

2. Fleming found that he could increase the current through an evacuated glass tube containing a filament and a plate by placing a .... charge on the plate.

3. Within certain limits, the higher the .... voltage on the plate, the greater will be the .... through the Fleming valve.

4. When an alternating-current generator feeds its output into a Fleming valve, ... current flows through the tube circuit.

5. The Fleming valve may be used as a .... in a radio receiver.

6. The Fleming valve is known also as a .... because it has two electrodes, namely a .... and a ....

7. The symbol for the Fleming valve is ....

8. A tuning circuit may be compared to an electrical machine known as an ....

9. The tuning circuit of a radio receiver gets its energy from the .... system.

10. In a Fleming valve that is fed by an alternating-current generator, the electrons flow from filament to plate only while the plate is ....

CHAPTER 14

The Vacuum-tube Detector—the Triode

QUESTIONS THIS CHAPTER ANSWERS

1. *What did De Forest contribute to radio?*

2. *How does a grid control the flow of current in the plate circuit?*

3. *Why is a grid-bias battery necessary?*

4. *How does a capacitor take the place of a grid-bias battery?*

5. *Why is grid leak necessary?*

6. *What is the principle of volume control?*

Soon after Fleming's diode tube appeared, in 1907, an American inventor, Lee De Forest, undertook to carry further some ideas suggested by one of Fleming's experiments. De Forest knew that when Fleming placed a positive charge on the plate of his tube by means of a battery connected between the plate and filament (Figure 58), a much greater electric current flowed through the meter than when there was no such charge. Further, the greater the positive charge on the plate, the greater the flow through the meter. (Actually, this co-ordinated increase did not go on forever. After the positive charge reached a certain value, placing a greater positive charge on the plate had no further effect.)

64. What is the purpose of A and B batteries? The circuit traveled by the electrons—starting from the filament of the tube, going across the vacuum in a stream to the plate and back again to the filament by way of the path provided by the meter, battery, and wire—is known as the *plate circuit.* The battery used to place a positive charge on the plate is known as the *plate battery* or *B battery*. The battery used to heat the filament is known as the *filament battery* or *A battery*. (See Figure 63.)

65. What is the function of a tube grid? Now, thought De Forest, if we could only use the advantages of the B battery and substitute our phones for the meter, we would get a much louder signal in our phones. For the greater the current flowing through the phones, the greater is the magnetic pull of the coil. Greater magnetic pull means that the diaphragm is bent more; the air is set moving more violently, and a louder signal results.

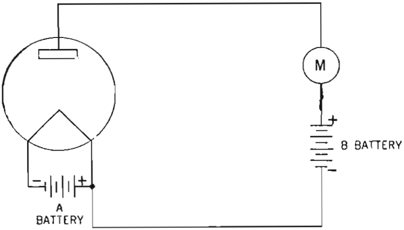


Fig. 63. Diode using a B battery to place a positive charge on the plate of the tube. Current flows through the meter.

At this point, however, a serious difficulty arose. The large current through the phones must be a direct current that fluctuates in step with the fluctuations of the incoming signal. De Forest quickly discovered that the small charges placed on the plate of the Fleming valve by the alternating current from the tuning circuit were undetectable in the presence of the relatively enormous positive charge placed on the plate by the B battery. Try as he would, De Forest could not utilize the advantages of a B battery in the diode tube. (See Figure 64.)

It was then that De Forest had a stroke of genius. Since the flow of current in the plate circuit starts with the stream of electrons shot out by the heated filament, he began to experiment with that electron stream.

Suppose, thought he, we were to place another electrode in the tube between the filament and plate. Being closer to the filament than the plate, this electrode would have a greater effect on the stream of electrons than would the plate. Thus a small positive charge on this new electrode would pull over electrons just as would a large positive charge on the plate. Also, a small negative charge on this new electrode would repel some of the stream of electrons, and thus a comparatively small number of

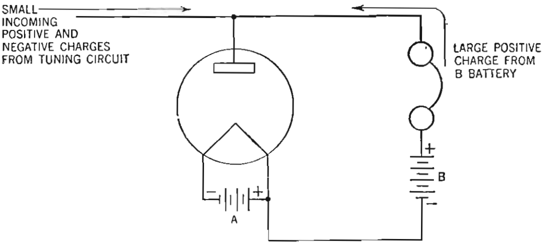


Fig. 64. Diagram showing how the weak positive and negative charges placed on the plate of the diode are overwhelmed by the large positive charge placed on the same plate by the B battery.

electrons would reach the plate. When few electrons reach the plate, only a very small current flows in the plate circuit. Here, then, thought De Forest, is a method for controlling the flow of current in the plate circuit by means of small charges on the new electrode.

But hold on! Further reasoning and experimenting convinced De Forest that when this new electrode was given a positive charge, it pulled over electrons, as expected—but these electrons went to this new electrode, and none found their way to the plate. After more experiments, De Forest eventually met this difficulty by making the new electrode in the form of a mesh of very fine wire, a *grid*. Since most of the grid consisted of open space, most of the electrons pulled over by a positive charge on the grid now shot through these open spaces and continued right on to the plate. The grid was the solution to his problem. (See Figure 65.)

66. How does the grid work? By study of the diagram in Figure 66, you can obtain an idea of how charges on the grid affect the flow of current in the plate circuit. If the grid has a small negative charge, it repels some of the electrons shooting off from the filament, and only a few of these electrons pass through the

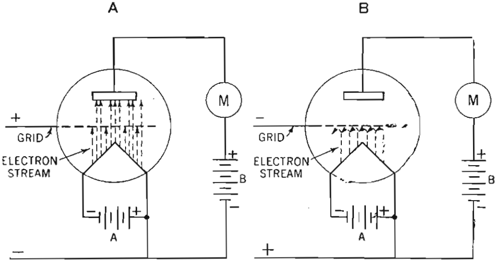


Fig. 65. (A) Diagram showing how a positive charge on the grid of De Forest's tube helps pull electrons from the heated filament to the plate. The meter shows that an electric current is flowing through it. (B) Diagram showing the effect of a negative charge on the grid. Since most of the electrons from the heated filament are repelled, few reach the plate. The meter shows that only a very small current is flowing through it.

open spaces of the grid to the positive plate. A small current flows through the plate circuit and thus through the phones. As the negative charge on the grid gets larger and larger, more and more electrons are repelled until none get through; therefore no current flows in the plate circuit.

As the grid gets a positive charge, it accelerates or speeds up the flow of electrons from the heated filament to the plate. The pull of the grid is now added to the pull of the plate. Most of the electron stream goes through the openwork of the grid to the plate. The more positive the grid gets, the greater the pull it exerts on the electrons; consequently, more electrons reach the plate and the plate current is greater.

67. How does the triode work? Since charges on the grid control the flow of electrons from the filament, we are able to control the flow of the large plate currents by means of a small charge on the grid. And this is just what De Forest set out to do. (See Figure 67.) He connected the small alternating-current out-

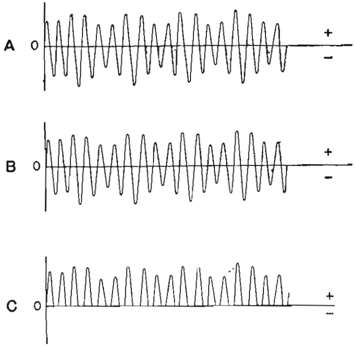


Fig. 66. Graphs showing flow of electric current in various parts of the triode circuit. (A) Alternating current flowing from the tuning circuit. (B) Positive and negative charges placed on the grid of De Forest's tube by this alternating current from the tuner. (C) Fluctuating direct current flowing through the meter.

put from the tuning circuit to the grid and studied the effects of various combinations upon the current in the plate circuit. When the positive half of the cycle of the alternating current from the tuner placed a positive charge on the grid, a large current flowed in the plate circuit. When the negative half of the cycle of the alternating current from the tuner placed a negative charge on the grid, very little current flowed in the plate circuit. These effects are shown by the graphs in Figure 66.

Now the remodeled tube, with its three parts—filament, grid, and plate—acts like an electrical gate or valve just as did the crystal detector and the diode tube. But this tube has the additional advantage that now the current that flows through the phones is not the small electrical current captured by the aerial but the very large current supplied by the B battery. Hence our signals will be much louder.

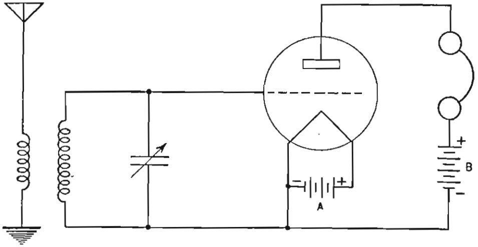
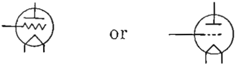


Fig. 67. Diagram showing how alternating current from the tuning circuit place positive and negative charges on the grid of De Forest's tube.

Because this new tube has three elements—the filament, the grid, and the plate—it is known as a *triode*. The symbol for the triode is:



68. What are the various circuits or paths of electrons? Look at the diagram in Figure 67. You will notice a number of paths or circuits through which electrons may flow. There is the *aerial-ground system* or *circuit*. Then there is the *tuning circuit*, consisting of the secondary of the antenna coupler and the variable capacitor. Then there is the *filament circuit* consisting of the A battery and the filament. There is the *plate circuit* consisting of the filament, the stream of electrons from the filament to the plate, the plate, the phones, the B battery, and the conductor leading back to the filament.

Finally there is the *grid circuit*. This path consists of the filament, the stream of electrons from the filament to the grid, the grid, the tuning circuit, and the conductor leading back to the filament. Just as current will flow through the plate circuit only when there is a positive charge on the plate, current will flow

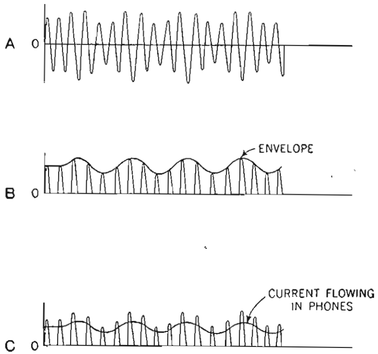


Fig. 68. Graphs showing flow of electric current in various parts of the diode circuit. (A) Alternating current flowing from the tuning circuit. (B) Pulsating direct current flowing in the plate circuit. (C) Fluctuating direct current flowing through the phones. Notice how closely the fluctuations here follow the fluctuations of the envelope in part B of this figure.

through the grid circuit only when there is a positive charge on the grid.

69. Why is a C battery, or grid-bias battery, necessary? You may have noticed a difficulty by now. In the diode, the bottom loop of the alternating-current cycle was completely cut off because the moment our plate went negative, all plate current ceased. The current flowing through the phones then fluctuated in step with the variations of the envelope and the signal was faithfully reproduced. (See Figure 68.)

But in the triode, connected as in Figure 67, the stream of electrons from the heated filament to the plate would continue to flow, even though the grid were slightly negative. In fact, this flow of electrons would continue until the grid assumed a fairly high negative charge because of the relatively high positive charge on the plate. Thus plate current, and current through our

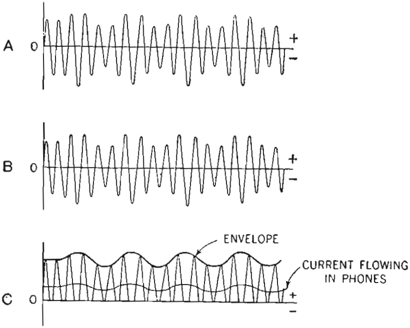


Fig. 69. Graphs showing flow of electric current in various parts of the triode circuit. (A) Alternating current flowing from the tuning circuit. (B) Positive and negative charges placed on the grid of the triode by that alternating current from the tuner. (C) Fluctuating direct current flowing in the plate circuit. Notice that the current flowing in the phones is very nearly a steady direct current in no way resembling the fluctuations of the envelope. This current will cause no sound or else a distortion of the signal will be heard in the phones.

phones, would flow during part of each negative cycle. In Figure 69-C we see that the graph of the current flowing through the phones does not correspond to the shape of the envelope. The practical effect is that our signal in the phones is distorted.

Here is how this difficulty was overcome. A small negative charge was placed on the grid by means of a battery. This charge was made too small to cut off all the electrons streaming from the heated filament to the plate. Now the alternating current from the tuner was fed into the grid. (See Figure 71.)

When the positive half cycle of the current from the tuner flowed into the grid, it reduced the negative charge placed there originally. This reduction meant that fewer electrons from the

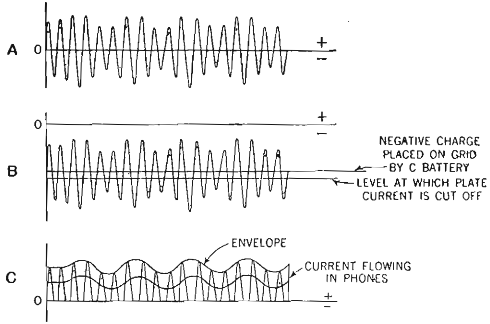


Fig. 70. Graphs showing effect of placing a steady negative charge or bias on the grid of the triode. (A) Alternating current flowing from the tuning circuit. (B) A steady negative charge or bias makes the grid negative. The positive half cycle of the current from the tuner makes the charge on the grid less negative. The negative half cycle of the current from the tuner makes the charge on the grid more negative to the point where the flow of current in the plate circuit is cut off. (C) Fluctuating direct current flowing in the plate circuit. Notice that now the current flowing in the phones resembles the envelope.

filament were repelled and more of them reached the plate. This greater flow of electrons, in turn, meant a larger plate current.

When the negative half cycle of the current from the tuner flowed into the grid, this current, by itself, could not place a negative charge on the grid great enough to cut off completely the flow of electrons to the plate. But if it were added to the negative charge we originally placed on the grid, then it would be able to stop the flow of electrons and thus to stop the flow of the plate current. Now, you can see, no current will flow in the plate circuit during the negative half cycle of the current from the tuner. Just as in the case of the diode, the fluctuations in the current flowing through our phones correspond to the shape of the envelope and, once again, our signal is faithfully reproduced. (See Figure 70.)

We place this constant negative charge on the grid by connecting a small battery in the grid circuit in such a way that the negative post of the battery is hooked up to the grid. This

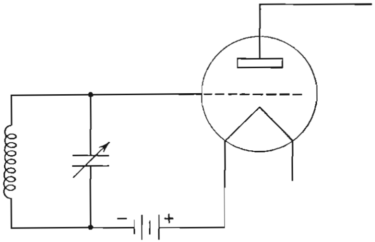


Fig. 71. Diagram showing how a C battery is connected to place a negative charge or bias on the grid of the triode. The completed diagram would include the earphones, A and B batteries connected just as in Figure 67.

battery is called a *C battery*, or *grid-bias battery*. It must be of such a size that, by itself, it cannot cut off the flow of electrons from the heated filament to the plate, but when added to the negative charge of the current flowing from the tuning circuit, it can do so. The size of this battery differs for different types of tubes. Each tube manufacturer supplies data to show how large this battery should be.

70. Why can a C battery be replaced by a capacitor? While the C battery is effective in placing a negative charge on the grid of the triode, it wears out in time, and we are faced with the nuisance of periodically replacing it. Accordingly, another method was evolved to accomplish the same result without the use of the battery: A small fixed capacitor was placed in the grid circuit as shown in Figure 72.

Here is how it works. When the negative half cycle of the alternating current from the tuning circuit reaches plate 1 of the capacitor, as shown in Figure 73-A, it places a negative charge on that plate. This charge drives off some of the electrons from plate 2 of the capacitor. These electrons seek to get as far away as possible from the negative charge. As a result, they are driven onto the grid of the tube. Here they remain, for the grid is cold

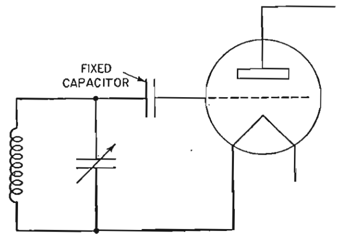


Fig. 72. Diagram showing how a fixed capacitor is connected to place a negative charge or bias on the grid of the triode.

and therefore cannot shoot off any electrons. Thus the grid gets a negative charge. But this charge is too small to stop entirely the flow of electrons from the heated filament to the plate.

During the positive half cycle of the alternating current from the tuner, a positive charge is placed on plate 1 of the capacitor (Figure 73-B). The electrons on the grid now are attracted back to plate 2. This movement leaves the grid with a positive charge, and most of the electrons shot out by the heated filament of the tube rush to the plate of the tube. It should be noted, however, that some of these electrons strike the positively charged wires of the grid and are pulled over to plate 2 of the capacitor.

During the next (negative) half-cycle, electrons are again piled up on plate 1 of the capacitor (Figure 73-C). Once again electrons stream away from plate 2 to the grid. This time, however, there are more electrons on the grid. The electrons that were collected by the grid from the stream shot out by the filament during the positive half cycle have been trapped and cannot get away. So this time the grid has a larger negative charge.

As this process goes on, a larger and larger negative charge is collected by the grid. You see, we now have the same effect as when we placed a C battery in the grid circuit.

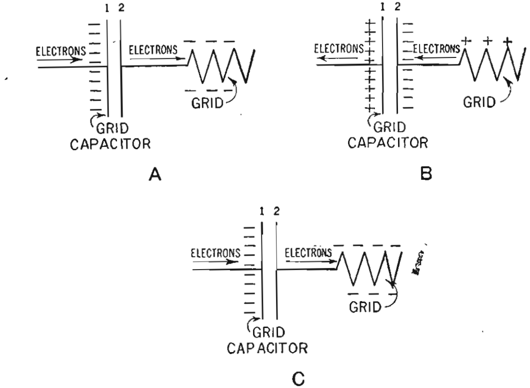


Fig. 73. The action of the grid capacitor. (A) A negative charge is placed on plate 1 of the capacitor by current from the tuning circuit. (B) A positive charge is placed on plate 1 of the capacitor by current from the tuning circuit. (C) Another negative charge is placed on plate 1 of the capacitor by current from the tuning circuit.

71. What is the function of the grid leak? But this process must not be permitted to go on indefinitely. Soon there will be accumulated upon the grid enough electrons to completely stop any electrons from reaching the plate of the tube. Since the electrons are trapped there, the action of the tube will be completely blocked and no signal can get through.

A method had to be worked out, therefore, to permit some of these electrons to flow off. A path was provided across the capacitor so that when a positive charge was placed on plate 1, some of these trapped electrons could flow across to that plate. Provision had to be made so that not all of these trapped electrons could escape, for that would destroy the effectiveness of the capacitor. Only enough of them should be permitted to leak off so that the action of the tube would not be blocked.

To provide this path, a *resistor* is connected across the capacitor. A resistor is a substance that retards the flow of electrons through it. It is usually made of a special type of wire

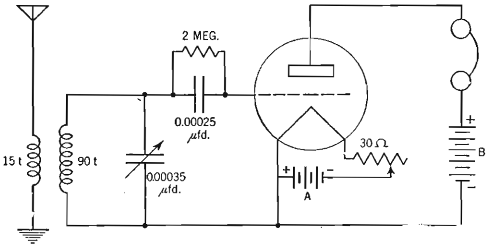


Fig. 74. Diagram of the complete receiving set using the triode as a detector. The symbol 2 meg. over the grid leak stands for 2 megohms (2,000,000 ohms). The symbol 30Ω over the rheostat stands for 30 ohms.

such as nichrome or of certain substances such as carbon. The greater the value of the resistor, the fewer the electrons that can flow through it. The symbol for a resistor is: .

In Figure 74 you have the diagram of a receiving set using a triode as a detector. The tube used is a type called 01A. This tube requires an A or filament battery of 6 volts. The B or plate battery is 22½ volts. The capacitor used in the grid circuit is called a *grid capacitor*. This capacitor usually uses mica as a dielectric, and its value is 0.00025 μfd. Across this capacitor is the

Micamold Radio Corp.

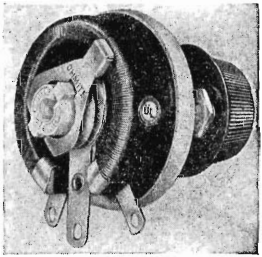
Mica capacitor.

resistor which furnishes the path by means of which the excess electrons *leak* off the grid. Quite naturally it is called a *grid leak.* The unit for measuring resistance is the *ohm.* The value of the grid leak is 2,000,000 ohms or 2 megohms, the prefix *meg-* meaning a million.

International Resistance Corp.

Fixed resistor or grid leak.

72. How is the volume of a reproducer controlled? In the filament circuit, between the A battery and one end of the filament, you will notice a device shown by the symbol: . This is the symbol for a variable resistor or a *rheostat,* which consists of a length of resistance wire over which a movable contact slides. This rheostat controls the amount of current that can flow from the A battery to the filament. The resistance offered by this rheostat can be made greater or less by increasing or decreasing the length of wire through which the current must pass. This variation in length is produced by the sliding contact or by a switch moving over contact points connected to various points on the wire. The more current flows through the filament, the hotter it gets; this rheostat therefore controls the heat of the filament. The hotter the filament the more electrons it shoots off. The rheostat therefore controls the quantity of electrons shot off by the filament.



Ohmite Mfg. Co.

Rheostat.

The more electrons hit the plate, the greater the plate current. The greater the plate current, the greater the current through the phones and the louder the volume of the signal. So you see that this rheostat finally controls the volume of the signal. As you have probably guessed, this rheostat is called a *volume control.* Its value is about 30 ohms.

Our receiving set, now, is quite an improvement over the one shown in Figure 22. By means of an antenna coupler we have improved its *selectivity*, that is, the ability to select the radio station desired and to reject all others. The use of the triode as a detector has increased the set's *sensitivity*. Now stations which were too weak to be heard on a crystal or diode detector set are heard in the phones.

SUMMARY

1. Lee De Forest, an American, devised the **triode** tube.

2. The principle of the triode is that a third element called a **grid** is placed in the vacuum tube between the filament and plate.

3. The grid, when charged positively, permits electrons to flow through it to the plate, but retards the flow of electrons when it is charged negatively.

4. By means of a **C battery** or by means of a **capacitor** and **grid leak** the grid may be given a negative charge of the right amount.

5. This right amount of negative charge is that charge which will not prevent electrons going from the filament to the plate during the positive half of an alternating-current cycle, but will prevent them during the negative half of the alternating-current cycle.

6. The heat of the filament, and hence the volume of the signal, is controlled by a variable resistor or **rheostat.**

SYMBOLS

Meter.


Fixed resistor.


Variable resistor or rheostat.


or

Triode

CHECK-UP

Part A

Underscore the words or phrases that make the statements correct. (Answers are on pages 301–302.)

1. The A battery is in the *(grid)* *(plate)* *(filament)* circuit, while the B battery is in the *(plate)* *(tuning)* *(filament)* circuit.

2. The grid in the triode tube was invented by *(Edison)* *(DeForest)* *(Fleming)*.

3. The grid is placed between the *(capacitor)* *(phones)* *(plate)* and the *(plate)* *(capacitor)* *(filament)*. Because the grid is an open mesh, most of the electrons emitted in the tube go to the *(capacitor)* *(plate)* *(A battery)*.

4. When the grid is more negative, the plate current *(increases)* *(pulsates faster)* *(decreases)*. When the grid is less negative, the plate current *(pulsates more slowly)* *(increases)* *(decreases)*.

5. Because the grid is closer to the *(plate)* *(A battery)* *(filament)* it has greater effect on the plate current than corresponding voltage charges on the *(grid)* *(plate)* *(filament)*.

6. The C battery places a constant *(positive)* *(negative)* *(alternating)* voltage on the *(plate)* *(grid)* *(filament)*.

7. The C battery may be replaced by a *(rheostat)* *(capacitor)* *(triode)* and a *(diode)* *(grid leak)* *(rheostat)* placed in the *(plate)* *(filament)* *(grid)* circuit.

8. The grid leak is a fixed *(rheostat)* *(resistor)* *(capacitor)*.

9. The unit for measuring resistance is the *(farad)* *(ohm)* *(volt)*.

10. Meg- and mega- are prefixes meaning *(millionths)* *(thousands)* *(million)*.

11. The rheostat is really a variable *(capacitor)* *(resistor)* *(grid leak)*.

12. A (*capacitor*) (*rheostat*) (*B battery*) placed in series with the filament may be used as a volume control.

13. "Grid bias" refers to the fixed (*negative*) (*alternating*) (*pulsating*) voltage placed on the grid of a tube.

Part B

Beneath the name of each radio part draw the symbol for that part:

TRIODE FIXED RESISTOR RHEOSTAT METER

Part C

In the space below draw a one-tube receiver using a triode as a detector and a grid leak and grid capacitor as a grid bias.

CHAPTER 15

The Regenerative Detector

QUESTIONS THIS CHAPTER ANSWERS

1. *How does a regenerative or feedback circuit increase sensitivity?*

2. *What is a plate coil or tickler?*

3. *How can we control oscillation or "spill over" in the receiving set?*

4. *How can we build a practical receiving set with a "feedback" system?*

73. What is the regenerative or feedback circuit? At this point in the development of the science of radio, there arose a tremendous desire for increased sensitivity in the receiving sets. The thrill of hearing a distant radio station entranced amateur and professional alike. The hue and cry was for more "DX" (long-distance) reception. This demand was satisfied by giving a new twist to the triode detector receiving set. We now call this device the *regenerative* or *feedback circuit.* Here is how it works:

When we considered the tuning circuit, you learned that there were two streams of electrons oscillating through that circuit in step with each other. One was the stream set flowing by the discharge of the tuning capacitor. The other was the stream set flowing by mutual induction from the aerial-ground system.

Theoretically, the oscillations of the electrons in the tuning circuit should have continued to build up or gain in strength indefinitely. You may see this if you think of a man pushing a swing. The second push, though no greater than the first, makes the swing travel farther, or we may say that the swinging is *built up.* So the successive pulses from the aerial-ground system should build up the oscillations of electrons in the tuning circuit.

Actually, however, the resistance in the circuit limited the degree to which these oscillations could be built up. So you see there are two reasons for reducing the resistance against current flow in the tuning circuit. One, as you know, is to make our set more selective. The other is to build up the oscillations of electrons. With less resistance a greater current will flow; therefore a weak impulse from a distant station will be built up to the point where we can hear it in our phones.

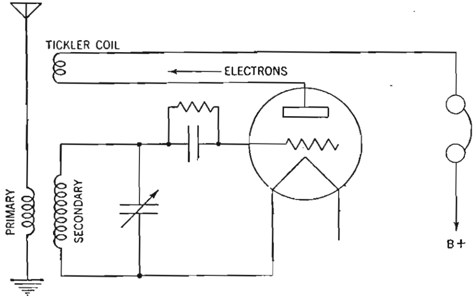


Fig. 75. Diagram showing how plate current is fed back to the tuning circuit by means of the tickler coil.

Try as we may, however, we cannot completely eliminate the resistance from our circuit. A certain minimum will always remain. This minimum can be made small enough so that it does not interfere with the selectivity of the set, but it will always remain large enough to limit the degree to which we can build up the oscillations in the tuning circuit.

An American scientist, Major E. H. Armstrong, conceived the idea of causing a third stream of electrons to flow in the tuning circuit in step with the other two. This third stream supplied the electrical energy to overcome the resistance in the circuit, and now the oscillations could build up to a very high degree. He accomplished this improvement by causing the plate current to flow through a coil of wire called a *plate coil* or *tickler*. This plate coil was placed in close proximity to the secondary of the antenna coupler. When the plate current flowed through the plate coil, a magnetic field was created around this coil. This field cut across the turns of the secondary of the antenna coupler and set a stream of electrons flowing in the tuning circuit just as did the primary of the antenna coupler.

So, you see, current from the plate circuit has been *fed back* to the tuning circuit. The fluctuating direct current flowing through the tickler coil sets up an alternating current in the secondary of the antenna coupler by transformer action (Figure 37-A). Since the variations in the plate current were produced by the variations of current flowing in the tuner, the two currents are in step. This arrangement of the three coils is sometimes called a *three-circuit tuner*.

However, the oscillations of electrons in the tuning circuit were built up so well that another problem presented itself.

74. Why did the regenerative set oscillate or "spill over"? It was stated in Chapter 2 that if electrical pulses are sent through a circuit 10,000 times or oftener per second, a radio wave is created. Here, now, electrical pulses are being sent through the tuning circuit tens of thousands and perhaps millions of times per second. Under normal conditions the oscillations of electrons in the tuning circuit are too weak to cause any damage.

But now, because the resistance of the tuning circuit has been overcome, these oscillations are built up to a point where a strong radio wave is created, and our receiving set becomes a transmitting station. This radio wave interferes with the incoming signal and causes clicks, whistles, and howls in our phones. Some of you may remember the early days of the regenerative receiver. You may remember how frequently these howls and whistles occurred. And you may remember receiving these howls and whistles from receiving sets as far away as several blocks!

When the oscillations become too strong and the receiving set becomes a transmitter, we say the set *oscillates* or *spills over*. The trick, then, is to permit the oscillations in the tuning circuit to build up to a point just before the set starts to oscillate. **It is at this point that** we get our loudest undistorted signal.

75. How may the tickler coil control feedback? This limitation is usually accomplished by one of three methods. First, there is the method of controlling the efficiency of the feedback action. If we place the tickler coil further away from the secondary of the antenna coupler, the electrical energy transmitted by mutual induction becomes smaller. This change means that a smaller stream of electrons is set flowing in the tuning circuit. The trick is to set a stream of electrons flowing which will just fail to over-

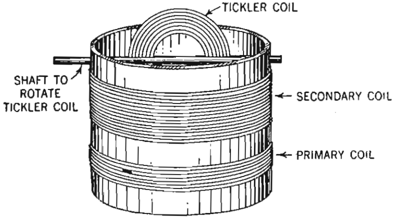


Fig. 76. Three-circuit tuner showing arrangement to vary the coupling between the secondary coil and the tickler coil.

come the resistance of the tuning circuit. It is this excess resistance that will prevent the oscillations from being built up too much.

The same effect is accomplished by changing the angle which the tickler coil makes with the secondary of the antenna coupler. When the two coils are parallel, you get the maximum feedback. When the two coils are at right angles, you get the minimum feedback. By making the angle adjustable, you are able to get the desired amount of feedback. When we use this method of controlling the feedback, we say that we vary the *coupling* between the two coils.

76. How may a variable capacitor control feedback? Another method is to utilize a *variable capacitor* connected as shown in Figure 77. Now some of the electrical energy flowing in the plate circuit is used up to place a charge on this capacitor. Hence there is less electrical energy left to be fed back to the tuning circuit. By varying the size of the capacitor, you can vary the amount of electrical energy drained away and thus control the amount of energy to be fed back to the tuning circuit. The variable capacitor used is usually of the same size as the one used in the tuning circuit.

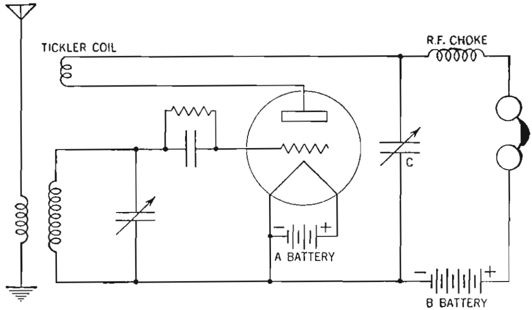


Fig. 77. Three-circuit tuner using a variable capacitor (C) to control the amount of feedback. The inductance marked "R. F. Choke" is a small coil of wire which impedes the flow of electrons to the phones and thus forces some of these electrons onto the variable capacitor (C).

The inductance marked "R.F. Choke" (radio-frequency choke coil) is a small coil of wire which hinders or impedes the flow of electrons to the phones and thus forces some of these electrons onto the variable capacitor used to control the feedback.

Bud Radio, Inc.

Radio-frequency choke coil.

77. How may a fixed capacitor and a rheostat be used to control feedback? The third method is to substitute a *fixed capacitor*, whose value is usually about 0.00025 μfd., for the variable capacitor described above. We now control the amount of electrical energy fed back to the tuner by placing our old friend, the *rheostat*, in the plate circuit, as shown in Figure 78. This rheostat, usually of about 50,000 ohms value, controls the total amount of current flowing in the plate circuit. Since a constant amount of electrical energy is drained off by the fixed capacitor, the variation in the total electrical energy in the plate circuit will determine how much will be fed back to the tuner. Since, by means of the rheostat, we can vary the current in the plate circuit, we have a means for controlling the feedback current.

Another variation using the rheostat to control the amount of feedback is merely to place a 50,000-ohm rheostat across the tickler coil as in Figure 79. Now the current flowing in the plate

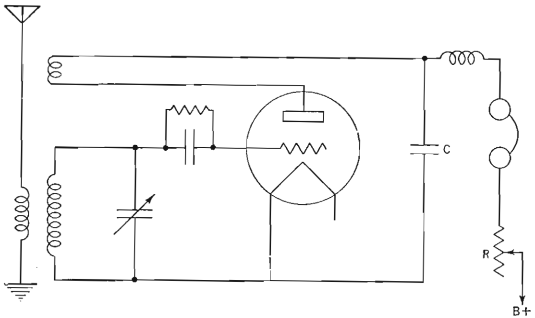


Fig 78. Three-circuit tuner using a fixed capacitor (C) of about 0.00025 microfarad and a rheostat (R) of about 50,000 ohms to control the amount of feedback.

circuit has two paths to follow. Part of it flows from the plate, through the rheostat and into the phones. None of this current is fed back to the tuner. The rest goes through the tickler coil and is fed back to the tuning circuit. The greater the resistance of the rheostat, the less current can flow through it and the more current flows through the tickler coil; and therefore, the more electrical energy is fed back. Thus by varying the resistance by means of the rheostat, you can vary the amount of feedback.

78. How can you build a regenerative set? These three controls of feedback—the coupling control (Figure 76), the variable capacitor (Figure 77), and the rheostat (Figures 78 and 79), are called *regenerative* or *feedback controls.*

If you wish to build a regenerative set, here is how to make the coils. Obtain a cardboard mailing tube about 2 in. in diameter and about 6 in. long. At about ½ in. from one end make a fine hole with a pin or needle. Thread in about a foot of No. 28 gauge double cotton-covered copper wire; this is to anchor the winding. Now wind on 15 turns of this wire, placing the turns next to each other. Anchor this end and all the ends of the other two coils the same way as above. This is your tickler coil.

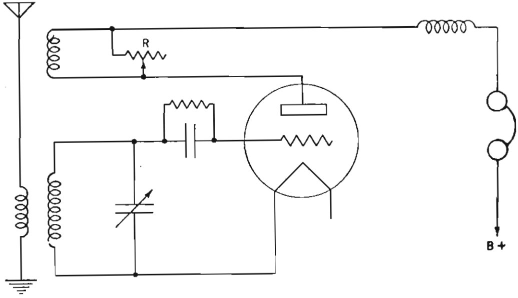


Fig. 79: Three-circuit tuner using a rheostat (R) of about 50,000 ohms to vary the amount of feedback.

Look at Figure 80 to see that you have the right idea for winding the coils.

About ⅛ in. from the bottom of the tickler, start winding the secondary of the antenna coupler. Note that all three coils must be wound in the same direction. Wind on 90 turns of wire. About ⅛ in. from the bottom of the secondary coil, wind on 15 turns for the primary of the antenna coupler.

Now connect the top of the tickler coil to the radio-frequency choke and phones and the bottom of this coil to the plate of the tube. Refer to Figures 77, 78, 79, and 80. The top of the secondary of the antenna coupler goes to one end of the variable tuning capacitor (usually the stationary plate terminal) and to the grid leak and grid capacitor. The bottom of this coil goes to the other end of the variable tuning capacitor (usually the rotary plate terminal) and the filament of the tube. The top of the primary coil of the antenna coupler goes to the antenna; the bottom goes to the ground.

Here is how you operate the regenerative receiver. First, tune in your station just as you would on any other set. Now rotate your regenerative control. The signal will get louder and louder

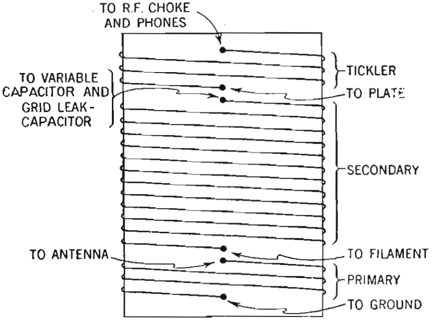


Fig. 80. Diagram showing construction and connections of the three-circuit tuner.

until a point is reached where you will hear clicks, whistles, o. howls. Now turn your regenerative control back to just before that point. Your set is now tuned in for most efficient reception.

We have now traced the development of radio receivers to a point where we have made a set that is both selective and sensitive. The crystal detector has been replaced by the more stable and efficient triode. Reception is not perfect yet, but millions of radio fans all over the world, sitting up in the small hours of the night, have listened over such radio receivers to that much desired "DX" station.

SUMMARY

1. The **regenerative principle** was added to radio receiving sets to provide greater sensitivity in radio receivers and enhance the possibility of receiving more distant stations.

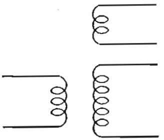
2. This regenerative or **feedback** principle depends upon a third coil, connected to the plate circuit, but coupled inductively to the secondary of the tuning circuit.

3. The electron stream in the secondary of the antenna coupler set flowing by the **tickler coil** oscillates in step with the incoming impulses and builds up their strength.

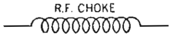
4. The fault of the regenerative system is its tendency to produce whistles in the phones by oscillating like a transmitting station.

5. This tendency to oscillate may be controlled (a) by a movable tickler coil; (b) by connecting the tickler coil in series with a variable capacitor; (c) by using a fixed capacitor in combination with a rheostat; (d) by using a rheostat across the tickler coil.

SYMBOLS



Three-circuit tuner.



Radio-frequency choke coil

CHECK-UP

Each statement below is either true or false. In the false statements one or more, but not necessarily all, of the italicized parts make it false. If a statement is true, encircle the T and do nothing else with it.

If a statement is false in any part, first encircle the F; then correct it by substituting the right word or phrase for the incorrect word or phrase in italics. Write your correction in the blank space at the end of the statement.

The samples below show you how to handle the statements. (Answers are on page 302.)

SAMPLES

(T) F Radio-frequency energy *travels in waves.* ....

T (F) *Direct* currents flow in cycles. Alternating ....

T F 1. The *resistance* in a tuning circuit limits the strength of the current oscillating in that circuit. ....

....

T F 2. The tickler of a regenerative detector builds up the signal strength by coupling energy from the *grid* circuit to the *filament* circuit. ....

T F 3. The regenerative detector was invented by *De Forest*. ....

T F 4. When regeneration in the detector is uncontrolled, the receiver actually becomes a *transmitter*. ....

T F 5. A regenerative receiver spills over when the *voltage* in the tuning circuit becomes too strong. ....

T F 6. The regenerative receiver gives the loudest undistorted signal *just before* the set spills over. ....

T F 7. Any device that regulates the flow of electrical energy in the tickler is called a *feedback control*..................

T F 8. One method of controlling the flow of electrons in the regenerative tuning circuit is by varying the distance between the *antenna-coupler primary coil* and the *antenna-coupler secondary coil*. ....

....

T F 9. The regenerative circuit was invented in order to make receiving sets *more selective*. ....

T F 10. The fluctuating direct current in the *tickler* of a regenerative circuit sets up alternating current in the *antenna-coupler secondary*..................

T F 11. When the tickler coil and the antenna-coupler secondary coil are at right angles to each other, you get the *least amount* of feedback. ....

T F 12. To control feedback by means of a fixed capacitor, a *rheostat* must be also used in the circuit. ....

T F 13. A rheostat controls electron flow by varying the *resistance* in the circuit, while a capacitor controls electron flow by *draining away* some of the electrons..................

CHAPTER 16

The Audio-frequency Amplifier

QUESTIONS THIS CHAPTER ANSWERS

1. *Why is an amplifier necessary in that part of the circuit in which the earphones are connected?*

2. *What is audio-frequency amplification?*

3. *How is a grid bias maintained in the amplifier tube?*

4. *How are detector tube and amplifier tube coupled?*

5. *Why must a grid bias be maintained in the amplifier tube?*

6. *What is transformer-coupled audio-frequency amplification?*

7. *What is resistance-coupled audio-frequency amplification?*

8. *What are the practical applications of audio-frequency amplifiers?*

79. What is audio-frequency (A.F.) amplification? Although our radio set has been developed to the point where it can bring in weak or distant stations and separate out the unwanted ones, it still has a serious drawback. We still have to use earphones. Not only is it a nuisance to wear them but, moreover, only the person who has them on his head can hear the radio program. To meet this objection the audio-frequency amplifier was developed.

You already know how we can attach a large paper cone to the diaphragm of the earphone and thus get a louder sound (§24). But in order to move this large cone we must have more electrical power than ordinarily comes out of the detector. It becomes necessary to amplify or build up the electrical current flowing out of the detector before it can properly operate the loudspeaker.

The triode furnishes us with the means for this building up. You know that a small current, placing electrical charges on the grid of the tube, will cause a much larger plate current to flow. This plate current closely follows the fluctuations and variations of the current being fed into the grid; thus we get out of the tube a much greater current than was put into it, while all the fluctuations are retained in their proper proportions. The signal coming out of the tube will accordingly be the same as the signal fed into it except that it will be much louder. Of course, you know that the B battery supplies the extra power.

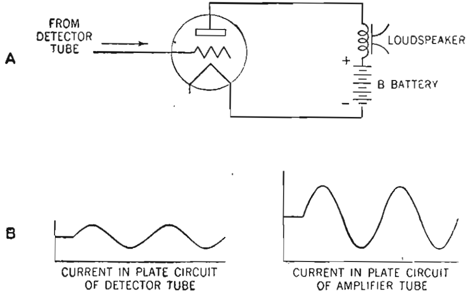


Fig. 81. (A) Audio-frequency amplifier showing how the signal from the detector tube is fed to the grid of the audio-frequency amplifier tube. (B) Graph showing relationship between current flowing in the plate circuit of the detector tube and current in plate circuit of the amplifier tube.

All we have to do, therefore, is to feed the plate current from our detector tube into the grid of another tube. The plate current flowing from this second tube will then be our amplified signal.

This second tube is called the *amplifier tube.* Theoretically, all we need is one such amplifier tube to give us the additional power required to operate the loudspeaker. In practice, however, we find that there are certain factors which limit the amplification possible with one tube. We therefore usually repeat the whole process, using a second amplifier tube to build the signal up still more to a point where the current will be strong enough to operate the loudspeaker. Each time we amplify the signal by the use of an additional tube, we say that we add one *stage of amplification.* Usually, two stages of amplification are required.

The electrical current flowing in the aerial-ground system and the tuning circuit is radio-frequency current. That is, it alternates millions of times per second. When this current comes out of the detector, it consists of a series of pulses. These pulses,

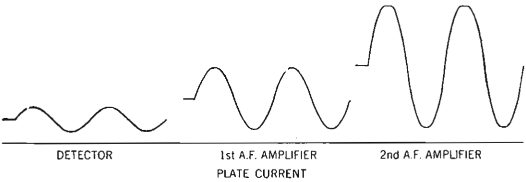


Fig. 82. Graphs showing plate current in the detector, the first audio-frequency amplifier, and the second audio-frequency amplifier.

too, occur millions of times per second, that is, at radio frequency. But when you examine Figure 56, you see that the current flowing through the phones is fluctuating at a much slower rate. A series or train of the fast pulses or fluctuations have combined to make one slow fluctuation or pulse.

It is this slow fluctuation which moves the diaphragm and thus produces the sound we hear. We therefore say that this slow fluctuation is at *audio frequency.* The range of audio frequency is from about 30 to 15,000 cycles per second. Inasmuch as we are now amplifying our signal after it passes out of our detector (after it is changed from radio frequency to audio frequency), we call the amplifier tubes *audio-frequency amplifiers.*

80. How are a detector tube and an amplifier tube coupled? The next thing to consider is how to feed the current flowing in the plate circuit of the detector tube into the amplifier tube, that is, to *couple* them. Look at Figure 83. You will see that the grid of the amplifier tube is connected to the plate of the detector tube. A difficulty will be noticed immediately. The large B battery of the detector tube, connected directly to the grid of the amplifier tube, will place a large positive charge on that grid and thus the fluctuations of plate current will be blanketed out and no signal will pass. A method must be devised that will pass on the fluctuations of plate current and yet be able to keep out the large positive charge of the B battery.

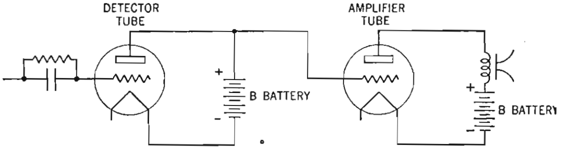


Fig. 83. Diagram showing plate of detector tube connected to the grid of the amplifier tube.

Here, again, we call upon our old friend the transformer. We connect the primary in the plate circuit of the detector tube and the secondary in the grid circuit of the amplifier tube. (See Figure 84.) Now the fluctuating plate current in the primary will set up an alternating voltage or electrical pressure in the secondary. This voltage will fluctuate in step with the fluctuations of plate current (Figure 37-A).

This fluctuating voltage will place fluctuating positive and negative charges on the grid of the amplifier tube and this, in turn, will control the plate current flowing in the plate circuit of the amplifier. This plate current in the amplifier tube will have

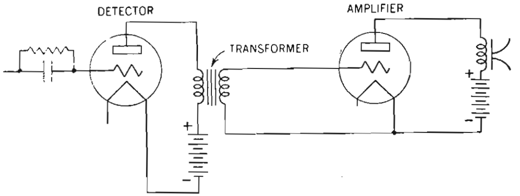
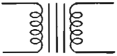


Fig. 84. Diagram showing how the detector is coupled to the audio-frequency amplifier by means of a transformer.

the same form as the plate current in the detector tube, but will have a greater amplitude, indicating greater power.

Because these currents are audio-frequency currents, we are able to utilize the greater efficiency of an iron-core transformer. The symbol for such a transformer is:  In addition, we are able to utilize the advantages of a step-up transformer, which gives us an additional amplification of the signal. In practice, it has been found that the maximum step-up per-

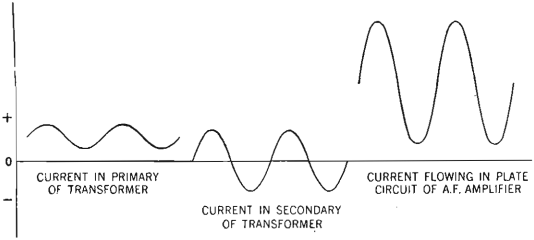


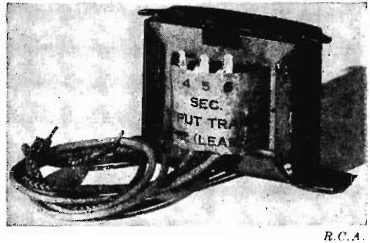
Fig. 85. Graphs showing current flowing in primary and secondary of the transformer and in the plate circuit of the audio-frequency amplifier. Note that the shape of all three curves is the same although the amplitudes vary.

missible is about 1 to 5; that is, the secondary has about five times as many turns as the primary. Any greater step-up results in distortion and other losses.

81. Why is a grid bias necessary? We must keep in mind that the amplifier must not only magnify the signal, but must reproduce it in its original form. In other words, there must be a minimum of distortion. One serious objection to our amplifier, as shown in Figure 84, is that when the grid of our amplifier tube becomes positively charged, it will attract some of the electrons streaming from the heated filament, and a current will flow in the grid circuit of the tube. This current will produce distortion.

To overcome this defect, a C battery is placed in the grid circuit, just as it is placed in the grid circuit of the detector tube

(§69). This battery places a negative *charge* or *bias* on the grid of the amplifier tube and thus prevents the flow of grid current. This grid bias keeps the grid negative at all times, and the negative and positive charges placed on the grid by the alternating



Audio-frequency transformer.

voltage across the secondary of the coupling transformer make the grid more or less negative.

82. How are tubes and grid bias matched? Another precaution must be taken. In the amplifier tube, unlike the detector tube, the negative charges placed on the grid by the transformer must

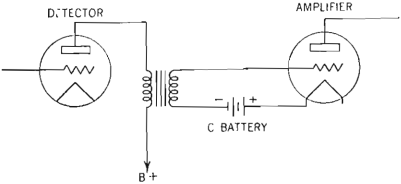


Diagram showing how a C battery is connected in the grid circuit of the amplifier tube.

be prevented from driving the grid so far negative as to cut off the flow of plate current. Such a situation would lop off part of the bottom loop of our curve, and distortion would arise (Figure 87-D). Manufacturers of tubes furnish charts showing the proper value of grid bias to be used with their tubes. Thus, if we use an R.C.A. type 01A tube as an amplifier with a plate battery of 135 volts, the C battery, or bias, must be −9 volts; that is, a C battery of 9 volts is used with the negative terminal connected to the secondary of the audio-frequency transformer and with the positive lead going to the filament of the tube (Figure 86).

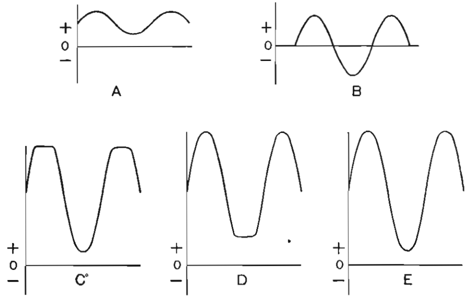


Fig. 87. Graphs showing effects of grid bias. (A) Graph of current flowing in primary of transformer. (B) Graph of current flowing in secondary of transformer. (C) Graph of current flowing in plate circuit of amplifier tube when grid bias is too low. A large positive charge on the grid drives it positive and it attracts electrons which would normally flow to the plate. A grid current flows and this causes distortion of the wave form. (D) Graph of plate current when grid bias is too high. A large negative charge drives the grid so far negative that all the electrons are repelled and no plate current flows. This, too, causes distortion of the wave form. (E) Graph of current flowing in plate circuit of amplifier tube when grid bias is just right. Note that the wave form corresponds to that of Figure A.

You may see from the above data that we can use B batteries of much greater voltage than are used in the detector circuit. Thus greater plate current, with enough power to operate the loudspeaker, will be possible.

83. How are transformers used for coupling audio-frequency amplifier tubes? This method of coupling one tube to another is called *transformer coupling.* The transformer used is called an *audio-frequency transformer.* The primary winding has two terminals, one marked P (plate) and the other marked B+ (B battery). The P terminal is connected to the plate of the detector tube, while the B+ goes to the positive terminal of the B battery. The secondary winding also has two terminals, marked G and F−, respectively. The G (grid) terminal is connected to the grid of the amplifier tube, while the F− (filament) goes to the negative post of the C battery.

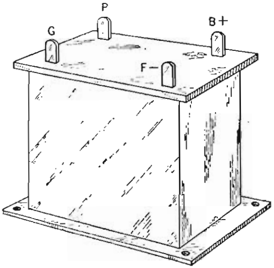


Fig. 88. The audio-frequency transformer.

84. How is a fixed capacitor used for coupling? There is another method used to couple one tube with another. A fixed capacitor is inserted between the plate of the detector tube and the grid of the amplifier tube (Figure 89). Now the stream of electrons flowing in the plate circuit of the detector tube divides at point x. Some flow to the positive post of the B battery, while others pile up on plate 1 of the capacitor. Thus a negative charge is placed on this plate. This negative charge drives elec-

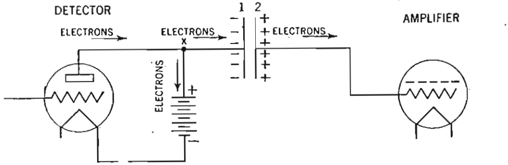


Fig. 89. Diagram showing how a fixed capacitor is used to couple the amplifier tube to the detector.

trons away from plate 2 of the capacitor, leaving a positive charge there. The electrons thus driven away pile up on the grid of the amplifier tube, making that grid negative. Fluctuations in the plate current of the detector tube thus cause a fluctuating negative charge to be placed upon the grid of the amplifier tube. This fluctuation in turn causes a fluctuating current to flow in the plate circuit of the amplifier tube.

This fixed capacitor is called a *coupling capacitor*. It has mica for its dielectric and its value is usually about 0.006 μfd.

85. Why do we need a resistor in the plate circuit? But we have the B battery in the plate circuit of the detector tube to contend with. Because of its high voltage, the positive post has a very large deficiency of electrons. Thus, unless some means is

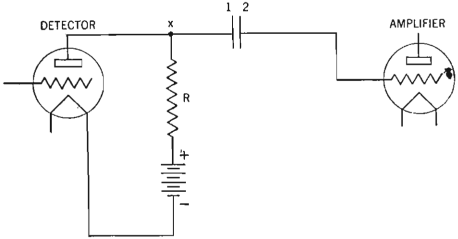


Fig. 90. Diagram showing how plate resistor (R) is placed in the circuit.

found to prevent it, all the electrons flowing in the plate circuit of the detector tube will be attracted to it, and none will be left to place a negative charge on the capacitor.

To meet this difficulty a resistor (Figure 90) is placed between the positive post of the B battery and point x. This resistor (R) retards the flow of electrons to the positive post of the B battery and thus forces some of the electrons flowing in the plate circuit to flow to plate 1 of the capacitor. This resistor is called a *plate resistor* and is usually about 100,000 ohms. As in the case of transformer coupling, a C battery is placed in the grid circuit of the amplifier tube to prevent the flow of grid current which would cause distortion.

86. What is resistance-coupled audio-frequency amplification? But there is still another difficulty to overcome. We are dealing with loud signals, which means that the stream of electrons may be very large. Thus it becomes possible that the stream of electrons set flowing from plate 2 of the capacitor may make the grid of the amplifier so negative as to completely cut off the flow of electrons from the heated filament to the plate.

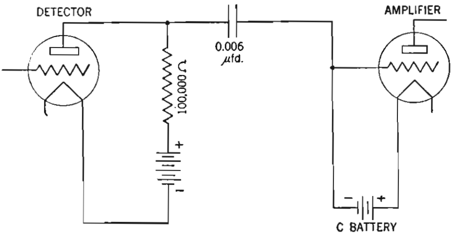


Fig. 91. Diagram showing how the C battery is connected in the grid circuit of the amplifier tube.

To meet this difficulty a path is provided for these electrons to leak off slowly from the grid to the filament. A resistor is placed in the grid circuit between the C battery and the grid. This resistor is called the *grid resistor*. Its value usually is about 2,000,000 ohms (2 megohms). This method of coupling is called *resistance coupling*. As in the case of the transformer-coupled

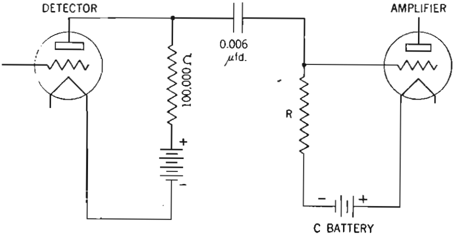


Fig. 92. Diagram showing how grid resistor (R) is placed in the circuit.

amplifier stage described above, this amplification is at audio frequency and it is therefore described as a stage of *resistance-coupled audio-frequency amplification.*

87. What are the relative advantages of transformer as compared to resistance coupling? Each method of coupling has certain advantages and disadvantages. The transformer method of coupling has the advantage that, stage for stage, it will give a greater amplification than does the resistance method of coupling. Two stages of transformer-coupled audio-frequency amplification are about equal to three stages of resistance-coupled audio-frequency amplification. The need of fewer stages with the transformers than with the resistors is due to the amplification resulting from the use of step-up transformers.

Further, we may use a B battery of less voltage with transformer coupling than is needed with resistance coupling to obtain the same plate current. This difference is due to the fact that the large resistor used for a plate resistor in the resistance-coupled audio-frequency amplifier cuts down the amount of positive charge that the B battery can place on the plate of the tube. Still another advantage is the simplicity of the transformer-coupled stage. Only one part is needed for the coupling, the audio-frequency transformer.

The resistance-coupled amplifier has the advantage that it reproduces the signal more faithfully. The audio-frequency transformer usually introduces a certain amount of distortion. Another advantage is that resistance coupling is cheaper and weighs less than the audio-frequency transformer.

88. What is the nature of the audio-frequency amplifier unit? In considering the radio receiving set as a whole, the several stages of audio-frequency amplification are usually treated together as a separate unit. In fact, in some modern receivers this unit is built separately and apart from the rest of the set. As previously stated, this unit may consist of two stages of transformer-coupled or three stages of resistance-coupled amplification. Often the two systems are combined, with one or two stages of resistance-coupled amplification followed by a stage of transformer-coupled amplification.

It is impractical to use more than two stages of transformer-coupled or three stages of resistance-coupled amplification. If we do, we may encounter serious distortion of the signal. Besides, for normal use, more amplification is not necessary.

In Figure 93, we have a detector followed by two stages of transformer-coupled amplification. The tubes used are triodes of a type known as 01A. Instead of using separate A batteries for each tube, the filaments of the tubes are hooked together in

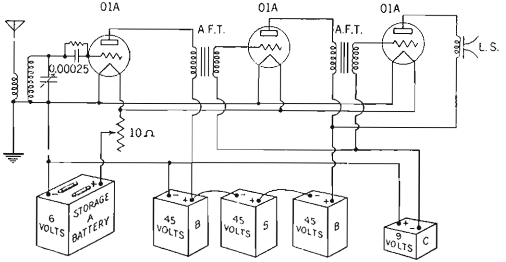


Fig. 93. Diagram showing detector and two stages of transformer-coupled audio-frequency amplification.

parallel and connected to a single battery supplying 6 volts. The rheostat used as a volume control now limits the amount of current flowing in the filaments of all three tubes. For this purpose we use a rheostat of 10 ohms.

To obtain the B battery of 135 volts, we connect three 45-volt batteries in *series;* that is, we connect the positive terminal of one to the negative terminal of another. To obtain the 45 volts needed for the detector tube, we make our connections between the negative terminal of the first battery and the positive terminal of this same battery. If, however, we connect between the negative terminal of the first battery and the positive terminal of the third battery, we obtain the 135 volts needed for our amplifier tubes.

The C-battery connections of the two amplifier tubes are likewise connected, and we now can use a single C battery of 9 volts.

89. How is the audio-frequency amplifier used in a public-address system? We can use the audio-frequency amplifier for other purposes than amplifying in a radio receiver. Suppose you were to feed an alternating voltage set up by a microphone into the grid of your amplifier tube. You would now have the public-address system used for large audiences.

The Turner Co.

Microphone.

The microphone is similar to the telephone transmitter of Figure 11. Speaking into the microphone varies its resistance and thus causes the direct current flowing through the primary of the transformer to vary. The direct current varies in step with the variations of the sound waves created by the speaker. This fluctuating direct current flowing through the primary of the transformer sets up a varying alternating voltage across the secondary. This alternating voltage places varying charges upon the grid of the amplifier tube, and this variation in turn causes a large fluctuating direct current to flow in the plate circuit of the tube. After another stage of amplification the current is strong enough to operate the powerful loudspeaker.

The transformer used in a microphone circuit is similar to the audio-frequency transformer used in the radio receiver. However, in connection with it note, in Figure 94, a device that looks like a rheostat across the secondary. This is known as a *potenti-*

ometer. It is a variable resistor with connections at both ends and the variable contact. Its use is to cut down the voltage output from the secondary of the microphone transformer

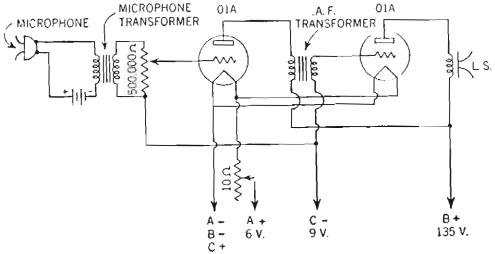
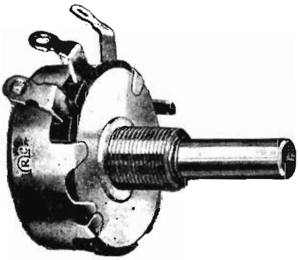


Fig. 94. Diagram showing circuit of the public-address system.

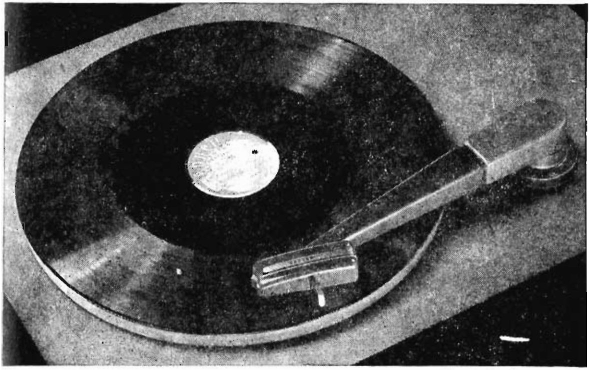
and thus to limit the amount of charge placed on the grid of the tube and thereby control the volume of the amplifier. Its value in this case is about 500,000 ohms. The symbol for a potentiometer is: .

90. How is the audio-frequency amplifier used in phonographs? Still another use for the audio-frequency amplifier is the electrical phonograph. Use is made of the peculiar properties of crystals of a chemical compound known as Rochelle salts. When one of these crystals is squeezed, it generates a minute alternating electrical voltage. This voltage varies with the variations in pressure upon the crystal. This phenomenon is known as the *piezoelectric effect.*



International Resistance Corp.

Potentiometer.



Brush Development Co.

Crystal pickup.

Such a crystal is mounted so that the vibrations of a phonograph needle, traveling in the grooves of a phonograph record, place a varying pressure upon it. In the crystal an alternating voltage is generated that varies in step with this pressure. This voltage is fed to the grid of the amplifier tube, placing a varying electrical charge upon it. This charge in turn causes a fluctuating

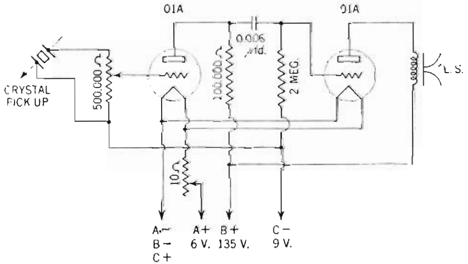


Fig. 95. Diagram showing circuit of the radio phonograph.

direct current to flow in the plate circuit of the tube. After another stage of amplification the current is strong enough to operate the loudspeaker. (See Figure 95.)

The crystal and its mounting are known as a *crystal phonograph pickup*. The symbol for such a pickup is:

Note that no transformer is necessary here to couple the crystal pickup with the tube. The reason is that the voltage generated is alternating voltage and it can be applied directly to the grid of the tube. A 500,000-ohm potentiometer acts as a volume control, just as in the case of the public-address system.

This suggests some uses to which the audio-frequency amplifier can be put. It can be used anywhere that a very small electrical voltage is to be amplified. It has been used successfully with photoelectric cells, in electrocardiograph machines, and the like. Each day brings forth new uses for this wonderful device.

SUMMARY

1. The purpose of the **audio-frequency amplifier** is to increase the intensity (loudness) of the signals so that a loudspeaker may be used instead of earphones.

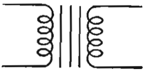
2. The principle of the audio-frequency amplifier is to connect the plate circuit of a tube to the grid of another tube. The plate current in the second tube will then be an amplified reproduction of the signal in the detector tube.

3. By connecting a third tube in the same manner to the plate circuit of the first amplifying tube a second stage of amplification may be made.

4. Distortion in the amplifying system is prevented by carefully balanced values of grid bias, plate resistors, and capacitors.

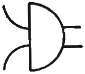
5. Audio-frequency amplifiers are used for public-address systems, to reproduce phonograph records, for amplifying signals of photoelectric cells, and for many other purposes.

SYMBOLS


Audio-frequency transformer.


Potentiometer.


Crystal pickup.


Microphone.

CHECK-UP

Part A

Each statement below is either true or false. If a statement is false, one or more, but not necessarily all, of the *italicized* parts make it false. If a statement is true, encircle the T and do nothing else with it.

If a statement is false in any part, first encircle the F; then correct it by substituting the right word, number, or phrase for the incorrect word, number, or phrase in italics. Write your correction in the blank space at the end of the statement. The samples show you how. (Answers are on pages 302–303.)

SAMPLES:

(T) F Radio-frequency energy *travels in waves.* ....

T (F) *Direct* currents flow in cycles. **Alternating.**

T F **1.** The range of audio frequencies is from *70 to 10,000* cycles per second. ....

T F **2.** To operate a loudspeaker, the output from the detector tube is fed to the *plate* of the amplifier tube. ....

T F **3.** To keep current from flowing in the grid circuit of an amplifier tube, a *positive* charge is placed on the *plate* of the tube. ....

T F **4.** Stage for stage, we get greater amplification from a *transformer-coupled audio-frequency amplifier* than from a *resistance-coupled one.* ....

....

....

T F **5.** The extra energy needed to drive a loudspeaker from an audio-frequency amplifier comes from the *C battery.* ....

T F **6.** The electrical pulsations that come out of the detector tube possess *audio frequency.* ....

T F **7.** By means of transformer coupling the direct current of the *detector plate circuit* is changed to alternating current in the *grid circuit of the amplifier.* ....

T F **8.** The current that flows in the plate circuit of an amplifier tube is a *direct current.* ....

T F **9.** The transformer that couples detector and amplifier has its *primary* connected to the detector and its *secondary* connected to the amplifier. ....

T F **10.** The purpose of the C battery is to keep the amplifier-tube grid *negative.* ....

T F **11.** In *resistance-coupled* audio-frequency amplification, capacitors are used..............................

T F **12.** In resistance-coupled amplification there must be resistance in the *detector-plate circuit* to force the electrons flowing from the detector-tube plate onto the coupling *capacitor.* ....

T F **13.** In resistance-coupled amplification, there must be resistance between C battery and amplifier-tube grid so that the *coupling-capacitor* voltage can control the amplifier grid. ....

T F **14.** It is not usually practical to use more than *four* stages of transformer-coupled amplification or *two* stages of resistance coupled amplification. ....

T F **15.** In a public-address system a *capacitor* is used across the primary of the microphone transformer to regulate the amount of charge placed on the *plate* of the amplifier tube to control the volume of sound. ________________

T F **16.** In an electrical phonograph the *needle vibrations* cause a tiny *alternating current* to flow in a piece of crystal. ________________

Part B

Beneath each name of a radio part draw the symbol for that part.

MICROPHONE	AUDIO-FREQUENCY TRANSFORMER	POTENTIOMETER	CRYSTAL PICKUP

CHAPTER 17

Eliminating the B Battery

QUESTIONS THIS CHAPTER ANSWERS

1. *What are the faults of A and B batteries?*

2. *How is the common alternating current converted into a steady direct current?*

3. *How is the common alternating current made to deliver higher voltage for the plate?*

4. *How is the common alternating current made to deliver a lower voltage for the filament?*

5. *What are the essential parts of a B eliminator and how does it work?*

91. What are some faults of batteries? Having eliminated the nuisance of the headphones, the next problem to be tackled is that of getting rid of the various batteries required. These batteries have several serious drawbacks. They have a limited life, even though the radio receiver is used infrequently. This short life means periodic replacements which are not only troublesome but costly. Besides, as the batteries start to wear out, the voltage delivered starts to fall off. This deterioration means uneven performance.

Furthermore, the batteries are quite bulky, especially those of the high-voltage type used as plate batteries for the amplifier tubes. To heat the filaments of the tubes, a storage battery is usually used. This battery must be recharged periodically as the current is used up. Besides this nuisance the storage battery is heavy, bulky, and contains an acid which may be spilled easily with disastrous results to clothing, rugs, and woodwork.

Since the use of house current for lighting purposes is fairly universal, it was only natural to seek a means of using this house current to replace the batteries.

92. What is a rectifier tube? The first battery to be eliminated was the plate or B battery. The house current most widely used in our country is alternating current with a voltage or electrical pressure of 110 volts. This alternating current usually has a frequency of 60 cycles per second.

Such an alternating current cannot be applied directly to the plate of the tube because this plate must always have a steady positive charge. Any fluctuations of the positive charge on the plate due to variations in the plate battery voltage would result

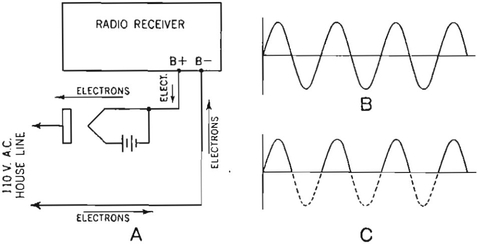


Fig. 96. (A) The diode as a rectifier tube. For simplicity, the circle around the symbol of the diode is omitted. (B) Wave form showing alternating current flowing in house line before rectification. (C) Wave form showing the alternating current after it has been rectified by the rectifier tube. The bottom half of the loop has been cut off and it now becomes a pulsating direct current.

in distortion of the signal. It becomes necessary, therefore, to change the alternating current of the house line to a steady direct current before it can be fed to the plate of the tube.

You will recall that the diode tube changes alternating current into pulsating direct current. So we feed the alternating current of the house line into a diode tube as in Figure 96. When the plate of the diode has a positive charge on it, current will flow from the house line to the plate circuits of the radio receiver. When a negative charge is placed on the plate of the diode, no current will flow. A diode used as indicated here is called a *rectifier tube.* We say that we have *rectified* the alternating current.

93. How is the pulsating direct current changed to a steady direct current? But it is not enough to change the house current from alternating current to *pulsating* direct current. We must change it to a *steady* direct current. To do this we must pass the pulsating direct current through a *filter*. In Figure 97, you will

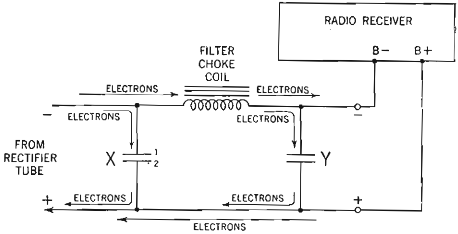
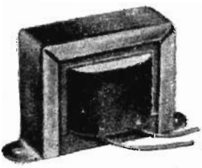


Fig. 97. Hookup showing the filter system.

notice that the pulsating direct current from the rectifier tube is fed into a network consisting of two capacitors (X and Y) and an iron-core inductance. This inductance contains many turns of wire and is called a *filter choke coil.* An inductance of 30 henries is usually used.



United Transformer Corp.

Filter choke coil.

As the electrons rush up to the choke coil, they encounter a very great opposition resulting from the many turns of wire and the self-inductance of the coil. As a result, they are forced to pile up on plate 1 of capacitor X. Here they accumulate until enough of them are piled up to overcome the resistance offered by the coil. Thus capacitor X acts as a sort of reservoir or storage tank for the electrons. On the other side of the choke coil, capacitor Y also acts as a storage tank for these electrons.

A result of the action of the choke coil and capacitors is shown in the graph of the wave form in Figure 98. The peaks of the pulsating direct current from the rectifier tube are leveled off and the hollows are filled in. The result in the receiving set is a steady direct current which is fed to the plates of the tubes. The action of the filter is to hold back the pulsating electron flow until a steady average flow is reached and maintained. When

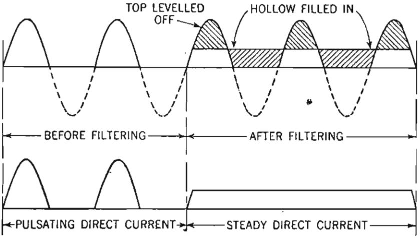


Fig. 98. Wave form showing how the filter system changes pulsating direct current to steady direct current.

this steady flow results, we say we have *filtered* the current flowing from the rectifier tube.

94. What is the purpose of the power transformer? The voltage of the current flowing out of the filter is about the same as the voltage of the house current, namely, 110 volts. As this voltage

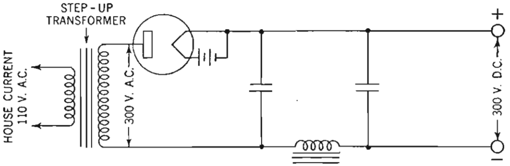


Fig. 99. B-battery eliminator using a step-up transformer.

does not place a very high charge on the plate, someone thought of using a step-up transformer to increase the house-current voltage to about 300 volts. Thus about 300 volts of steady direct current flow out of the filter, and we are able to place a higher positive charge on the plates of the tubes in the receiver; a greater plate current flows, and a louder sound comes out of the loudspeaker.

In practice, the primary of the step-up transformer is connected to the 110-volt alternating current of the house line. The

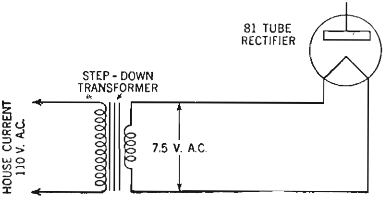


Fig. 100. Step-down transformer used to heat the filament of the rectifier tube.

secondary is connected to the rectifier tube and filter (see Figure 99). The step-up transformer used here is called a *power transformer.*

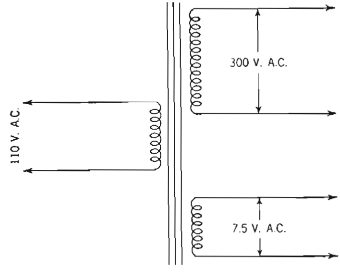
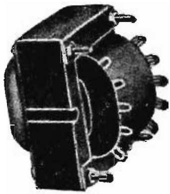


Fig. 101. Transformer with two secondaries to step up the voltage for the plate supply and to step down the voltage for the filament of the rectifier tube.

95. How is a step-down transformer used for the rectifier? To eliminate the necessity for using a filament battery for the rectifier tube, a step-down transformer is used to step down the 110-volt house alternating current to a value that the rectifier tube requires. If we use a type 81 rectifier tube, the transformer steps down the 110-volt alternating current to $7\frac{1}{2}$-volt alternating current. Using alternating current on the filament of the rectifier tube does not cause any interference with the signal.

The primary of the step-down transformer is connected to the 110-volt alternating-current line, and the secondary is connected across the filament of the rectifier tube in place of the filament battery. The step-down transformer used here is called a *filament transformer*. The wiring diagram is shown in Figure 100. For convenience, the two secondaries, the step-up to the plate of the rectifier tube and the step-down to the filament may, by suitable winding, be made to operate from the same primary (see Figure 101).



United Transformer Corp.

Power transformer.

96. What is full-wave rectification? Still another improvement was made to utilize the half cycle of alternating current blocked out by the action of the rectifier tube

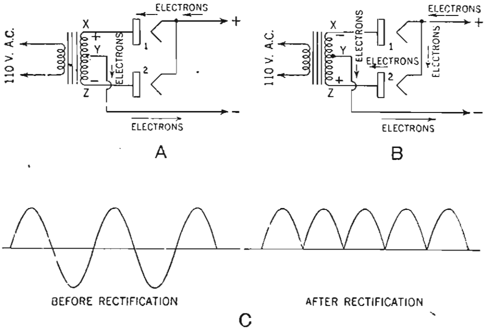


Fig. 102. Full-wave rectification using two rectifier tubes. For simplicity, the circles around the tube symbols are omitted. (A) Electron flow during one half cycle. (B) Electron flow during the next half cycle. (C) Wave form showing full-wave rectification.

(Figure 96). By connecting up two rectifier tubes as shown in Figure 102, this half cycle could be put to use.

In Figure 102-A, when point X of the secondary of the power transformer has a positive charge on it, point Z has a negative charge. This situation means that the plate of rectifier tube 1 is positive and the plate of rectifier tube 2 is negative. Electrons then stream from the filament of tube 1 to the plate and through the secondary to point Y, the electrical mid-point of the secondary. Since Z is negative, it repels these electrons, and they are forced to stream through the wire connecting Y to the filter circuit. Tube 2 does not operate. During the next half cycle (Figure 102-B) the charges on the secondary are reversed. Now tube 1 does not operate, while electrons from tube 2 stream to point Y and to the filter circuit.

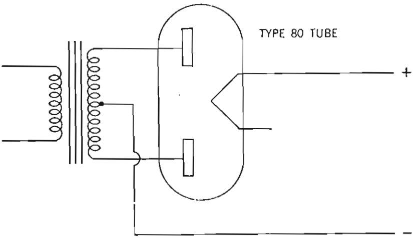


Fig. 103. Type 80 rectifier tube with one filament and two plates. This tube is used for full-wave rectification.

This method of rectification, using both halves of the alternating-current cycle, is called *full-wave rectification.* The method previously described, using only one half of the cycle, is called *half-wave rectification.* Full-wave rectification is easier to filter because the hollows between the direct-current pulses are smaller (Figure 102-C).

A logical development was to combine the two rectifier tubes into one, using two plates and one filament. In this double tube the filament is constantly emitting electrons, which are attracted first to one plate and then to the other as the charges on these plates are alternately positive and negative. An example of a full-wave rectifier tube is the type 80.

97. How does a potentiometer act as a form of voltage divider? After full-wave rectification was perfected, one more thing remained to be done. The steady direct current flowing out of the filter circuit was at an electrical pressure of about 300 volts. This voltage is suitable for the plates of the amplifier tubes, but it is too high for the plate of a detector tube, where a maximum

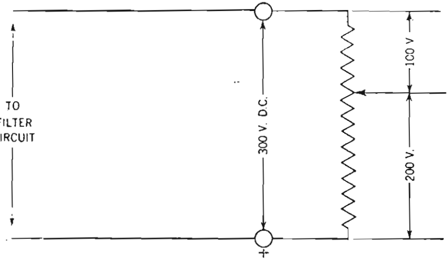
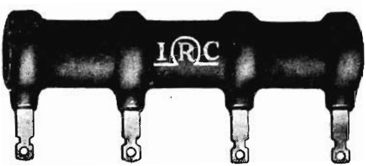


Fig. 104. Diagram showing how a potentiometer is hooked up as a voltage divider.

of 100 volts is needed. A means had to be devised to enable us to tap off a lower voltage for the detector tube. This object was accomplished by connecting a potentiometer across the output terminals of the filter circuit.

Here is how the potentiometer works: Assume that the electrical pressure at the output terminals of the filter circuit is 300 volts. This statement means that the electrons piled up on the negative terminal are seeking to get to the positive terminal with a force which is equal to this electrical pressure of 300 volts. Electricians call this a *drop* of 300 volts. Now we connect a resistor from the negative terminal to the positive terminal. The electrons use up the 300-volt pressure in traveling the entire length of

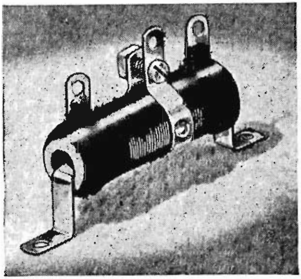


International Resistance Corp.

Tapped-resistor voltage divider.

the resistor to the positive terminal. But the drop, or fall in pressure (technically, the drop in potential), is proportional at any point to the fraction of the resistor overcome at that point.

Suppose we take a point one third of the way down the resistor. At this point the electrons have used up one third the pressure, and the pressure of the electrons at that point seeking to reach the positive terminal is 200 volts. At a point two thirds of the way down the resistor, two thirds of the original total voltage (or pressure) has been used, and the pressure between that point and the positive terminal is only 100 volts. So, by moving the slider of the potentiometer from point to point on the resistor we can get any desired voltage out of the filter circuit. The potentiometer, hooked up in this circuit, is called a *voltage divider*.



Ohmite Mfg. Co.

Variable-resistor voltage divider.

The size of the voltage divider varies with the number of tubes used in the receiver. Generally, the resistance is about 15,000 to 25,000 ohms. The resistance wire must also be heavy enough to stand the current that flows through it without burning out. The amount of current a resistor can safely pass at a given voltage is expressed by its rating in *watts*. A *watt* is a unit of electrical power. For a resistor, the rating in watts is measured by the product of the current through it and the voltage (pressure) across it. Hence, with a given voltage, as the current increases, the rated number of watts must increase. It follows that the more current needed for the plate currents in the radio receiver, the heavier this resistor must be. In the present case, with an assumed pressure of 300 volts, the resistor must be rated at about 25 watts.

98. How is a dropping resistor used to reduce voltage on the detector-tube plate? There is another way by which we can get the lower voltage needed for the plate of the detector tube. Instead of connecting the positive output terminal directly to the B terminal of the audio-frequency transformer in the plate circuit of the detector tube, we insert a resistor of about 5000

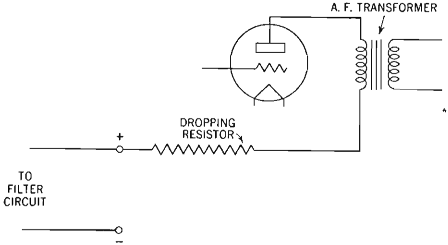
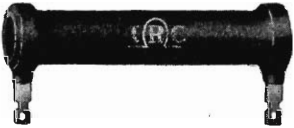


Fig. 105. Circuit showing use of a dropping resistor to obtain the lower B voltage required for the plate of the detector tube.

ohms between the two points (see Figure 105). This plan involves the same principle of drop or fall in potential, because some of the electrical pressure is used up in forcing current through this resistor. As a result, a smaller positive charge is placed on the plate of the detector tube. This resistor is called a *dropping resistor*.

99. How does the B eliminator work? Here, now, in Figure 106, is the plan for our completed *B-battery eliminator*. The primary of the power transformer is connected to the house line, which supplies 110-volt alternating current. The step-up secondary increases this voltage to 300 volts. The ends of this secondary are connected to the plates of the type 80 rectifier tube.



International Resistance Corp.

Wire-wound dropping resistor.

The step-down secondary reduces the voltage to 5 volts. The ends of this secondary are connected to the filament of the rectifier tube. The negative line of the B-battery eliminator comes from the mid-point or *center tap* of the step-up secondary and is connected to one end of the filter input. The positive line comes from the filament of the rectifier tube and goes to the other end of the filter input. At this point the current is pulsating direct current at about 300 volts. When this current passes through the filter, it comes out as a steady direct current at about 300 volts. It makes no difference whether the choke coil is in the positive or negative line. In circuit diagrams it is usually shown in the positive line.

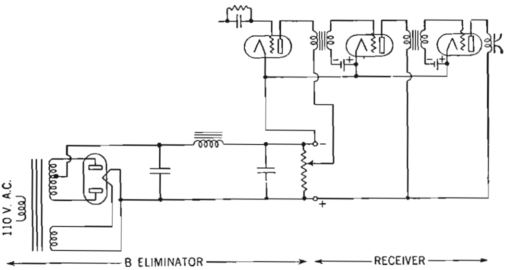


Fig. 106. Completed B eliminator, showing how it is connected to the radio receiver. See if you can name each part and state its function. Where is the aerial-ground system connected?

Across the negative and positive terminals of the B-battery eliminator the electrical pressure is 300 volts. The negative terminal is connected to the filaments of the tubes in the radio receiver, just as is the negative post of the B batteries when there is no eliminator. Similarly, the positive terminal of the eliminator is connected to the B+ terminal of the second audio-frequency transformer and the loudspeaker. Across the terminals of the eliminator, a potentiometer is connected. The sliding tap is adjusted to a point where the electrical pressure or voltage is of the desired value, about 100 volts. A connection is made from this sliding tap to the B+ terminal of the first audio-frequency transformer.

100. How are electrolytic capacitors used? The capacitors used in the filter circuit are very large, about 8 μfd. each. For this purpose we generally use capacitors whose plates are made of tinfoil and whose dielectric is waxed paper. Recently, we have been using *electrolytic capacitors.* These capacitors have plates of aluminum and an aluminum oxide dielectric. In using these electrolytic capacitors, care must be taken that the terminal marked POSITIVE or + is connected to the positive line and the terminal marked NEGATIVE or − is connected to the negative

P. R. Mallory & Co.

Electrolytic capacitor.

line of the filter circuit. Failure to observe this precaution may destroy the capacitor.

The capacitors used in the filter circuit are called *filter capacitors.* Care must be taken that the dielectric is strong enough to withstand the electrical pressure—in this instance, at least 300 volts. This rating is usually marked on the side of the capacitor.

SUMMARY

1. Batteries became such a nuisance in radio sets that means were sought to eliminate them.

2. The ordinary current delivered to the home is alternating current of 60 cycles at a pressure of 110 volts.

3. By passing the alternating current through a diode tube the current is rectified to pulsating direct current.

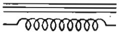
4. By the use of coils having high resistance, called choke coils, together with capacitors, the pulsating current is changed to steady current. This system of chokes and capacitors is called a **filter system.**

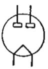
5. Full-wave rectifying tubes (type 80) are made with one filament and two plates. This design makes use of the half cycle of alternating current that is blocked off during rectification by a single diode.

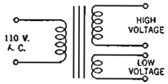
6. Potentiometers are variable resistors by the use of which a high voltage may be reduced to any desired voltage through the principle that *drop* in pressure is proportional to resistance overcome.

7. The B-battery eliminator consists of a type 80 tube with resistors and filters so connected that all the functions of the dry-cell B battery are performed by energy from house alternating current.

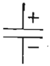
SYMBOLS


Filter choke.


Full-wave rectifier.



Power trans- former.



Electrolytic capacitor.

CHECK-UP

Part A

In the blank spaces write the words, phrases, graphs, or numbers needed to complete the statements correctly. (Answers are on page 303.)

1. The most frequently used type of current supply throughout the country is .... -volt alternating current at a frequency of ....

2. When we use a diode to change an alternating current to a pulsating direct current, the current is said to have been ....

3. To change a pulsating direct current into a smooth, steady direct current, we first must pass it through a .... system which usually consists of .... and ....

4. The power transformer is used to step .... the voltage of the house power lines for the plate of the diode and step it .... for the filament.

5. The wave form of the output of a half-wave rectifier is ...., while that of a full-wave rectifier is .... An example of the full-wave rectifier is the .... type tube.

6. The voltage divider is a resistance device used to tap off different ....

7. The amount of current that a particular resistor can safely pass at any given voltage is given by its rating in ....

8. A capacitor with aluminum plates and aluminum oxide dielectric is called an .... capacitor.

Part B

Below each name of a radio part draw the symbol for that part.

FILTER CHOKE COIL   POWER TRANSFORMER

CHAPTER 18

Eliminating the A Battery

QUESTIONS THIS CHAPTER ANSWERS

1. *What are the difficulties of heating a filament with an alternating current?*

2. *How does a cathode-sleeve tube permit the use of alternating current on the filament?*

101. Why is alternating current unsatisfactory for the filament? The next battery to be eliminated was the A or filament battery. It is simple enough to use a step-down filament transformer to

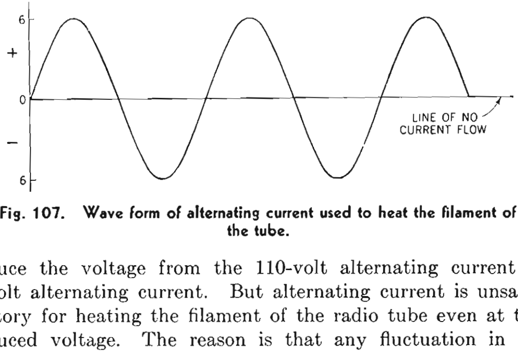


Fig. 107. Wave form of alternating current used to heat the filament of the tube.

reduce the voltage from the 110-volt alternating current to 6-volt alternating current. But alternating current is unsatisfactory for heating the filament of the radio tube even at this reduced voltage. The reason is that any fluctuation in the stream of electrons shot out by the heated filament causes a hum or noise with the signal. The plate current is the current produced by the stream of electrons from the filament to the plate. Examine the wave-form picture of the alternating current used to heat the filament in Figure 107.

When the alternating-current cycle reaches its peak (whether the positive or negative peak makes no difference here), the electrons are streaming through the filament at their maximum rate, and the filament is being heated to maximum temperature. The electrons being emitted by the heated filament are shooting out at the maximum rate. When the alternating-current cycle reaches the line of no current flow, however, the filament starts to cool off, and the number of electrons emitted starts to drop off. The result is a fluctuation in the number of the electrons reaching the plate, with resulting distortion of the signal.

102. What various methods of controlling the temperature of the filament were tried? One method used to combat this fluctuation in the temperature of the filament was to make the mass of the filament greater. Instead of using a thin wire, a ribbon type of filament was used. Because of its greater mass, the temperature in such a filament does not fluctuate as much as in the thinner ones during the changes in the alternating-current cycle.

But the ribbon filament was not wholly successful for two reasons: (1) some fluctuations still remained, and (2) to heat this massive filament required great amounts of electric current.

Another method used to overcome the difficulty was to convert the 6-volt alternating current to direct current, using a rectifier consisting of plates of copper and copper oxide. The action of this rectifier is similar to that of the crystal detector. Still another method of rectifying the alternating current was to use a chemical rectifier. Plates of lead and aluminum were suspended in a solution of borax. This chemical rectifier passes current only in one direction. The diode tube also was used as a rectifier, following the method described in the previous chapter.

All these methods of rectification were not very practical. They required special apparatus for the rectification and filter systems. The chemical rectifier had the additional drawback of being spilled easily.

The use of alternating current directly on the filament of the radio tube was tried in a number of ways, but one difficulty always remained. The grid of the tube, as you know, must be connected to the filament as shown in Figure 108. So, if alternating current is sent through the filament, then during one half of the cycle a positive charge is placed on the grid, as in Figure

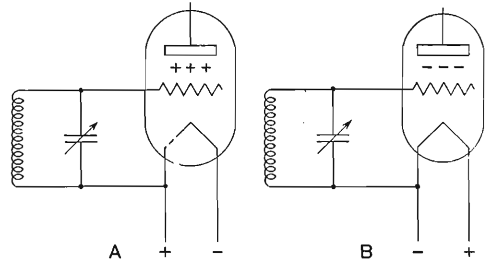


Fig. 108. Circuits showing how alternating current flowing through the filament places an alternating charge on the grid of the tube.

108-A. During the next half of the cycle a negative charge is placed on the grid (Figure 108-B). Thus an alternating charge is placed on the grid by the alternating current flowing in the filament. This charge interferes with the flow of electrons to the plate and distortion results.

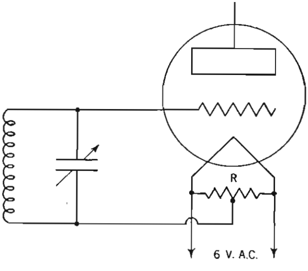


Fig. 109. Circuit showing the use of a 20- to 40-ohm center-tapped resistor (R) to reduce hum.

To help correct this fault a resistor of 20 to 40 ohms was connected across the filament. At the electrical center of this resistor, a tap was placed. To this tap was connected the wire going to the grid circuit (see Figure 109). It can be seen that whichever side of the filament is positive or negative, the center tap, being halfway between them, is always at the same electrical pressure. Thus a constant charge is placed on the grid and there are no unwanted fluctuations in the plate current. This scheme, together with the use of the heavy ribbon-type filament, gave fairly good results.

103. How does a cathode sleeve permit use of A.C. on the filament? But a better method, permitting the use of alternating current on the filament, was subsequently worked out. Around the filament, but not touching it, a sleeve of metal is slipped. Now the filament is used as a stove to heat this sleeve. As the sleeve becomes hot, it emits the stream of electrons which reaches the plate.

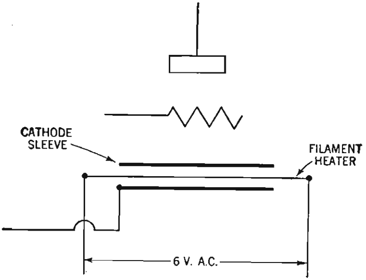


Fig. 110. Diagram of tube with a cathode sleeve used as an emitter of electrons.

This sleeve is now the surface which gives off the electrons and is therefore called the *cathode*. Because it is quite massive, the temperature of the cathode does not change with the alternating-current cycle of the current flowing through the filament. Thus the stream of electrons it emits is steady. The symbol for the cathode is: .

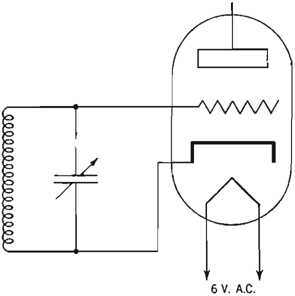


Fig. 111. Circuit showing how the cathode is connected to the grid return.

The wire going to the grid, called the *grid return*, is connected to the cathode instead of to the filament. The filament is thus removed from the circuit bearing the radio signals. Hence the current used to heat the filament may be either alternating or direct current without causing distortion of signals. In modern tubes the cathode is usually coated with special chemicals that make it a more efficient emitter of electrons. We shall discuss this matter more fully later.

104. How is the cathode-type tube hooked up with the B-battery eliminator? The use of the cathode simplifies things a great deal. The only extra piece of apparatus for this new type of tube is the step-down filament transformer. An example of a tube using this cathode is the type 27.

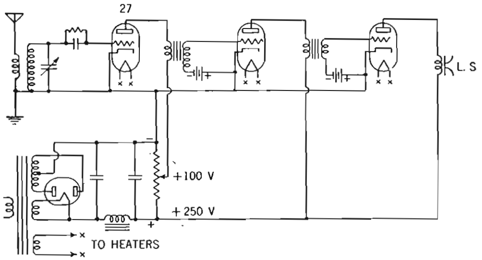


Fig. 112. Radio circuit showing the use of a B-battery eliminator and cathode-type tubes.

We have now eliminated the need for the A or filament battery. A typical hookup using the cathode-type tube is shown in Figure 112. In studying this wiring diagram you should notice that the B— terminal of the B-battery eliminator is now connected to the cathode instead of the filament. Notice, also, that a third secondary winding has been added to the power transformer. This is a step-down secondary giving the 2½ volts needed for the filament of the type 27 tube.

SUMMARY

1. The alternating current is unsatisfactory for heating the filaments of radio tubes because of the uneven flow of electrons to the plate.

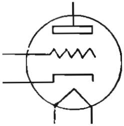
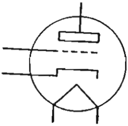
2. Various means of correcting the faults of the alternating current as a substitute for the A battery were tried before a successful method was found.

3. The device which was successful is the **cathode sleeve.** The principle in this is that the filament bearing the alternating current does not touch the cathode but merely heats it because it is close to it. The cathode therefore emits the electrons used in the plate circuit to carry the radio signals.

4. The type 27 tube has this cathode sleeve and needs to be operated at $2\frac{1}{2}$ volts alternating current furnished by a step-down transformer.

SYMBOLS


Cathode in a tube.


or

A triode employing a cathode.

CHECK-UP

Part A

Underscore the words or phrases that make the statements correct. (Answers are on page 303.)

1. The purpose of the A battery is to heat the (*filament*) (*plate*) (*grid*) of the tube.

2. Using heavy ribbon filaments reduced signal hum because the (*temperature*) (*resistance*) (*mass*) of the filament did not vary so much.

3. The use of the center-tap filament resistor kept the voltage on the (*grid*) (*filament*) (*plate*) constant with respect to the (*plate*) (*grid*) (*filament*) when no signal was coming in.

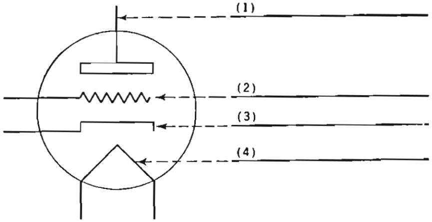
4. The most recent method for using alternating current for heating tubes makes use of a (*rectifier*) (*metal sleeve*) (*resistor*) called a (*grid return*) (*cathode*) (*filter*) which emits electrons when heated by the (*A battery*) (*filament*) (*cathode*).

5. In a cathode-type tube the alternating current flows in the (*heater*) (*grid*) (*plate*) circuit.

6. In the cathode-type tube hookup the (*negative*) (*positive*) terminal of the B-battery eliminator is connected to the (*plate*) (*filament*) (*sleeve*) of the cathode-type tube.

Part B

In the following diagram label the parts indicated:



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CHAPTER 19

Eliminating the C Battery

QUESTIONS THIS CHAPTER ANSWERS

1. *How may a voltage divider be used to eliminate the C battery?*
2. *How may a bias resistor be used to eliminate the C battery?*
3. *How does a by-pass capacitor prevent distortion?*

105. How does a voltage divider maintain the grid bias? Having succeeded in eliminating the A and B batteries, radio engineers next tried to get rid of the C battery. It proved to be a simple matter to do away with this battery. Let us recall the function of the C battery. Figure 113 shows the C battery con-

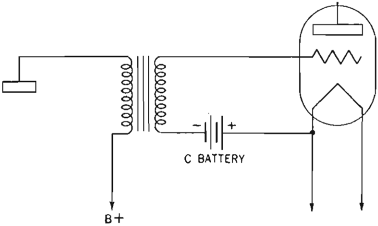


Fig. 113. Circuit showing a C battery connected in the grid circuit of an amplifying tube. Why is this battery called a grid-bias battery?

nected in the grid circuit of the triode. Since the C battery (or grid-bias battery) is connected with the negative post to the grid return and the positive post to the filament, the grid is more negative than the filament. So all we have to do is to work out a system that makes the grid slightly more negative than the filament, and our C battery is eliminated.

Turn back to Figure 106. The most negative point of the B eliminator is the negative terminal. Note that the filaments of the radio tubes are connected to that point. Now consider a point on the voltage divider a little distance away from the negative terminal and toward the positive terminal. As you now know, this point is a little more positive than the negative terminal.

Now, connect the filament to this new point and connect the grid return to the negative terminal (Fig. 114-A). The grid in

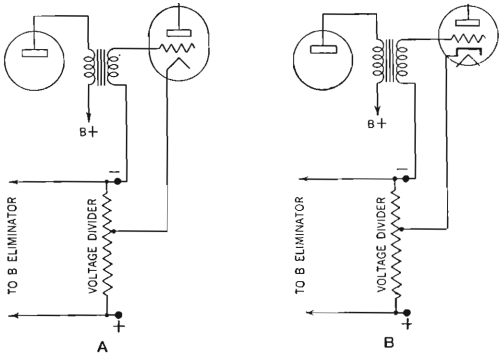


Fig. 114. (A) Circuit showing how a filament-type tube is connected to obtain the grid bias from the voltage divider. (B) Circuit showing how a cathode-type tube is connected to obtain the grid bias from the voltage divider.

this hookup is slightly more negative than the filament, and we have eliminated the necessity for a C battery. Figure 114-B shows how a cathode-type tube is hooked up to eliminate the C battery.

106. How does a bias resistor eliminate the C battery? Other methods can be used to eliminate the C battery. For example, it has already been stated that the most negative point of the B eliminator is the negative terminal. This statement means that the greatest excess of electrons has accumulated there. Hence, when the grid return is connected to this terminal, the grid, too, is negative.

The cathode, however, is not connected directly to the negative terminal of the B eliminator, but through a resistance of about 2000 ohms, as in Figure 115. To understand this hookup, compare the pathways of electrons from the B-battery eliminator to the grid and to the cathode respectively. As the cathode shoots off electrons, other electrons are drawn up from the large supply on the negative terminal of the B eliminator. But some of the electrical pressure is lost in pushing these electrons through the 2000-ohm resistor. In this hookup, then, the cathode is slightly less negative than the negative terminal of the B eliminator.

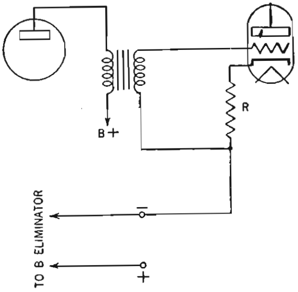


Fig. 115. Circuit showing how a bias resistor (R) is used to obtain grid bias.

The grid of the tube, connected to this negative terminal without the resistor between it and the terminal, is therefore slightly more negative than the cathode. So now again there is no need for the C battery. The resistor we connected in series with the cathode of the tube is called a *bias resistor*. Different types of tubes use different bias resistors. The 2000-ohm resistor mentioned here is suitable for the type 27 tube. The bias resistor performs a function similar to that of the dropping resistor explained in §98.

107. How does a by-pass capacitor prevent reduction of amplification in the tube? If you examine Figure 116, you will notice that this bias resistor is in the plate circuit. The electrons stream up from the negative terminal of the B eliminator, through the bias resistor to the cathode, across to the plate, through the winding of the loudspeaker, and back to the positive terminal of the B eliminator. Since a fluctuating direct current is flowing in that plate circuit, the difference in electrical pressure between the cathode and the grid will also fluctuate.

This condition is not desirable, for it reduces the amplification of the tube. To overcome this effect, a large capacitor of about 1 μfd. is connected across (in parallel with) the bias resistor. This capacitor, called a *by-pass capacitor*, smoothes out the

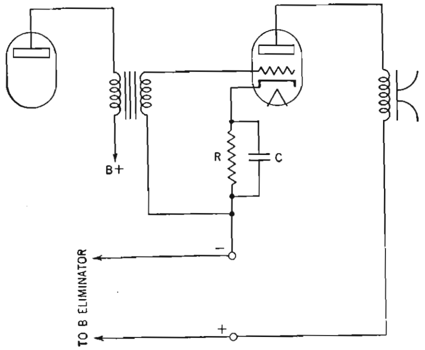


Fig. 116. Circuit showing bias resistor (R) and by-pass capacitor (C).

fluctuations on the same principle as the filter capacitors in the filter circuit of the B eliminator.

108. The complete no-battery receiver. Having succeeded in eliminating all batteries, we are now ready to present our no-battery radio receiving set. Such a circuit is shown in Figure 117. In this diagram, the wires connecting the filaments of the tubes to the step-down secondary, which gives the 2½ volts of alternating current needed to heat these filaments, are omitted for the sake of simplicity. In wiring this set, however, a certain precaution must be taken. These wires, carrying alternating current, have a fluctuating magnetic field around them. If this field cuts across any other conductor near them, currents will be induced which will interfere with the reception of the signal. To overcome this unwanted effect, the wires carrying alternating current

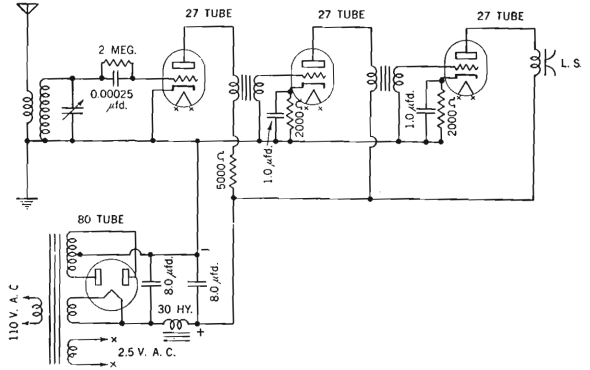


Fig. 117. **Diagram showing the circuit of an all-electric receiving set.**

to the filaments are twisted around each other in such a way that the magnetic fields of these wires neutralize one another.

SUMMARY

1. To have a grid of a tube function properly it must have a small negative charge at all times.

2. The C battery which supplies a negative charge to the grid may be eliminated by properly connecting the grid to the B-battery eliminator.

3. One method of connecting the grid so as to obtain the suitable negative charge is to connect the grid to the B-eliminator negative terminal, and connect either filament or cathode to the voltage divider at a point away from the negative terminal and toward the positive terminal.

4. A second method of eliminating the C battery is as follows: With both grid and cathode connected to the B-eliminator negative terminal, a resistor is connected in series with the cathode to keep the cathode slightly less negative than the B-eliminator negative terminal. When this hookup is used, a by-pass capacitor is connected across (in parallel with) the resistor to smooth out current fluctuations.

5. Wires bearing alternating current to the filament should be twisted together to neutralize the magnetic fields produced in single wires by the current.

CHECK-UP

In the blank spaces write the words, phrases, or numbers that are needed to complete the statements correctly. (Answers are on page 303.)

1. The purpose of the C battery is to make the grid .... with respect to the ....

2. Instead of using a separate C battery we may tap off a voltage from the .... of the power supply for grid bias.

3. The reason for connecting the filament or the cathode to the voltage divider at a point away from the negative terminal and toward the positive terminal is to make the .... slightly less .... than the ....

4. The purpose of the cathode bias resistor is to make the end connected to the grid more .... than the end connected to the cathode.

5. The bias resistor is in the .... circuit.

6. The cathode by-pass capacitor is connected in .... with the resistor.

7. The cathode by-pass capacitor smooths out the .... variations across the cathode resistor and gives a constant .... bias.

CHAPTER 20

The A.C.-D.C. Power Supply

QUESTIONS THIS CHAPTER ANSWERS

1. *How is the power transformer eliminated?*
2. *How is voltage reduced for the filament current?*
3. *Why are filaments connected in series?*

109. How does the half-wave rectifier system eliminate the power transformer? The battery eliminators described in the previous chapters all assume the use of 110-volt alternating current. In a number of localities, however, the house mains supply 110-volt direct current. Since a transformer will not operate on steady direct current, it becomes obvious that the A- and B-battery eliminators previously described will not work in these direct-current localities.

There are other reasons for not using the power transformer, even in alternating-current localities. The popularity of the midget receiving set has caused great demand for small, light receivers that can be built cheaply. Since the power transformer is bulky, heavy, and expensive, its elimination was desired by the receiving-set manufacturers. Let us see how the problem was solved.

The answer is in our half-wave rectifier system (Figure 99). If we eliminate the step-up transformer and feed the 110-volt alternating current directly to the plate of the rectifier tube and filter system, we can change the house current to a steady direct current. True, we can only get about 110 volts output, but with the development of the new and more efficient tubes, this voltage is enough for ordinary purposes.

Using this scheme and applying 110-volt direct current so that the positive lead goes to the plate of the rectifier tube, we get the same result as with the alternating current. So here we have a B-battery eliminator that works equally well on alternating or direct current and uses no power transformer.

110. How is the voltage of the filament current reduced? Now for the filament current. When the house mains supply 110-volt alternating current, we can get the small voltage required to heat the filaments by one of two methods. We can use a step-down transformer as described in Chapter 18. Or else we can force the 110-volt alternating current to go through a resistor before it goes through the filaments. When current goes through this resistor, its electrical pressure is reduced to (that is, *drops* to) the small amount necessary to force it through the filaments.

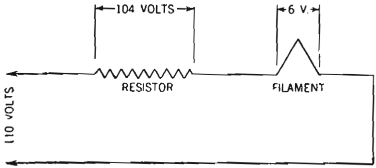


Fig. 118. Diagram showing how a resistor is used to cut down the 110-volt house current to a value suitable for use on the filament of the tube.

This second method is not as desirable as the step-down transformer method, because it wastes most of the current going through the resistor. But in a direct-current locality only the resistor method of obtaining the filament current can be used. We therefore are compelled to use this method if the receiving set is to be operated in both types of localities.

111. Why are filaments connected in series? An increase in efficiency is gained if we connect our filaments in series. Assume that the rectifier tube requires 5 volts to force the current through its filament, while the detector tube, the first audio-frequency amplifier tube, and the second audio-frequency amplifier tube each require 6 volts. When any electrical conductors are connected in series, the resistance of the circuit is the sum of the resistances of all the parts. Hence 23 volts are required for the filaments of the tubes, and only 87 volts are wasted in the resistance. (23 volts + 87 volts = 110 volts.)

Modern tubes are being manufactured that require even greater voltage for their filaments, and when they are used there is still smaller waste. As a matter of fact, some tubes use 110 volts on their filaments. These tubes are connected in parallel across the 110-volt line, and no resistor is needed.

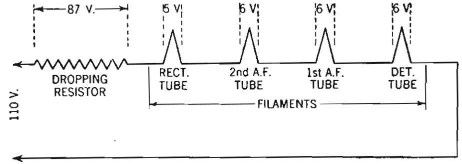


Fig. 119. Diagram showing how the dropping resistor and the filaments of the rectifier, detector, and first and second audio-frequency amplifier tubes are connected in series across the 110-volt house line.

112. What is a line-cord resistor? The resistor used in these circuits is called a *dropping resistor*. Its value obviously must vary with the type and number of tubes used. One variety of dropping resistor is the *line-cord resistor*. It resembles a common two-wire extension cord attached to a plug of the type used in the ordinary type of electrical outlet. But in addition to the

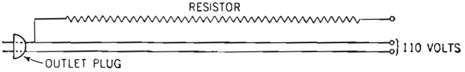


Fig. 120. Diagram showing a line cord with a built-in resistor. The electric cord and resistor are covered with an asbestos and cotton casing and the assembly looks very much like the electric cord used to connect an electric iron.

two wires of this electric cord and attached to one of the terminals of the plug there is a wire resistor of the proper value. The voltage drop in such a resistor is made to provide for the correct voltage in the filament.

This arrangement furnishes a convenient method for attaching the set to the house current and gives the additional advantage of having the resistor outside the set. Since the dropping resistor heats up somewhat because of the resistance to the current passing through it, it is advantageous to have it outside the set. Needless to say, you must not shorten or cut this cord. If you do so, you will reduce the value of the dropping resistor.

113. What are other features of A.C.-D.C. sets? The C battery is eliminated as described in Chapter 19. Since the grid bias

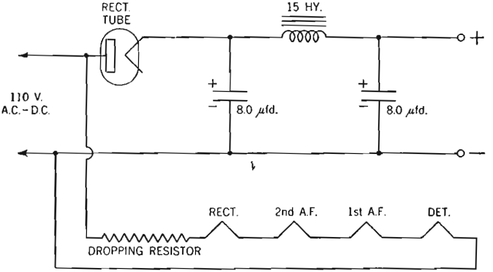


Fig. 121. Diagram showing the circuit of the complete A.C.-D.C. power supply. The symbol 15 HY. stands for a filter choke.

must be negative and not variable, the proper bias can be obtained by using proper resistors with any direct-current power supply.

It is possible, then, to wire a receiving set so that the plug supplying the electrical energy for all purposes may be used in any outlet for the house current, regardless of whether the supply is alternating or direct current. Figure 121 shows the complete A.C.-D.C. power supply. Practically any radio tube can be used as a rectifier. Some tubes, however, like the type 25Z5, are more efficient for this purpose.

If a receiving set fails to work in a direct-current locality when the set is plugged into the electrical outlet, remove the plug from the outlet, reverse it, and plug it in again. The chances are that you have plugged it in so that the negative line is connected to the plate of the rectifier tube. Reversing the plug will remedy this error.

SUMMARY

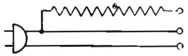
1. B-battery eliminators made to operate by the use of step-up and step-down transformers cannot be used on direct-current house mains.

2. The principle involved in the modern A.C.-D.C. receivers is to use resistors instead of transformers to produce lower voltages and to use smaller tubes of new types.

3. A.C.-D.C. sets operate by plugging in to any outlet carrying commercial current. The extension cord usually contains a line cord resistor to provide the correct voltage for the filaments.

4. When using direct-current circuits, it is sometimes necessary to turn the plug around in the outlet fixture so that the positive voltage may be on the right wire.

SYMBOL



Line-cord resistor.

CHECK-UP

In the blank spaces write the words, phrases, or numbers that correctly complete the statements. (Answers are on page 304.)

1. In the A.C.-D.C. power supply, the 110-volt current is fed directly to the .... of the rectifier tube. The voltage output of such a power supply is about .... volts.

2. In an A.C.-D.C. power supply, the filaments of the tubes are usually connected in .... with each other and with the .... which is used to dissipate the excess voltage.

3. The resistor in the power line which dissipates the excess voltage sometimes is called the .... resistor.

4. When only direct current is available to operate a set, a .... must be used to get correct voltage unless the tubes can carry the full voltage.

5. When 110-volt tubes are used with a 110-volt current, no .... is needed, and the tubes are connected in .... across the line.

CHAPTER 21

The Dynamic Speaker

QUESTIONS THIS CHAPTER ANSWERS

1. *What is a permanent-magnet dynamic speaker?*
2. *What is an electromagnetic dynamic speaker?*
3. *How is the current supplied to the electromagnetic dynamic speaker?*

114. How does the permanent-magnet dynamic speaker work? Turn back to Figure 19. Although we have greatly improved our radio receiver since we built the crystal detector set, our loudspeaker has remained a paper cone fastened to the diaphragm of the earphone. Now let us give it some attention.

The loudspeaker, as shown, has one very bad fault. Our amplified signal is carried by a large current. This current from the plate circuit of the last amplifier tube passes through the coil of the speaker. When the resulting strong pull is exerted on the diaphragm, it is bent back until it touches the end of the permanent magnet. The effect is that the speaker rattles on loud signals.

An ingenious device was evolved to overcome this defect. A speaker coil, called a *voice coil,* was wound on a small tube of bakelite. This tube was mounted so that it could slide back and forth on the permanent magnet. To this tube, the paper cone was attached. Also attached to this tube, to keep it in place, was a thin, springy sheet of bakelite called a *spider.*

The permanent magnet appearing in Figure 122 has a magnetic field around it. The fluctuating plate current, flowing through the voice coil, sets up a second, fluctuating magnetic field around the coil. These two magnetic fields, reacting with each other, move the voice coil back and forth on the permanent magnet.

The greater the current flowing through the voice coil, the more this coil is moved along the permanent magnet.

The thin, springy spider permits the voice coil to move, but forces it to come back once the pull ceases. The paper cone, connected to the voice coil, moves with it. Now, large plate currents can move the paper cone quite vigorously without the danger of a diaphragm striking the end of the magnet and thus causing rattling.

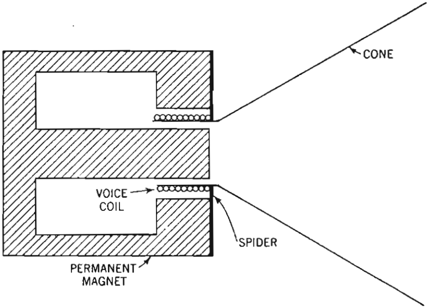
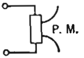


Fig. 122. Diagram of a permanent-magnet dynamic speaker.

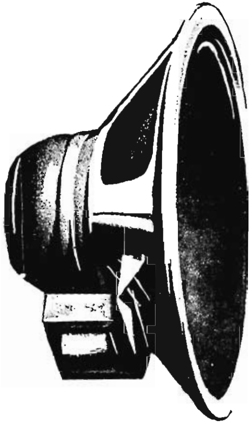
Of necessity, the voice coil, and the tube upon which it is wound, must be very light. The coil consists of a few turns of fine copper wire and the tube is made of very thin bakelite. This type of speaker is called a *dynamic speaker*. Since it has a permanent magnet, we call it a *permanent-magnet dynamic speaker*.

The symbol for this type of speaker is: 

or 

115. How are speaker and amplifier tube coupled? There are two reasons why the voice coil cannot be connected directly in the plate circuit of the last amplifier tube. First of all, since the wire of the coil is very fine, the heavy plate current would burn it out. Secondly, it has been found that the most efficient transfer of power takes place when the resistance of the voice coil equals the resistance of the amplifier tube.

The tube resistance is quite high, about 9000 ohms for the type 27 tube. But since the voice coil must be kept light, it is wound with a few turns of wire, and its resistance usually is from 2 to 30 ohms.



Cinaudograph Speakers, Inc.

Permanent-magnet dynamic speaker.

Here our old friend the step-down transformer comes to the rescue. The primary, which is connected in the plate circuit, has a great many turns, and its impedance equals the tube resistance, thus insuring the maximum transfer of power. The secondary has few turns, and its resistance is made to equal the resistance of the voice coil, thus again insuring the maximum power transfer. In Figure 123 you can see that in this hookup the heavy plate current does not flow through the voice coil; thus the danger of burning it up is removed.

The step-down transformer, used in connection with the dynamic speaker, is called an *output transformer*. Since different tubes have different resistances and the voice coils of different speakers, too, may have different resistances, an output transformer of different design must be used to match each new combination of amplifier-tube and voice-coil resistance.

116. What is an electromagnetic dynamic speaker? The permanent-magnet dynamic speaker still has several drawbacks. The permanent magnet deteriorates in time, and the speaker gradually becomes weaker. This fault may be partly remedied by the use of such alloys as Alnico, which make better, longer-lasting permanent magnets. But a more serious fault in the permanent-magnet speaker is the fact that where very loud sound is desired, as for auditorium or outdoor use, the permanent magnet cannot create a magnetic field great enough to move the paper cone properly.

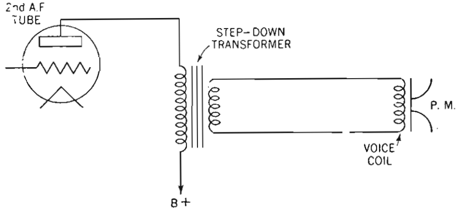


Fig. 123. Diagram showing how a step-down transformer (output transformer) is used to couple the voice coil of the permanent-magnet dynamic speaker to the plate circuit of the second audio-frequency tube.

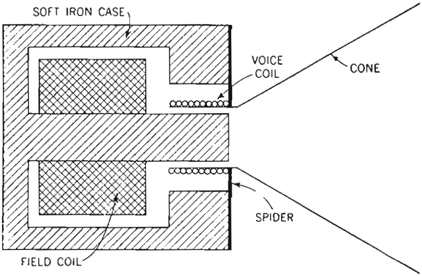
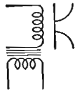
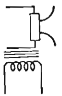


Fig. 124. Diagram of an electromagnetic dynamic speaker. The field coil replaces the permanent magnet of the permanent-magnet dynamic speaker.

To overcome these difficulties, a variation of the dynamic speaker is made which has an electromagnet replacing the permanent magnet. This electromagnet, called the *field coil,* is connected to a source of steady direct current. Since the field coil consists of a great many turns of wire, we now have a constant, powerful magnet which sets up a strong magnetic field as long as the current flowing through it is steady and constant. This field coil is wound around a soft-iron rod upon which the voice coil slides.

This type of dynamic speaker is called an *electromagnetic dynamic speaker.* As in the case of the permanent-magnet dynamic speaker, electrical energy is transferred from the plate circuit of the last amplifier tube to the voice coil by means of an output transformer. The symbol for the electromagnetic dynamic speaker is:  or 

117. How is current supplied for the field coil of the electromagnetic dynamic speaker? There are several means for obtaining the steady direct current needed for the field coil of this speaker.

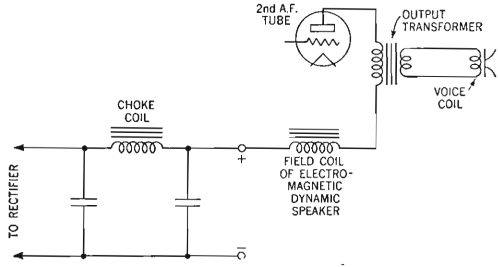


Fig. 125. Diagram showing how current is obtained from the power supply to operate the field coil of the electromagnetic dynamic speaker.

We may use a separate storage battery of 6 or 12 volts for this purpose. The field coil must be designed to operate on this low voltage. The use of storage batteries is a nuisance, but this method is used for special purposes, such as operating a loudspeaker in a moving automobile.

Another method, without a battery, is to use a separate rectifier and filter circuit for the speaker. The systems described in Chapter 17 and Chapter 20 can be used. For these systems we must design the field coil to operate on the higher voltages obtained. This method of obtaining a field-coil current supply is used chiefly for auditorium or outdoor purposes where very loud sound is desired.

The method that is most commonly used for supplying current to the field coil without the use of batteries is to pass the steady direct current flowing out of the B eliminator through the field coil before it is passed on to the radio receiver. Not only does this system eliminate the need for a separate storage battery or power supply for the speaker, but the field coil acts as a second choke coil and thus helps further to filter the plate current supplied to the radio receiver.

The electromagnetic dynamic speaker is widely used in sets that remain permanently near a source of house current. In portable receivers, however, to avoid the necessity for using a separate battery to energize the field coil, permanent-magnet dynamic speakers are usually used.

SUMMARY

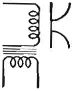
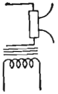
1. In the **permanent-magnet dynamic speaker,** a **voice coil,** consisting of a small, light coil of a few turns of fine wire, is mounted so that it may slide back and forth on a permanent magnet. This voice coil is connected to the output of the final audio-frequency amplifier tube through a transformer. The fluctuating plate current flowing through this coil sets up a fluctuating magnetic field around the coil. This fluctuating magnetic field reacts with the constant magnetic field around the permanent magnet, and, as a result, the voice coil is forced to move back and forth on the permanent magnet. Attached to the voice coil is a large paper cone, and, as it moves with the voice coil, it sets large volumes of air in motion, thus producing loud sounds. A thin, springy bakelite strip, called a **spider,** tends to keep the voice coil in its original position.

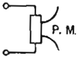
2. In the **electromagnetic dynamic speaker** an electromagnet replaces the permanent magnet for producing the constant magnetic field. Because the electromagnet may have a more powerful field than does the permanent magnet, the interaction with the magnetic field around the voice coil may be greater and a louder sound may result.

3. An output transformer is used to match the voice coil to the final audio-frequency amplifier tube and to keep the large plate currents from burning up the fine wires of that coil.

4. The electromagnet of the electromagnetic dynamic speaker, often called the **field coil,** may be used as a filter choke coil in the B power supply.

SYMBOLS

 or  Electromagnetic dynamic speaker.

or 

Permanent-magnet dynamic speaker.

CHECK-UP

If a statement is true, encircle the T. If a statement is false, encircle the F. (Answers are on page 304.)

T F **1.** The signal that operates a permanent-magnet dynamic speaker comes from the plate of the last audio-frequency tube.

T F **2.** A step-up transformer is used to couple the last audio-frequency tube with the voice coil to increase the volume of sound of a permanent-magnet dynamic speaker.

T F **3.** A field coil is used in the electromagnetic dynamic speaker.

T F **4.** Electromagnetic dynamic speakers do not use output transformers.

T F **5.** The current that creates the electromagnet in the electromagnetic dynamic speaker may come from the B-battery eliminator and is direct current.

T F **6.** Where very loud sound is desired, the electromagnetic speaker may be powered by a separate rectifier and filter circuit.

T F **7.** In an electromagnetic dynamic speaker the voice coil is often used as a choke coil in the power-supply filter section.

T F **8.** One purpose of the output transformer in the loudspeaker circuit is to permit maximum power transfer from the amplifier tube to the voice coil.

CHAPTER 22

The Radio-frequency Amplifier

QUESTIONS THIS CHAPTER ANSWERS

1. *What is the purpose of the radio-frequency amplifier?*

2. *What are the parts of a tuned radio-frequency amplifier?*

3. *How are the faults of a tuned radio-frequency amplifier corrected?*

4. *How are radio- and audio-frequency amplifying systems connected in a five-tube receiving set?*

118. What is the radio-frequency amplifier? To utilize fully the powers of radio, the receiver must be made much more sensitive than the set we have just finished describing. True, the audio amplifier can build up the signal from a whisper in the earphones to a volume loud enough to fill a large auditorium; but in order to function, it must receive this signal from the detector. The radio-frequency current in the aerial-ground system must be powerful enough to operate the detector properly.

Now a very powerful transmitting station, operating a few miles from the receiver, can set currents flowing in the aerial-ground system large enough to give satisfactory results. But weak stations, many miles away, are unable to emit a wave with sufficient energy to build up a signal that can be passed on to the audio amplifier. The problem therefore is to devise a system that will build up the signal before it reaches the detector.

When radio development encountered this problem, the three-element radio tube once again was called on to act as an amplifier. In this case the current flowing into the amplifier alternates at a frequency of hundreds of thousands or even millions of cycles per second. It alternates at a radio frequency. For this reason the amplifier is called a *radio-frequency amplifier* to distinguish it from the audio-frequency amplifier in whose circuit the current alternates at audio frequency, that is, between 30 cycles and 15,000 cycles per second.

The radio-frequency amplifier works in the same way as does the audio-frequency amplifier. A small alternating voltage places an alternating charge upon the grid of the radio tube. This grid charge, in turn, controls the large plate current supplied by the B battery or B power supply (see §79).

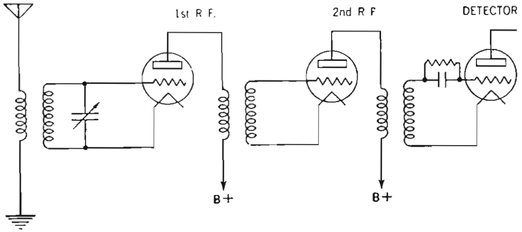


Fig. 126. Diagram showing the circuit of two transformer-coupled radio-frequency amplifier stages. The C batteries have been omitted from this diagram for simplicity.

The methods for coupling one radio-frequency amplifier tube to another are likewise the same methods used in the audio-frequency amplifier: either transformer or resistance coupling. But resistance coupling in radio-frequency amplifiers is seldom used, and we need not discuss it here. The method of coupling most commonly used is transformer coupling. The transformer used for radio-frequency amplification differs from the audio transformer in that it is usually an air-core transformer and has fewer turns.

119. What is tuned radio-frequency amplification? If you examine Figure 126, you will see that the radio-frequency transformer resembles the antenna coupler. The only difference is that the secondary winding of the antenna coupler is in a tuning or "tuned" circuit, while the secondary of the radio-frequency transformer is not. However, it was soon discovered that certain advantages could be gained if the secondary of the radio-frequency transformer was made a part of a tuned circuit by connecting it with a variable capacitor similar to the one used to tune the secondary of the antenna coupler.

You already have learned how the tuning circuit permits the signal from the station of the desired frequency to flow through it and tends to stop all others. However, some unwanted frequencies do manage to get through the tuner. If the signal is forced to pass through a series of such tuning circuits, however, the

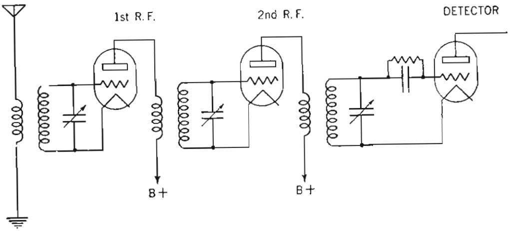


Fig. 127. Diagram showing the circuit of two tuned radio-frequency amplifier stages.

chances for the unwanted frequencies to leak through become proportionately less. In this way our set becomes more selective.

A radio-frequency transformer whose secondary is tuned by means of a variable capacitor is called a *tuned radio-frequency transformer.* The tuned radio-frequency transformer is practically the same as the antenna coupler, while the variable capacitor used for tuning is similar in size to that used in the tuning circuit. The secondaries of the transformers are all tuned to the same frequency as the secondary of the antenna coupler. A stage of radio-frequency amplification using a tuned radio-frequency transformer with a variable capacitor is called a stage of *tuned radio-frequency amplification.*

When we use two stages of tuned radio-frequency amplification (Figure 127), we have three tuned circuits. Thus our set is much more selective than if we had only one tuned circuit (Figure 126).

Tuned radio-frequency amplification has another advantage over an untuned stage. Since the natural frequency of the tuned circuits is the same as the frequency of the incoming signal, the oscillations of the electrons in the tuned circuits are permitted to build up, and this building up results in a louder signal. Of course, one disadvantage of the tuned stage is that it requires an additional variable capacitor, and an additional dial or knob must be manipulated.

120. How are the effects of stray magnetic fields eliminated in radio-frequency amplification? One of the difficulties encountered

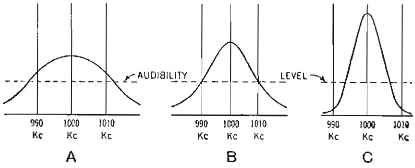


Fig. 128. (A) Tuning curve with one tuned circuit. Notice that stations at 990 kc. and 1010 kc. are heard when the set is tuned to 1000 kc. (B) Tuning curve with two tuned circuits. Note that the two unwanted stations are just at the audibility level. (C) Tuning curve with three tuned circuits. The two unwanted stations cannot be heard.

in the manufacture of the radio-frequency amplifier is the fact that the magnetic field around one radio-frequency transformer may be large enough to cut across the coils of another such transformer. This action sets an unwanted current flowing in the second transformer, and oscillations and distortion of the signal result. This evil is remedied in several ways. Of course, we may space these transformers far enough apart to prevent this unwanted effect. But this plan is not practical, especially since we do not want our receiving set to be too large.

Another solution is to mount our transformers so that the windings, and hence the magnetic fields, are at right angles to each other (Figure 129-B). In such an arrangement, the transfer of energy from one transformer to another is at a minimum. (See the discussion of coupling in the regenerative receiver in §75.)

Still another solution is to design our transformer so that its magnetic field is kept close to it. A short coil of large diameter has a wider magnetic field around it than a long coil of smaller

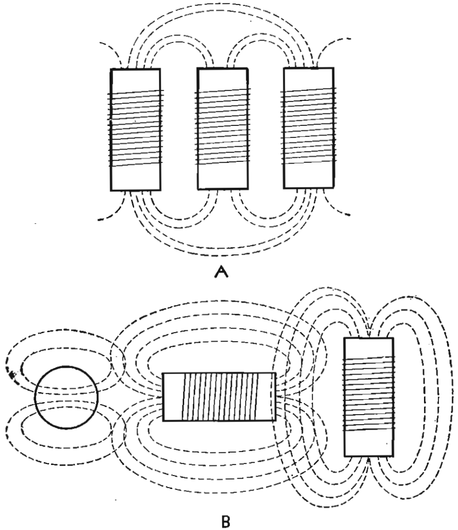


Fig. 129. Tuned radio-frequency transformers mounted near each other. The dotted lines around each coil represent its magnetic field. (A) The radio-frequency transformers are mounted parallel to each other. Note how the magnetic fields couple the coils to each other. The transfer of electrical energy from one coil to the other is fairly large. (B) The radio-frequency transformers are mounted at right angles to each other. Note that transfer of electrical energy from one coil to the others is at minimum efficiency.

diameter (Figure 130). We now make our transformers an inch or less in diameter and use more turns of wire.

Another solution is to surround the transformer with a metal shield or case. This shield absorbs the magnetic field and very little of it gets through. This method is called *shielding*, and modern radio receivers use this device together with the narrower

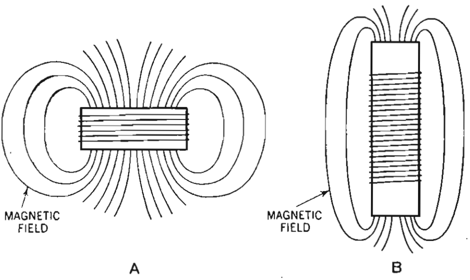


Fig. 130. (A) Magnetic field around a short coil of large diameter. Note how the field spreads out. (B) Magnetic field around a long coil of small diameter. Note that the magnetic field remains close to the coil.

coil. The symbol signifying a shielded coil consists of a dotted line placed around this coil. The metals most commonly used for shielding are aluminum and copper.

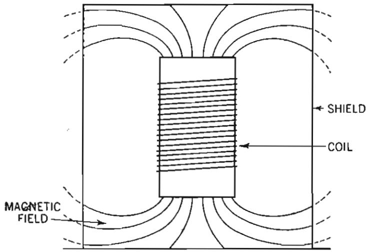


Fig. 131. Coil shielded by a metallic can. Note that very little of the magnetic field penetrates the shield.

Shielding is often used also to protect the radio-frequency amplifier tube from the effects of stray magnetic fields. Less frequently, the entire radio-frequency amplifier stage, consisting of the transformer, the variable capacitor, the radio tube, and the wiring, is enclosed in a shielding case. Such complete shielding is rarely necessary. It is usually enough to shield the radio-frequency transformer and tube. All metal used for shielding must be connected to the ground of the receiver. Thus any electrical charge on the shields is drawn off to the ground and away from the radio receiver where it might affect the component parts.

Audio-frequency amplifiers are less subject to the effects of these stray magnetic fields. Nevertheless, the audio transformers are usually shielded and mounted so that the windings of one transformer are at right angles to the windings of the other.

121. Why must feedback be eliminated? In designing radio-frequency amplifiers, means must be taken to avoid feedback. In the regenerative detector circuit we deliberately caused some of the plate current to be fed back to the grid circuit (see §73). This feedback was carefully controlled and made the set more sensitive. In the radio-frequency amplifier, however, such feedback is undesirable for it results in oscillation and other distortions of the signal. Such feedback may come from several sources, and all of it must be eliminated.

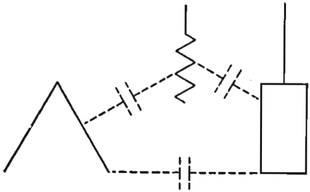


Fig. 132. Diagram showing the capacitance effect existing between the electrodes of the triode. The result is the same as if small capacitors were connected between the electrodes.

The chief source of feedback lies in the tube itself. Any two conductors, separated by a dielectric, will form a capacitor. The electrodes of the tube are such conductors. The dielectric is the vacuum between them. Thus a capacitance exists between the filament and the grid, the grid and the plate, and the filament and the plate. Because of the small area of the conductors, these capacitors have small capacitance. But small though it is, the capacitance provided by the combination of the grid and the plate causes considerable trouble. By means of this small capacitance effect, the output circuit (the plate circuit) and the input circuit (the grid circuit) are linked and feedback occurs.

Examine the circuit of the stage of radio-frequency amplification shown in Figure 133. The B battery places a positive charge on the plate of the tube. Fluctuations of the plate current, resulting from the signal, will cause this positive charge on the plate to fluctuate.

Now consider the plate and grid as two conductors forming a capacitor. The plate of the tube, being charged positively, causes a certain number of electrons to gather on the grid. The grid gets a negative charge. The more positively charged the plate, the more electrons are pulled over to the opposite electrode of the capacitor, the grid. The more highly positive

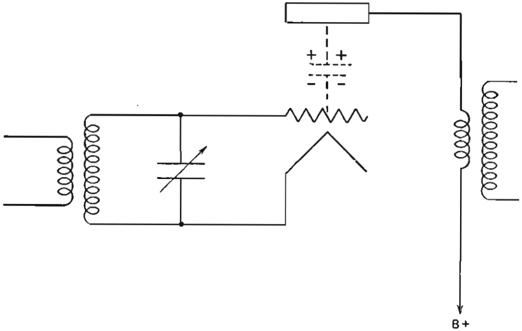


Fig. 133. How the charge on the plate causes an opposite charge to be placed on the grid of the tube.

the plate, then, the more electrons flow through the secondary of the radio-frequency transformer to the grid. As the plate loses some of its positive charge, some electrons are forced to flow from the grid back through the secondary of the radio-frequency transformer.

Thus the fluctuating charge on the plate of the tube sets up a corresponding oscillation of the electrons in the grid circuit. This oscillation causes distortion and must be eliminated.

122. How is the influence of tube capacitance corrected? There are several methods of correcting for this tube capacitance. One is to connect a 500-1000-ohm resistor in the grid circuit. This resistor uses up the electrical pressure of the electrons set oscillating in the grid circuit described above, and the distortion is therefore eliminated. This method of eliminating feedback is called the *losser method.* It suffers from the disadvantage that

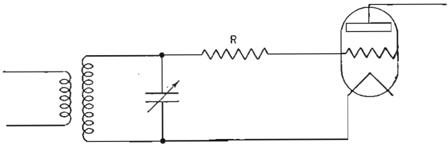


Fig. 134. The "losser" method of preventing oscillations in the radio-frequency amplifier. The resistor R dissipates the unwanted flow of electrons.

it dissipates not only the unwanted flow of electrons caused by feedback, but also some of the desired signal voltage. The result is a loss of amplification.

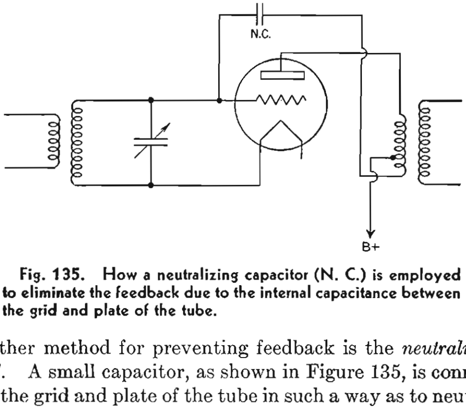


Fig. 135. How a neutralizing capacitor (N. C.) is employed to eliminate the feedback due to the internal capacitance between the grid and plate of the tube.

Another method for preventing feedback is the *neutralization method.* A small capacitor, as shown in Figure 135, is connected across the grid and plate of the tube in such a way as to neutralize the plate-to-grid capacitance. This plan eliminates the feedback without a resulting loss of amplification. This small fixed capacitor is called the *neutralizing capacitor.* One end of the neutralizing capacitor is connected to the grid of the tube, while the other end is connected to the bottom of the primary of the radio-frequency transformer. The B+ is brought to a tap on this primary near the bottom of the coil.

This neutralizing capacitor acts as a storage tank, and electrons which, without it, would have been sent oscillating in the grid circuit are instead stored on its negative plate. The action is as though a flow of electrons equal to the feedback, but opposite in direction, were taking place. The opposing streams of electrons cancel out, and there is no feedback.

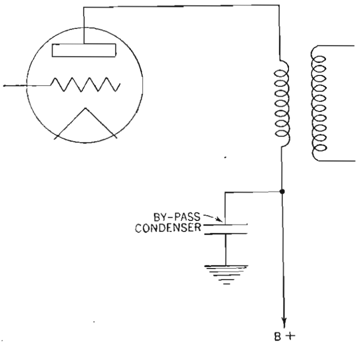


Fig. 136. How a fixed capacitor is used to by-pass any radio-frequency current leaking across the B supply.

Feedback due to capacitance within the tube is eliminated in modern sets by using tubes of the screen-grid class. We will discuss this more fully in the chapter dealing with types of tubes.

123. How does a by-pass capacitor correct leakage? A loss of amplification may be encountered in the radio-frequency amplifier due to the radio-frequency voltage drop across the B battery or the B eliminator. This difficulty is remedied by providing a separate path for any radio-frequency current which finds itself in the plate circuit.

A fixed capacitor whose value is about 0.006 μfd. is connected from the B+ terminal of the primary of the radio-frequency transformer to the ground (Figure 136). Then any radio-frequency current leaking across the B battery flows through the capacitor to the ground (which is an easy path for radio-frequency current), rather than through the primary of the radio-frequency transformer (which presents a high resistance to radio-frequency currents). We call such a fixed capacitor a *by-pass capacitor.*

124. What is the purpose of a radio-frequency choke coil? We use a slightly different device to prevent any radio-frequency current that finds itself in the plate circuit of the detector tube

Solar Manufacturing Corp.

Paper tubular capacitor.

from going into the audio-frequency amplifier, where it may cause some distortion.

Between the plate and the primary of the first audio transformer we connect a small inductance whose value is about 20 millihenries. We call this inductance a *radio-frequency choke coil.*

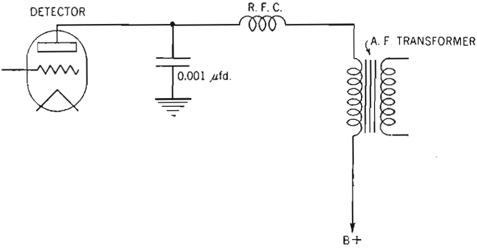
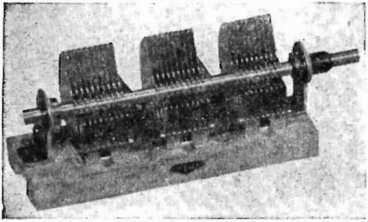


Fig. 137. How a radio-frequency choke coil (R. F. C.) and by-pass capacitor are used to keep stray radio-frequency currents from leaking into the audio-frequency amplifier.

This choke coil offers a great opposition or impedance to the radio-frequency current, but not to the fluctuating direct current. To permit the radio-frequency current to escape we connect a small fixed capacitor of about 0.001 μfd. from a point between the plate and the choke coil to the ground.

As in the case of audio-frequency amplification, a negative bias is placed on the grid of the radio-frequency amplifier tube to prevent distortion. Here, too, care must be taken not to make this negative bias too great, else detection will take place. (See §82.)

125. What are gang variable capacitors? It is customary to use two stages of tuned radio-frequency amplification before the detector of the receiving set. Using fewer than two stages means not enough amplification, while using more makes it extremely difficult to control oscillations. In Figure 127, on page 187, you will see that such a receiver, using two stages of tuned radio-frequency amplification, has three variable capacitors which must be manipulated to bring in the desired station. Since all three tuned circuits are very nearly alike, the variable capacitors, too, will be meshed or unmeshed to about the same degree for receiving any given station.



Bud Radio, Inc.

Three-gang variable capacitor.

It becomes logical, therefore, to connect all three variable capacitors so that they may be operated simultaneously by turning one dial. This process of connecting the variable capacitors is called *ganging*. Early methods of ganging the variable capacitors consisted of hooking them up with gears or a belt. This practice soon gave way to the simpler method of mounting all three variable capacitors on one shaft. We now speak of a *three-gang variable capacitor*.

126. Why are trimmers used with variable capacitors? It is quite obvious that all three tuning circuits must be identical if the set is to function properly with ganged capacitors. It is impossible, however, to make two coils or two variable capacitors that are absolutely identical. Small variations are bound to creep in.

To overcome these slight discrepancies, a very small capacitor, called a *trimmer*, is connected across each variable capacitor of the tuning circuits. This trimmer usually consists of two metal plates, about ½ in. square, that are separated by a sheet of mica.

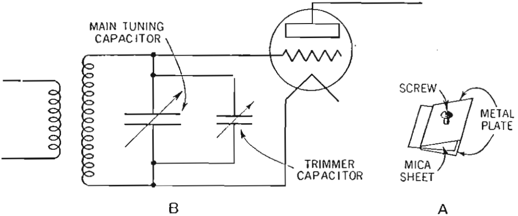
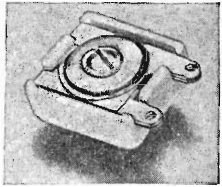


Fig. 138. (A) Trimmer capacitor used to align the radio-frequency amplifier stages. (B) Circuit showing how the trimmer is connected across the main tuning capacitor.

Turning a screw separates the plates or brings them closer together, thus varying the capacitance of the trimmer. This small capacitor is usually mounted at the side of the variable capacitor.



P. R. Mallory & Co.

Trimmer capacitor.

These trimmers are adjusted to compensate for the discrepancies in the various tuning circuits. Their action is to vary slightly the amount of capacitance in the tuning circuit to make the natural frequency of that circuit equal to that of all the other tuning circuits. Once adjusted, the trimmers are left in those positions. This process of matching up the various tuning circuits of a radio receiver is called *aligning the set.*

127. Why are trimmers used on aerials? While on the subject of the trimmer capacitor, it should be noted here that in modern practice one of these trimmers, called the *aerial trimmer*, is usually connected in series with the aerial-ground system (see Figure 139). The effect of this small capacitor is to lengthen or shorten the aerial electrically.

This change in the aerial is desirable because each set will work most efficiently with an aerial of a certain length. Of course, you may go up on the roof and snip off some of the wire from the aerial, but it is much simpler to adjust the aerial trimmer until the signals are at their loudest. Once set, the trimmer is left alone until a new aerial is put up.

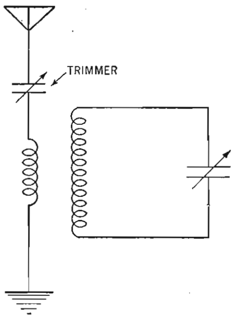


Fig. 139. Use of trimmer capacitor to adjust the aerial to the radio receiver.

128. What are the relative values of radio amplification and audio amplification? In comparing our two types of amplification we must remember that they complement each other. We cannot use too many stages of either radio-frequency or audio-frequency amplification without running into oscillations, noises, or distortion of signals. Our modern receiving set therefore usually consists of two stages of radio-frequency amplification, the detector, and two or three stages of audio-frequency amplification.

A stage of tuned radio-frequency amplification has certain advantages over a stage of audio-frequency amplification. First of all, the sensitivity of the set is increased by radio-frequency amplification. In addition, the selectivity of the receiver is improved. Further, stage for stage, radio-frequency amplification gives greater gain than audio-frequency amplification. On the other hand, the power output of the audio-frequency amplifier is greater than that of the radio-frequency amplifier. Under normal conditions, the radio-frequency amplifier and detector cannot operate a loudspeaker. Currents large enough for this purpose do not flow in their plate circuits.

Another feature of the audio-frequency amplifier is that it is normally more stable than the radio-frequency amplifier. If the set is properly designed, we have no oscillations in the audio-frequency stages and need not neutralize the internal capacitance of the tube. Since the audio-frequency stage does not require any controls that need be manipulated, we are not troubled with such things as ganging or alignment of circuits.

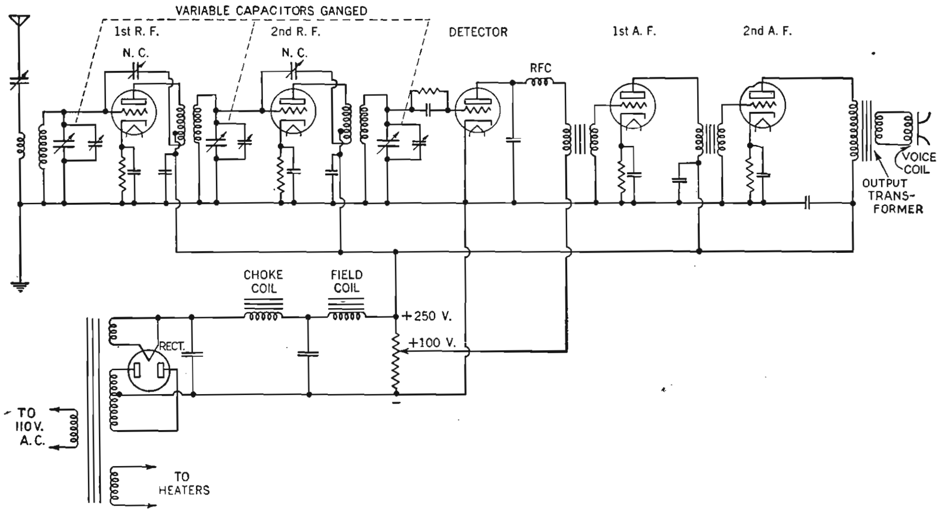


Fig. 140. Circuit for a complete tuned radio-frequency receiver.

129. How is the five-tube set hooked up? Figure 140 shows the circuit of a five-tube receiver with two stages of neutralized tuned radio-frequency amplification, a detector, and two stages of transformer-coupled audio-frequency amplification. This set is known as a *tuned radio-frequency* (T.R.F.) *receiver*. The dotted lines connecting the three variable capacitors show that they are ganged together. For the sake of simplicity the diagram does not show the connections of the filaments of the tubes, or the dotted lines indicating shielding around the antenna coupler, the radio-frequency transformers, and the radio-frequency and detector tubes.

SUMMARY

1. It has been found necessary to amplify the radio-frequency signals before transforming them into audio frequencies in order to obtain reception from distant radio stations.

2. The system developed to produce amplification of the radio-frequency currents is called the **tuned radio-frequency amplifier.**

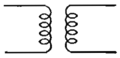
3. The tuned radio-frequency amplifier employs a transformer whose secondary is tuned by means of a variable capacitor, similar to that of the antenna coupler.

4. Two stages of tuned radio-frequency amplification, together with the tuner connected to the aerial-ground system, provide three tuned circuits. This arrangement gives great sensitivity as well as selectivity.

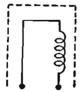
5. To avoid feedback from the radio-frequency amplifying system, several precautions must be taken, namely: use of narrow coils; setting coils at right angles to one another; shielding coils and tubes by metal covers; correcting influence of capacitance in tubes by resistors, capacitors, or choke coils.

6. Modern five-tube sets have two stages of tuned radio-frequency amplification, two stages of audio-frequency amplification, ganged capacitors, and shielded tubes and transformers.

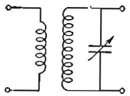
SYMBOLS



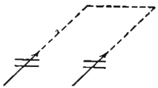
Radio-frequency transformer.



Shielded coil



Radio-frequency transformer with tuned secondary.



Ganged capacitors.

CHECK-UP

Each statement below is either true or false. If it is false, one or more, but not necessarily all, of the *italicized* parts make it false. If a statement is true, encircle the T and do nothing else with it. If a statement is false in any part, first encircle the F; then correct it by substituting the right word or phrase for the incorrect word or phrase in italics. Write your correction in the blank space at the end of the statement. The samples show you how. (Answers are on page 304.)

SAMPLES:

(T) F Radio-frequency energy *travels in waves.* ....

T (F) *Direct* currents flow in cycles. Alternating

T F **1.** A radio-frequency amplifier amplifies the signal before it reaches the *antenna coupler.* ....

....

T F **2.** The method of coupling stages of radio-frequency amplifiers most commonly used is that of *resistance* coupling. ....

T F **3.** The advantage of the tuned radio-frequency amplifier over the untuned radio-frequency amplifier is that it makes the set *both more sensitive and more selective.* ....

T F **4.** To help overcome the effects of stray magnetic fields, we mount the transformers at *right angles* to each other. ....

T F **5.** Shields around the transformers usually are made of *tin* or *zinc* and they are connected to the *lead-in of the aerial.* ....

T F **6.** The chief source of feedback in the tuned radio-frequency amplifier is the *capacitance* between the *plate* and *grid* of the tube. ....

T F **7.** We may eliminate feedback from the tubes by use of a *neutralizing* capacitor, which is a *fixed* capacitor. ....

T F **8.** In modern sets feedback from tubes is eliminated through the use of *rectifier* tubes. ....

T F **9.** Modern tuned radio-frequency receivers need only one tuning control because of the use of *variable* tuning capacitors. ....

T F **10.** To overcome small variations in the various tuned circuits, we usually use small *transformers* called trimmers. ....

T F **11.** A stage of tuned radio-frequency amplification gives *greater* amplification than a stage of audio-frequency amplification. ....

T F **12.** A stage of audio-frequency amplification normally is *less stable* than a stage of tuned radio-frequency amplification. ....

T F **13.** An aerial may be lengthened or shortened electrically by the use of a small adjustable *potentiometer*. ....

T F **14.** To keep radio-frequency current from passing from detector to audio-frequency amplifier, a *radio-frequency choke coil* provides impedance between detector and *first audio-frequency transformer*. ....

TEST 2—CHAPTERS 13–22

In the blank spaces write the words, phrases, or numbers needed to complete the statements correctly. (Answers are on page 304.)

1. In the diode, when the filament is heated to incandescence and a positive charge is placed on the plate, electrons flow from the (*a*) .... to the (*b*) .... within the tube.

2. The introduction of a (*a*) .... in a diode enables us to insert a B battery in the (*b*) ....

3. In the triode detector, we may use either a C battery or a .... and .... in the grid circuit.

4. In a regenerative circuit, energy is fed from the (*a*) .... circuit to the (*b*) .... circuit.

5. Regeneration must be controlled and limited in order to prevent it from causing the set to ....

6. The range of audio frequencies is from about .... to .... cycles per second.

7. An audio-frequency amplifier may be connected or coupled to a detector by .... or .... coupling.

8. (*a*) .... coupling gives more faithful reproduction of the signal than (*b*) .... coupling

9. In eliminating the B battery, we (*a*) .... the alternating current by means of a diode-type tube and then (*b*) .... it to get smooth direct current.

10. The method of rectification whereby we use both halves of the alternating-current cycle is known as .... rectification.

11. We may eliminate the A battery by using tubes with sleeved .... to which the grid return is connected.

12. To replace the C battery, use is often made of a (*a*) .... in the plate circuit with a (*b*) .... connected across it.

13. In the electrodynamic loudspeaker, a (*a*) .... moves in the magnetic field set up by the (*b*) ....

14. Because of .... within a triode, such a tube must be neutralized when it is used as a radio-frequency amplifier.

15. Capacitors of tuning circuits are said to be .... when they are made to rotate from a single shaft.

CHAPTER 23

Volume Control

QUESTIONS THIS CHAPTER ANSWERS

1. *How is volume controlled in battery sets?*

2. *What problems arise in controlling the volume in nonbattery sets?*

3. *What devices are used to control the volume automatically?*

4. *How are modern sets wired for automatic volume control?*

130. How is volume controlled in battery sets? Every radio receiving set must have some method for controlling volume or loudness of the sounds from the speaker. Otherwise, nearby powerful stations would blast through the loudspeaker with uncomfortable loudness and less powerful stations would be heard very faintly.

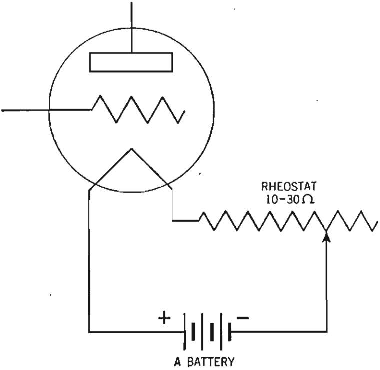


Fig. 141. Rheostat in the filament circuit used to control volume.

Volume control for battery-operated sets is a relatively simple matter. The most common device is a rheostat of from 10 to 30 ohms connected in series with the A battery and the filaments of the radio tubes, as in Figure 141. This rheostat controls the temperature of the filament and in this way controls the quantity of electrons emitted by the filament and therefore the plate current flowing in the plate circuit. This current, in turn, controls the loudness of the signal coming out of the loudspeaker.

Another method, less frequently used, is to connect a rheostat of about 250,000 ohms in the plate circuit of the tube (see Figure 142). This rheostat controls the positive charge placed on the plate by the B battery and in this way controls the plate current

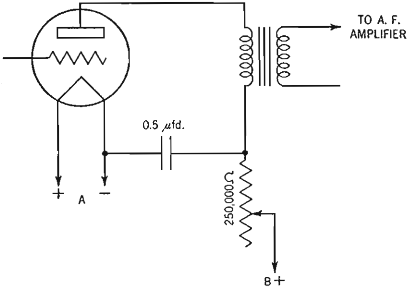


Fig. 142. Circuit showing how a rheostat in the plate circuit is used to control volume. This device is unsatisfactory.

and thus the loudness of the sound. This rheostat must be by-passed by a fixed capacitor of about 0.5 μfd. to filter off any radio-frequency currents that may leak through. This method is rarely used, as it has a tendency to upset the tuning of the set unless the value of the rheostat is kept very high, in which case it does not permit a large positive charge to be placed on the plate.

131. How is volume controlled in house-current sets? In the nonbattery set it is desirable to keep the filament current constant. This requirement rules out the rheostat in the filament circuit. Other methods of volume control were developed.

One method is to connect a 25,000-ohm potentiometer across the primary of the antenna coupler and to connect the aerial to the sliding arm, as in Figure 143. This hookup controls the amount of current fed into the tuner and thus controls the sound ultimately coming from the loudspeaker. This method suffers

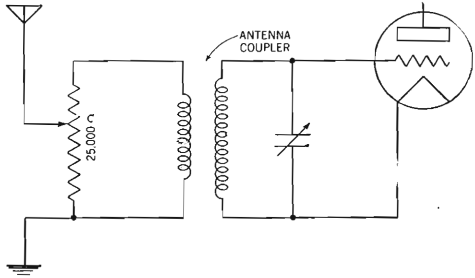


Fig. 143. Circuit showing how a potentiometer across the primary of the antenna coupler is used as a volume control.

from the disadvantage that although it cuts down the amount of electrical energy picked up by the aerial and therefore the amount of outside static or outside electrical interference, it does

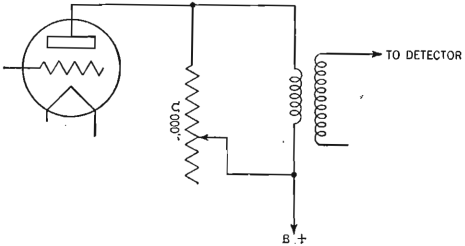


Fig. 144. Circuit showing how a rheostat connected across the primary of the last radio-frequency transformer is used as a volume control.

not reduce the amount of electrical interference created inside the set itself. These latter interferences come through and are amplified within the set. The result is that the set is quite noisy.

Another method, shown in Figure 144, is to connect a 5000-ohm rheostat across the primary of the transformer in the plate circuit of the second radio-frequency tube. This method has the advantage of cutting down the electrical interference in the radio-frequency stages within the set at the same time that it cuts down the signal strength by dissipating a part of the plate current of the second radio-frequency stage.

Still another method of volume control, shown in Figure 145, is to connect a 500,000-ohm potentiometer across the secondary

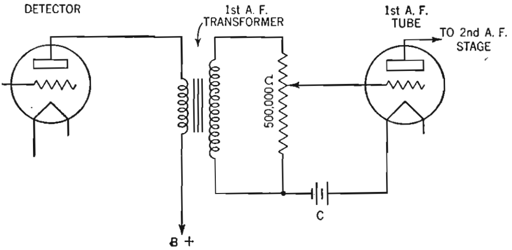


Fig. 145. Circuit showing how a potentiometer is connected across the secondary of the first audio-frequency transformer to act as a volume control.

of the first audio-frequency transformer. The grid of the first audio-frequency tube is connected to the sliding arm. The potentiometer then controls the charge placed on the grid of the tube.

Sometimes the method shown in Figure 145 is combined with that shown in Figure 144. The 500,000-ohm potentiometer and 5000-ohm rheostat are mounted on the same shaft so that, although they are insulated from each other, they are rotated together by the same control knob.

132. How is volume controlled when a cathode-type tube is used? The use of a cathode and a grid bias resistor furnishes us with a simple and effective means of controlling the volume. Hooked up in series with the bias resistor is a rheostat, as in Figure 146. By varying the rheostat, the resistance used to place a negative charge on the grid of the amplifier tube is made larger or smaller. (This resistance now consists of the bias resistor plus the resistance of the rheostat.) This variation in turn makes the grid more

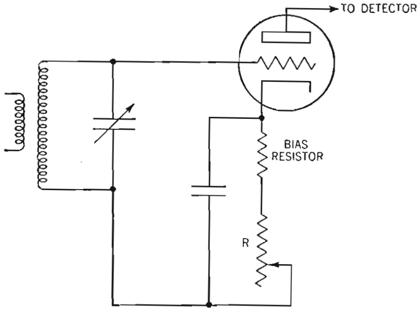


Fig. 146. Circuit showing how a rheostat (R) is placed in series with the bias resistor to act as a volume control.

negative or less negative. The more negative the grid, the smaller the number of electrons flowing to the plate and the less the amplification. (See Chapters 14 and 19.)

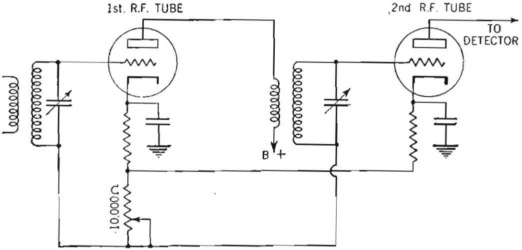


Fig. 147. Circuit showing how the rheostat used as a volume control varies the grid bias of both radio-frequency tubes.

This rheostat may be connected to the bias resistors of one or more tubes and thus control the amount of amplification supplied by these tubes. The value of this rheostat varies from about 5000 to 50,000 ohms, depending upon the number of tubes controlled. The more tubes so controlled, the lower the value of the rheostat.

133. Why is there need for automatic volume control? While on the subject of the volume of the sound coming out of the radio receiver, let us consider two problems which must be solved for the greater enjoyment of radio reception.

First: Having tuned in a fairly weak station, you turn the volume control up to give a loud sound. Now you tune in another station. As you turn the dial, you happen to pass a powerful station. Since the volume control is turned up to "loud," the new station comes in with an earsplitting blast.

Second: You will soon become acquainted with the nuisance of *fading*. The signal will rise and fall, grow louder and softer. We say this signal "fades in" and "fades out." This problem is the more serious. Just why a radio wave behaves in this manner is not fully known, although we have theories that tend to explain it. We think it is due to the shifting of a layer of electrified air particles, called the "Heaviside layer," far above the surface of the earth. It is not our purpose at this point to discuss this phenomenon, except to recognize that it exists and tends to spoil our enjoyment of the radio program.

If we had a method of automatically turning our volume control to "loud" when the signal became weaker and to "soft" when the signal became stronger, both of these problems would be solved. This task is accomplished by the *automatic volume control* (abbreviated A.V.C.).

134. How is volume automatically controlled by regulation of grid bias? How automatic volume control operates is fairly easy to understand. A portion of the signal current is taken off (usually before it reaches the detector), and rectified to direct current. Thus the greater the signal strength, the larger the resulting direct current; the smaller the signal strength, the less the direct current. This direct current is then fed to the grid returns of the amplifying tubes, where a negative bias is placed on the grids.

Since greater signal strength yields larger direct current, the grids become more negative. This negative charge on the grids cuts down the amplification of the tubes. Contrariwise, the smaller the signal strength, the less the direct current and the less negative the grids. The effect of less negative grids is to increase the amplification of the tubes. The variable-*mu* tube, about which you will learn in §171, is designed to do this job.

The net effect is that the greater the signal strength, the less the tubes will amplify it, and the less the signal strength, the more

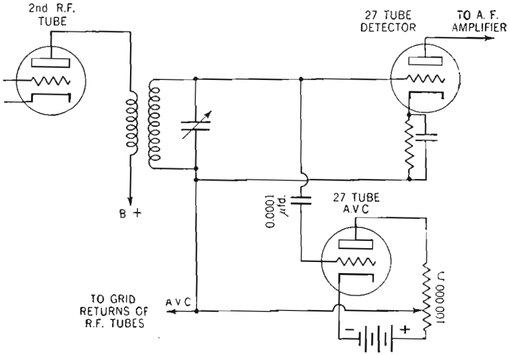


Fig. 148. Circuit showing hookup using a type-27 tube to obtain the automatic-volume-control voltage. Note that the detector is of the grid-bias type.

the tubes will amplify it. This arrangement tends to keep the volume of sound coming out of the loudspeaker at a constant level and helps to eliminate blasting and fading.

One method of obtaining automatic volume control is shown in Figure 148. Note that the detector tube is connected up as a grid-bias detector, using a bias resistor in the cathode circuit. The grid of the automatic-volume-control tube is connected to the grid of the detector tube through a 0.0001-μfd. capacitor. Thus a small part of the signal voltage is tapped off. The greater the signal, the more positive the charge placed on the grid of the detector. Likewise, a greater positive charge is placed on the upper plate of the 0.0001-μfd. capacitor. Accordingly, more electrons are drawn from the grid of the automatic-volume-control tube to the lower plate of the capacitor; therefore a greater positive charge is placed on the grid of the automatic-volume-control tube.

This charge causes more electrons to stream across from the cathode of the automatic-volume-control tube to its plate. Hence, more electrons will flow through the plate circuit and through the sliding arm of the 100,000-ohm potentiometer to the grid returns of the amplifier tubes. This electron surge, in turn, places a greater grid bias or negative charge on the grids of these amplifier tubes. The flow of electrons to the plates of these tubes is cut down, and less amplification results. The louder the signal, therefore, the less the amplification. The smaller the signal, the less negative bias on the grids of the radio-frequency tubes and the greater the amplification.

135. What are the details of the automatic-volume-control system? By means of a voltage divider across the B eliminator, as described in §97, we can get the voltage to replace the plate battery as well as that needed to place a negative bias on the grid of the automatic-volume-control tube (Figure 149). A 2-megohm resistor is used as a grid leak, and the cathode and plate are by-passed by 0.1-μfd. capacitors to the ground to eliminate any radio-frequency current that may have leaked through.

The 250,000-ohm resistor and the 0.5-μfd. capacitor in the automatic-volume-control line are used to filter out unwanted fluctuations just as the choke coil and filter capacitors do in the B eliminator. The arrangement of these devices is shown by the wiring diagram in Figure 149.

The potentiometer of 100,000 ohms limits the automatic-volume-control voltage. The loudest station is tuned in and the potentiometer is adjusted manually until a comfortable volume is reached. It is left in this position, and no signal will come through with a greater volume. Blasting is eliminated. Should the signal strength drop, however, the amplification of the radio-frequency tubes is increased to bring the volume up.

136. How may the triode be replaced by a diode for the detector? Since the action of the automatic-volume-control tube is to

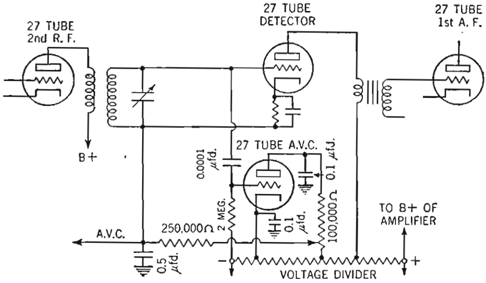


Fig. 149. Complete automatic-volume-control circuit showing the by-pass capacitors and filter resistors.

rectify the signal current and feed it to the grid returns of the radio-frequency amplifier tubes, it becomes obvious that a diode may be used for this purpose instead of the triode shown in Fig-

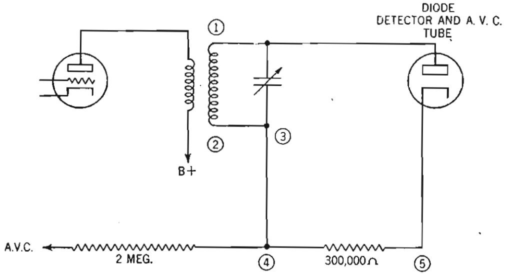


Fig. 150. Circuit showing how the diode acts as a detector and automatic-volume-control tube.

ure 149. A logical step for improvement is to employ a circuit using a diode tube both as a detector and as an automatic-volume-control tube. The advantage of a diode detector over a triode is that the diode does not distort the signal. The disadvantage of the diode detector is that it adds no amplification. This defect, however, is overcome through the great amplification possible from the radio-frequency stages.

Figure 150 shows this circuit. As in the case of the ordinary diode detector (see Chapter 13), the signal is impressed on the plate of the diode. When the plate is negative, no electrons are attracted from the cathode. When the plate is positive, electrons are attracted and are set flowing around the plate circuit from the plate to points 1, 2, 3, 4, 5, and back to the cathode. The more positive the plate, the greater the plate current.

At point 4, the electron stream divides. A portion flows through the 2-megohm resistor and thus furnishes the automatic-volume-control voltage which is applied to the grid returns of the radio-frequency amplifiers.

137. How does the complete automatic-volume-control system work? Since the 300,000-ohm resistor furnishes an easier path for the flow of electrons than does the 2-megohm resistor, the greater part of the electron stream flows toward point 5. This part is fed into the audio amplifier as shown in Figure 151.

The 300,000-ohm resistor consists of two resistors in series, one of 50,000 ohms and the other 250,000 ohms. The major electron stream flows through the 50,000-ohm resistor to the junction of these two resistors. Here the 250,000-ohm resistor holds back the electrons and forces them to go to the plate of the 0.01 μfd. coupling capacitor that couples the diode detector with the grid of the first audio-frequency amplifier tube. You recognize, of course, that this system really is the same as a stage of resistance-coupled audio-frequency amplification (see Chapter 16). The 1-megohm potentiometer controls the strength of the electrical charges placed on the grid of the first audio-frequency amplifier tube and thus acts as a manual volume control.

The 0.0001-μfd. capacitor by-passes to the ground the unwanted radio-frequency currents that may have leaked into the diode plate circuit. The 2-megohm resistor and 0.1-μfd. capacitor in the automatic-volume-control line are there to smooth out the automatic-volume-control voltage and to remove any audio-frequency currents that may be present.

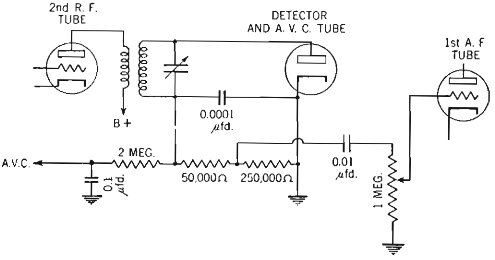


Fig. 151. Circuit showing complete automatic-volume-control circuit.

138. What is the type-55 tube? Tube manufacturers soon came out with a tube that combined the diode and triode in one envelope (glass bulb). Such a tube is the type 55. This tube has a single cathode, one surface of which emits electrons to the

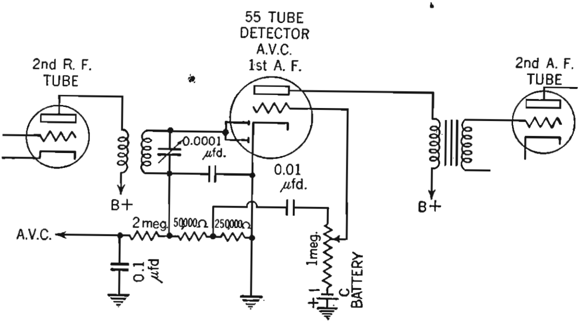


Fig. 152. Circuit showing how the type-55 tube is used as a detector, automatic volume control, and first audio-frequency amplifier.

diode plate, while the other surface sends electrons to the grid and plate of the triode. Actually, there are two diode plates in this tube, but for our purpose we connect them together and treat them as one plate. The advantage of such a tube is that in one envelope we have the diode detector, the automatic-volume-control tube, and the first audio-frequency amplifying tube. Figure 152 shows how the type-55 tube is connected in the circuit.

Other automatic-volume-control circuits have been developed, but the principle upon which they work is the same as that described here.

SUMMARY

1. The loudness of the signals coming from the speaker is known as **volume.**

2. In battery sets, volume is easily controlled by a rheostat that regulates the current in the filament and hence the temperature and the number of electrons emitted.

3. In nonbattery sets the filament current needs to be kept constant, so that the rheostat control in the filament circuit is not practical.

4. Control of volume by a potentiometer across the primary of the antenna coupler is less satisfactory than the use of a rheostat across the primary of the transformer in the plate circuit of the second radio-frequency tube.

5. Another method of volume control, sometimes combined with the last method mentioned in item 4, is to use a high resistance (500,000-ohm) potentiometer across the secondary of the first audio transformer.

6. A cathode-type tube with a grid-bias resistor and a rheostat hooked up in series is a good practical method for manual volume control.

7. Automatic volume control is achieved by devices which give a greater negative grid bias when greater currents come through, and a less negative grid bias when less current comes through. This negative bias in turn controls directly the amplification in the radio-frequency amplifiers.

8. Modern tubes of the 55 type combine the triode and diode in one envelope.

CHECK-UP

Underscore the words, phrases, or numbers that correctly complete the statements. (Answers are on page 304.)

1. In a battery-operated receiver the most common method of volume control is to vary the voltage in the (*filament*) (*grid*) (*antenna-coupler primary*) by means of a (*potentiometer*) (*transformer*) (*rheostat*) in series with the (*A battery*) (*B battery*) (*C battery*).

2. In a house-current set, volume may be controlled by connecting a (*rheostat*) (*potentiometer*) (*variable capacitor*) across the (*primary*) (*secondary*) of the transformer in the (*plate*) (*grid*) (*filament*) circuit of the second radio-frequency tube.

3. In a house-current set, volume may be controlled by connecting a (*rheostat*) (*gang capacitor*) (*potentiometer*) across the (*primary*) (*secondary*) of the first audio-frequency transformer. This method controls volume by controlling the voltage on the (*grid*) (*plate*) (*filament*) of the audio-frequency tube.

4. With cathode-type tubes, using cathode bias, volume may be controlled by a (*rheostat*) (*potentiometer*) (*variable capacitor*) which can vary the (*oscillations*) (*resistance*) (*frequency*) used to place a negative charge on the (*grid*) (*plate*) (*cathode*) of the amplifier tube.

5. Automatic volume control is achieved by automatically regulating the (*signal strength in the antenna*) (*the flow of electrons in the audio-frequency amplifier tubes*) (*the negative charge on the grids of the radio-frequency amplifier tubes*).

6. In automatic volume control, part of the signal current is (*changed to direct current*) (*stepped-up in voltage*) (*reduced in frequency*) and fed to the (*plates*) (*grids*) (*filaments*) of the (*audio-frequency*) (*radio-frequency*) (*detector*) tubes.

7. The (*Type* 27) (*Type* 55) (*Type* 80) tube combines both diode and triode in one envelope.

CHAPTER 24

Tone Control

QUESTIONS THIS CHAPTER ANSWERS

1. *How is the tone of sound waves related to the frequency?*

2. *What factors in radio receiving sets affect tone?*

3. *How do methods oj tone control separate high-pitched tones from low-pitched tones?*

139. What is meant by "tone"? In the last chapter you learned how the volume of sound coming out of the loudspeaker may be controlled. In this chapter you will learn how we control the tone of the radio receiving set.

As you know, sound is caused by air waves; these strike our eardrums and produce the sensation we call "hearing." To describe a sound we say not merely that it is loud or soft, but we also describe its tone. The tone depends upon the frequencies that make up the sound wave. The human ear can detect frequencies from about 30 cycles to 15,000 cycles per second. Those sound waves whose frequencies are low are described as *deep, bass* or *low-pitched sounds.* Those whose frequencies approach 15,000 cycles per second are called *shrill, treble,* or *high-pitched* sounds. Those whose frequencies fall in between are called *middle-register* sounds.

Music and speech, generally, are not composed of sounds having only one frequency. High-frequency and low-frequency sound waves usually are merged to produce a distinctive combination. If the result of mixing these sound waves of different frequencies is a sound whose predominant tone is that of the middle register, we say the sound has a *normal* tone.

If the sound has a preponderance of high-frequency sound waves, we say the tone is *high-pitched.* Women's voices generally fall into this category. If the sound has a preponderance of low-frequency sound waves, we say the tone is *low-pitched*. Men's voices generally fall into this category.

The tone of the sound coming out of the loudspeaker of the radio receiver, then, may be normal, high-pitched, or low-pitched, depending upon the combination of high-frequency and low-frequency sound waves present.

140. What determines the tone of a radio receiver? Since tone is an audio-frequency phenomenon, we must look for the answer in the audio-frequency part of the set, that is, in the events after the electron impulses have reached the plate of the detector tube. Investigation shows that the audio-frequency amplifier usually does not amplify all the frequencies at the same rate. Thus the high frequencies may be amplified more than the low frequencies, or vice versa. Or some intermediate frequencies may be amplified more or less than those at either end of the audio scale. Furthermore, the loudspeaker does not respond to all frequencies in like degree. The early speakers of the metallic-horn type failed to bring out the deep notes. The result was an unpleasant "tinny" sound.

Good practice in designing a radio set is to match the loudspeaker to the audio-frequency amplifier so that one compensates for the variations of the other. The result is a fairly uniform reproduction of sound at all frequencies.

141. What is the problem of tone control? It also is desirable to be able to control the tone of a radio set. Speech is clearer when it is somewhat higher pitched. On the other hand, many people prefer their music somewhat lower pitched. Some people do not enjoy listening to a soprano voice because of the preponderance of high-frequency tones.

The ideal method for controlling the tone of a radio receiver would be by means of controls which would regulate the amplification of the high-frequency notes and low-frequency notes separately. Such a method does exist, but it is quite complicated. It is used almost exclusively for public-address systems and studio purposes. The ordinary radio receiver uses a much simpler method which closely approximates the ideal method in results.

There is a peculiarity about human hearing. Take a sound of normal tone. The high frequencies and low frequencies are present in certain proportions. If, now, we amplify the low frequencies, we get a bass, low-pitched sound which has the same normal amount of the high-frequencies, but more of the low frequencies. Take the same sound of normal tone and remove some of the high frequencies. Although we have not added any new low frequencies, nevertheless we get the effect of a bass, low-pitched sound. This is called *false bass.*

Similarly, if we remove some of the low frequencies from the normal tone, we get the effect of a high-pitched, treble tone. This is a *false treble.*

142. How can we separate high pitch from low pitch? Our next problem is to devise a method of removing either some of the high frequencies or some of the low frequencies. The electric currents flowing in the audio-frequency amplifier fluctuate within the audio range, that is, between 30 cycles and 15,000 cycles per second. These currents cause the diaphragm or cone of the loudspeaker to vibrate in step with them. Thus a current fluctuating at about 100 cycles per second will cause a deep note to come forth from the loudspeaker, while a current fluctuating at about 10,000 cycles per second will produce a high-pitched note. Remember that when we speak here of high frequency, we mean high audio frequency and not radio frequency.

To remove some of the high-frequency current, we place a fixed capacitor across the path of the audio-frequency current. It may be shown that a capacitor furnishes a path of lower impedance than that of the plate circuit to currents of high frequencies but not for currents of low frequencies. Hence, the fluctuating current flowing in the plate circuit of the detector tube divides at point x (Figure 153). Some of the high-frequency current passes through the 0.002-μfd. capacitor and goes on to the positive terminal of the B eliminator. The main part of the plate current, however, containing all the low frequencies, passes through the primary of the first audio-frequency transformer and is amplified. Since some of the high frequencies are missing from the sound emitted by the loudspeaker, our radio set now has a bass tone.

We can vary the amount of high-frequency current by-passed by the capacitor by connecting a 500,000-ohm rheostat in series with it, as in Figure 154. The more the resistance in the circuit, the less the amount of high-frequency current that will be by-passed and therefore the more treble the tone.

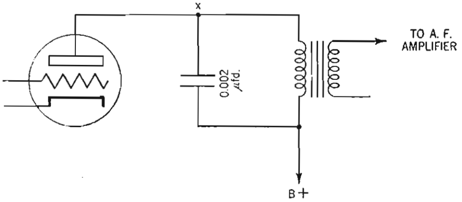


Fig. 153. Circuit showing how a capacitor is used to filter out some of the high-frequency current.

The combination of fixed capacitor and rheostat is called a *tone control.* It may be placed anywhere in the audio circuit,

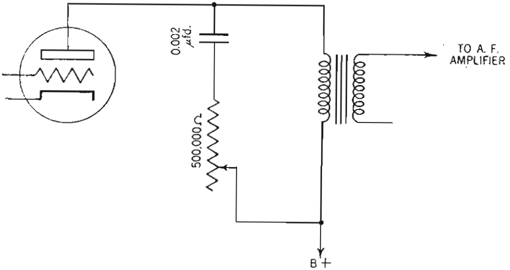


Fig. 154. Circuit showing how a rheostat is connected in series with the capacitor to control the amount of high-frequency current filtered out.

across the primary of the audio transformer (as shown) or across the secondary. It may be applied to any of the audio-frequency stages.

143. How is tone controlled by an alternate path to the ground? Another type of tone control is shown in Figure 155. This tone control consists of two arms. In one arm, A, is a 0.1-μfd. capacitor. In the other, B, a 0.1-μfd. capacitor is connected in series with a choke coil of about 85 millihenries. One end of each arm is connected to the plate of the final audio-frequency tube. Across the other ends a 100,000-ohm potentiometer is connected with the sliding arm going to the ground.

The action of the choke coil is opposite to that of the capacitor. It offers a higher impedance to currents of higher frequencies. Hence it conducts more readily the parts of the current with low frequencies.

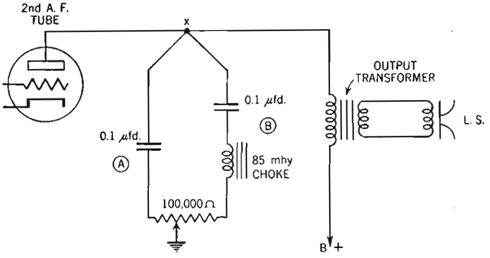


Fig. 155. Circuit showing a "treble-bass" tone control.

First, consider the circuit with the sliding arm of the potentiometer all the way to the left. None of the resistance is in arm A; it is all in arm B. Current flowing in the plate circuit of the audio-frequency tube divides at point x in Figure 155. Some of the high-frequency current is lost through the capacitor. The main part of the current passes through the output transformer, and our set now has a bass tone.

When the slider arm is at the extreme right, the entire 100,000 ohms is in arm A. This resistance prevents the loss of the high-frequency currents. As a result, the diverted current flowing from point x must now pass through arm B. Since the choke coil offers a high impedance to the high-frequency current, it is only low-frequency currents that pass through and go on to the ground. Since we have lost some of the low frequencies, our tone now is treble.

Moving the sliding arm of the potentiometer varies the amount of high or low frequencies lost; thus the tone of the set is controlled.

144. How is tone controlled by using two speakers? There is still another method of tone control that is sometimes used. Some sets have two speakers. One is a speaker which reproduces the low frequencies better than the high frequencies. The other reproduces the high frequencies better. Both of these speakers are connected to the output transformer by a potentiometer which controls the amount of current flowing through each (Figure 156).

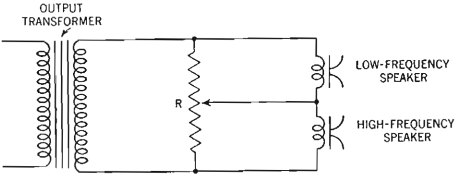


Fig. 156. Circuit showing how tone control may be obtained through the use of high-frequency and low-frequency loudspeakers. The potentiometer (R) determines which speaker shall obtain the greater current.

Thus if more current flows through the high-frequency speaker and less through the low-frequency speaker, the high frequencies are louder and the tone is treble. If the conditions are reversed, the tone is bass. The potentiometer, then, acts as a tone control.

Different manufacturers of radio sets may use different types of devices for tone control, but upon analysis of the circuits you will see that they usually are variations of the ones described here.

SUMMARY

1. Sounds having regular frequencies are called musical **tones.**

2. The frequency of a tone is related to its **pitch**: low pitch means low frequency and high pitch means high frequency.

3. The tones coming from a speaker are influenced both by the arrangement of the parts of the audio-frequency system and also by the kind of loudspeaker.

4. The principles of **tone control** that are made use of within the receiver are: (1) capacitors offer a path of less impedance to high-frequency currents than to low-frequency currents. (2) Choke coils offer more impedance to high-frequency currents and less impedance to low-frequency currents.

5. The most successful tone control makes use of a divided circuit leading to the ground, in one arm of which is a capacitor and in the other arm a choke coil. A slide arm on the potentiometer controls the tone by permitting more or less high-frequency current to pass through.

6. Two speakers having different qualities—one good for high pitch, the other for low pitch—may be hooked to one receiver. The tone can be controlled by varying the amounts of current in the two speakers.

CHECK-UP

In the blank spaces write the words, phrases, or numbers needed to complete the statements correctly. (Answers are on page 304.)

1. The human ear can hear sounds with frequencies from about .... cycles per second to .... cycles per second.

2. Audio-frequency amplifiers usually fail to amplify different frequencies to the .... degree.

3. Most sounds are combinations of many ....

4. A false bass is a complex sound from which some of the .... frequencies have been removed.

5. A false treble is a complex sound from which some of the .... frequencies have been removed.

6. Tone control is performed in the .... stages of a receiver since we are dealing with .... frequencies.

7. A simple tone control makes use of a .... and a ....

8. Another method of tone control makes use of two speakers, one of which reproduces better the .... frequencies, and the other reproduces better the .... frequencies. A .... is used to determine which speaker shall get the greater current.

CHAPTER 25

The Superheterodyne Receiver

QUESTIONS THIS CHAPTER ANSWERS

1. *Why is the tuned radio-frequency amplifier not satisfactory?*

2. *What is the principle of beats?*

3. *How is the principle of beat currents applied to obtain sharp tuning over a wide range of frequencies?*

4. *What are the essential principles of the superheterodyne receiver?*

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145. What are the faults of tuned radio-frequency amplifiers? It is interesting to note how one great invention or discovery leads to other inventions or discoveries. Many examples of this are found in the history of radio. After the invention of the system of tuned radio-frequency amplification, radio engineers began looking for means to correct the flaws and drawbacks of this circuit. This search led to the next improvement. The drawbacks of the circuit were found to be in the inability to have a wide range of reception and at the same time sharp tuning.

To obtain maximum sensitivity and selectivity, the tuning circuit should have a natural frequency exactly equal to the frequency of the broadcasting station. But our tuning circuit is made so that we may tune in all frequencies lying in the broadcasting range, that is, from 550 to 1600 kilocycles. To obtain this broad coverage a compromise is made in the design of our tuned radio-frequency transformer, and some of the selectivity and sensitivity is sacrificed.

146. What is the general principle of a superheterodyne? The ideal way would be to have a separate set of tuned radio-frequency transformers for each frequency received. This, of course, is impractical for home receivers. The invention of the superheterodyne receiver resulted from the experiments seeking to approach this ideal condition. In the system to which the name superheterodyne is given we have, instead of a separate set of tuned radio-frequency transformers for each frequency received, one set of tuned radio-frequency transformers that are tuned to one predetermined frequency. After selecting the radio station we desire, we change the frequency of the currents flowing in our receiver to that certain predetermined frequency and then feed it into our tuned radio-frequency amplifier.

In this manner we have the advantage of using tuned radio-frequency transformers that operate at only one frequency without the drawback of needing a separate set for each frequency. Our set is more selective and sensitive than the tuned radio-frequency set described in Chapter 22.

147. What is meant by "beats"? In order to understand how the frequency of the incoming signal is changed to that for which the radio-frequency transformers are tuned, you must first learn about the phenomenon of *beats*.

Strike middle C on the piano. The sound you hear has a frequency of 256 cycles per second. Now strike the note before it, B on the piano. This note has a frequency of 240 cycles per second. Now strike both keys together. The sound you hear is neither B nor C but a mixture of the two. If you listen closely, you will notice that this new sound rises and falls in loudness or intensity. If you can time this rise and fall of sound, you will notice that it occurs 16 times per second, the exact difference between the frequencies of B and C.

We call this rise and fall the *beat note*. Its frequency (that is, the number of beats) is equal to the difference between the frequencies of the notes producing it. The production of beat notes occurs not only in the case of sound waves; it occurs whenever any kind of waves of different frequencies clash or beat against each other. Thus, under certain conditions, light waves may produce beats. Also, radio waves of different frequencies may be mixed, resulting in beats whose frequency equals the difference between those of the two original waves.

Now we can explain how we are able to change the frequency of the incoming signal to that for which the radio-frequency transformers are tuned. The problem is to mix with the incoming signal another radio-frequency current whose frequency is such that the difference between the two is equal to the predetermined and desired frequency.

148. How are beat frequencies formed in the receiver? Assume we have set our radio-frequency transformers so that their natural frequency is 175 kc. Let us suppose that we are receiving the signal from a station whose frequency is 1000 kc. All we need do is to generate a radio-frequency current whose frequency is 1175 kc. We mix this radio-frequency current with the

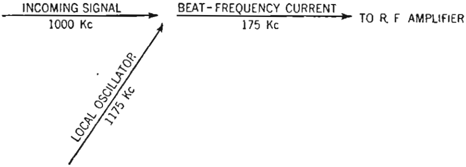


Fig. 157. Diagram showing how the incoming signal mixes with the current produced by the local oscillator to produce the beat-frequency current.

incoming signal (1000 kc.) and a *beat current* results whose frequency is 175 kc. (1175 kc. − 1000 kc. = 175 kc.) This 175-kc. beat current is fed into the radio-frequency transformers, and amplification occurs at maximum efficiency. The idea is shown in diagram form in Figure 157.

The device used to generate the radio-frequency current which beats against the incoming signal is called the *local oscillator*.

To make this process clearer let us consider another example using the same tuning system having a natural frequency of 175 kc. Assume that the incoming signal has a frequency of 800 kc. The local oscillator must now produce a radio-frequency current whose frequency is 975 kc. The beat-current frequency, again, is 175 kc., the frequency at which the radio-frequency transformers are set.

To produce a beat-frequency current of 175 kc., the local oscillator produces a radio-frequency current whose frequency is 175 kc. above that of the incoming signal. Since frequencies in the broadcast band lie between 550 kc. and 1600 kc., the local oscillator for our set must be capable of producing radio-frequency currents whose frequencies are between 725 kc. (550 + 175) and 1775 kc. (1600 + 175). Further, we must connect together the control that selects the incoming signal with the control that regulates the local oscillator in such a way that the difference in frequency is always 175 kc.

Heterodyning is another name for the production of beats. It is from this word that we get the name of our new type radio set, the *superheterodyne receiver*.

149. Where does beat production occur? As in the case of the tuned radio-frequency receiver, the incoming signal is selected by the tuning circuit consisting of the antenna coupler with a variable capacitor across the secondary. The radio wave, a modulated carrier wave, causes a correspondingly modulated radio-frequency current to flow in the tuning circuit. This radio-frequency current is fed into the grid of an ordinary grid-leak-capacitor detector. Without the local oscillator present, the modulated radio-frequency current would pass through this detector. The radio-frequency part or component would be eliminated, and the modulating component (the audio-frequency component) would appear at the output of the detector tube. Here is another way of explaining detection; you now can see why the detector tube is sometimes called the *demodulator tube*.

But in the superheterodyne system, before detection occurs the steady or unmodulated radio-frequency current from the local oscillator is mixed with the incoming signal. As a result, coming out of the plate of the detector tube is a new radio-frequency current whose frequency is the beat frequency and whose amplitudes are modulated in the same way as was the incoming signal. This new radio-frequency current is then fed into the radio-frequency amplifiers that are tuned to the same frequency.

Since the mixing of the two radio-frequency currents takes place in the detector tube, this tube is also called the *mixer tube*.

It is called the *first detector tube* to distinguish it from the *second detector tube* which follows the radio-frequency amplifier tubes.

150. What is the principle of the local oscillator? For the local oscillator we have to go back to the regenerative receiver (Chapter 15). Turn back to Figure 75. Current flowing in the plate circuit of the triode is fed back to the tuned circuit by means of a plate coil. This feedback overcomes the resistance of the tuned circuit, and the radio-frequency current flowing in that circuit (the oscillations of the electrons) is built up (see Figure 158). The frequency of this radio-frequency current is determined by the electrical values of the inductance and variable

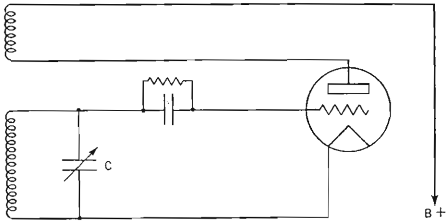


Fig. 158. Circuit of the local oscillator. Note how it resembles the regenerative detector.

capacitor in the tuned circuit ($L \times C$). Changing the setting of the variable capacitor will change the frequency of the current produced.

Here, then, is our local oscillator. By connecting the variable capacitor of this oscillator with the variable capacitor of the first detector circuit so that they turn together, and selecting the proper component parts (L and C), we are able to produce a radio-frequency current which at all times will be 175 kc. above the frequency of the incoming signal (see Figure 159). Note that 175 kc. is taken only as an example. Actually we can make this difference any frequency we wish, provided we have set our radio-frequency transformers to tune to that frequency.

151. How is the oscillator coupled to the first detector? Several methods are used in feeding the radio-frequency current generated by the local oscillator into the mixing tube. One such method is to make the circuits *inductive-coupled.* A coil of wire is placed near the tuned circuit of the oscillator. The radio-frequency current generated by the oscillator is passed on to this coil of wire by induction. The ends of the coil are con-

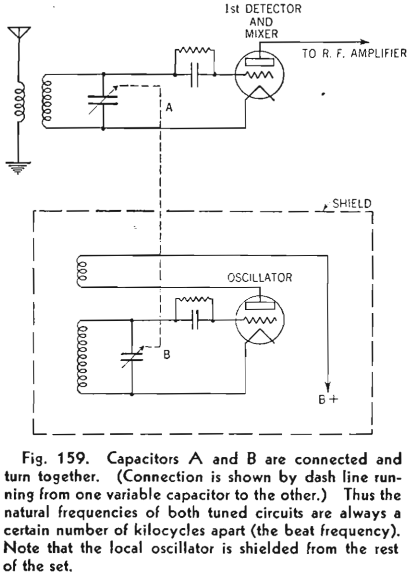


Fig. 159. Capacitors A and B are connected and turn together. (Connection is shown by dash line running from one variable capacitor to the other.) Thus the natural frequencies of both tuned circuits are always a certain number of kilocycles apart (the beat frequency). Note that the local oscillator is shielded from the rest of the set.

nected in the grid circuit of the first detector and mixer tube, as shown in Figure 160. In this manner the radio-frequency current of the oscillator is mixed with the radio-frequency current flowing in the first detector and mixer circuit. The beat-frequency current results.

A variation of this method of coupling is to connect the ends of the coil in the cathode circuit of the detector and mixer tube, as in Figure 161. When this method is used, it is customary to have the first detector hooked up as a resistor-biased detector.

Another method is to make the circuits *capacity-coupled.* This time a small fixed capacitor transfers the radio-frequency current from the oscillator to the grid of the first detector and mixer tube, as shown in Figure 162. The radio-frequency choke in the plate

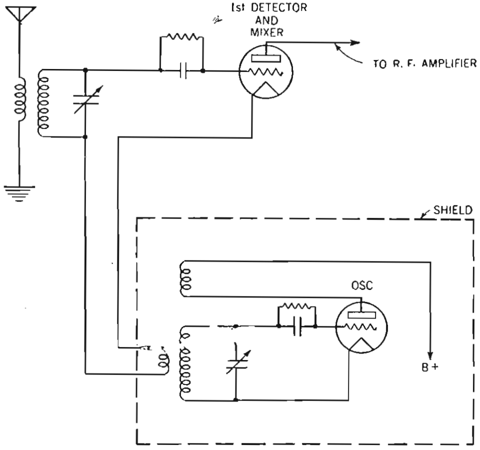


Fig. 160. Circuit showing how current from the local oscillator is inductively coupled to the first detector and mixer circuit. The dotted lines showing that both variable capacitors are connected to each other are omitted from this diagram for the sake of clarity.

circuit of the oscillator tube forces the radio-frequency current through the coupling capacitor to the grid of the first detector tube.

With the invention of new types of tubes, a third method of coupling was invented. In this method the two circuits are coupled through the electrodes within the tube itself. We will discuss this electron coupling further in the chapter dealing with types of tubes (see §176).

152. What is the intermediate-frequency amplifier? Coming out of the first detector and mixer tube is the beat-frequency current (175 kc. in our example). This is a radio-frequency current, since it lies well above the audio range of about 15 kc. per second. But it is lower than the broadcast frequencies which lie between 550 kc. and 1600 kc. per second. We therefore call this beat frequency the *intermediate frequency* (abbreviated to I.F.). The

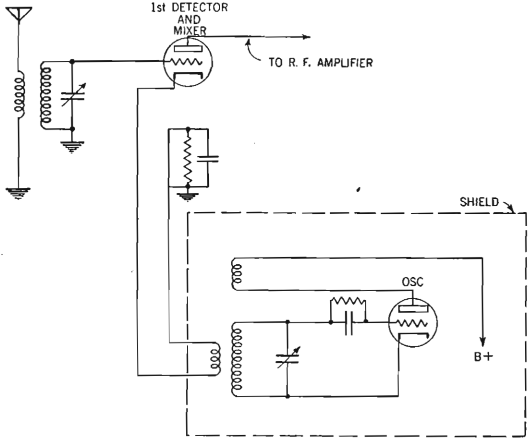


Fig. 161. Circuit showing how current from the local oscillator is inductively coupled to the cathode of the first detector and mixer tube.

tuned radio-frequency transformers which are set for this beat frequency are called intermediate-frequency transformers, and the amplifier is called an *intermediate-frequency amplifier.*

The intermediate-frequency transformers differ from the regular radio-frequency transformers in a number of ways. Since they are tuned to a lower frequency, they have a greater number of turns of wire. Also, since they are to respond to only one frequency, the variable capacitor is eliminated. Instead, we use a trimmer capacitor adjusted to align the various tuned circuits.

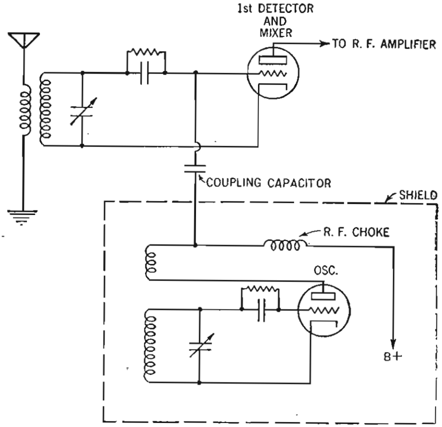


Fig. 162. Circuit showing how a small fixed capacitor is used to couple the current from the local oscillator to the grid of the first detector and mixer tube.

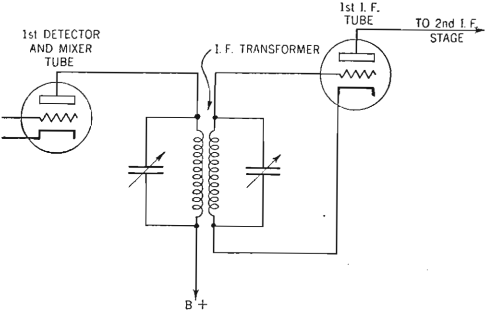


Fig. 163. Circuit of the intermediate-frequency transformer.

Another difference is that the primary of the intermediate-frequency transformer, too, is usually tuned by means of a trimmer capacitor. This arrangement, of course, increases the selectivity of the set. While it is quite possible to tune the primary of the ordinary radio-frequency transformer, the difficulty of ganging the extra variable capacitors needed presents quite a problem; therefore this primary is not tuned. A diagram of the intermediate-frequency transformer used for an amplifier is shown in Figure 163.

Meissner Mfg. Co.

Cutaway view of intermediate-frequency transformer.

As previously stated, the use of an intermediate-frequency transformer tuned to a fixed frequency means much greater sensitivity and selectivity. So sensitive is the superheterodyne set that it is quite possible to use a small loop aerial built inside the cabinet of the set itself instead of a long wire up on the roof.

The increase in selectivity may be shown by the tuning curves in Figure 164. In Figure 164-A the curve indicates that when you tune in the 1000-kc. station, the two stations whose frequencies lie 30 kc. on either side can be heard slightly. This tuning curve is typical for the tuned radio-frequency receiver. Figure 164-B represents the tuning curve of the superheterodyne receiver. Here you will notice that stations 30 kc. away from the desired station (1000 kc.) lie well below the level of audibility.

153. How may a receiver be too selective? So selective is the superheterodyne that another problem may be presented. The set may be too selective! Here is what happens:

At the radio station, audio-frequency currents whose frequencies run up to 15 kc. per second are mixed with the steady radio-frequency carrier current generated by the transmitting set to produce the modulated radio-frequency current. Assume that our broadcasting station has a carrier wave whose frequency is 1000 kc. per second. The resulting beat current then is 1000 kc. minus 15 kc., or 985 kc. per second.

In discussing the production of beats we have omitted to tell you that when waves of two frequencies are mixed, not only is the beat frequency the *difference* between these two frequencies, but a beat frequency is also produced which is the *sum* of these two frequencies.

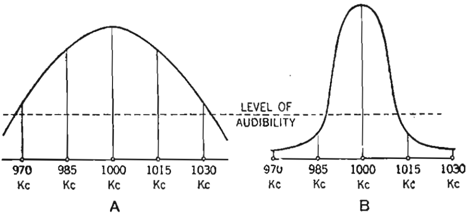


Fig. 164. (A) Tuning curve for the tuned radio-frequency receiver tuned to 1000 kc. Note that stations whose frequencies are 970 kc. and 1030 kc. lie above the level of audibility. This condition means that they may be heard faintly in the background of the desired station. (B) Tuning curve for the superheterodyne receiver tuned to 1000 kc. Note that the unwanted stations fall below the level of audibility.

When we considered the beat-frequency current produced by mixing the incoming signal with the radio-frequency current generated by the local oscillator, we omitted the beat produced by adding the two frequencies because it lay well outside the range of our receiver. You will recall that we assumed an incoming signal whose frequency was 1000 kc. per second. One beat frequency produced was 175 kc. The other beat frequency which we did not consider was 1000 kc. plus 1175 kc. or 2175 kc. Since our intermediate-frequency transformers were tuned to 175 kc., the second beat could not be amplified.

But at the transmitting station the mixing of the 15-kc.-per-second audio current with the 1000-kc.-per-second carrier current produces beat currents that have two different frequencies, one of 985 kc. and the other of 1015 kc. per second. The radio station, therefore, broadcasts a wave whose frequency lies between 985 kc. and 1015 kc. per second. The difference between the two frequencies (30 kc.) is called the *band width.*

Now if you will turn back to Figure 164-B, you will notice from the tuning curve for the superheterodyne receiver that when it is tuned to 1000 kc., the extremes of the 30-kc. band width lie below the level of audibility. In other words, so great is the

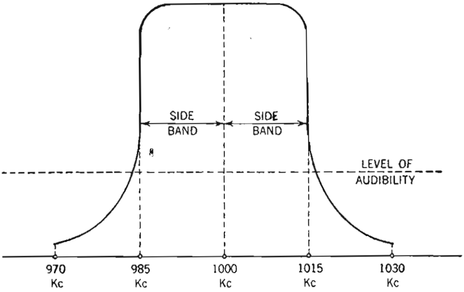


Fig. 165. Ideal tuning curve for the superheterodyne receiver. Note that the side bands are fully received, while the unwanted stations are well below the level of audibility.

selectivity and so narrow is the tuning curve that the beat frequencies of 985 kc. and 1015 kc. lie below the level of audibility. We say the receiver has *cut the side bands.* This means that some of the high notes will not be heard. Thus the tone of the set will be too bass.

To remedy this defect we are compelled to reduce the selectivity of the set. The ideal condition would be to have the 985 kc. and 1015 kc. on the tuning curve a little above the level of audibility as shown in Figure 165. This broadening is accomplished by adjusting the trimmer capacitors so that the set is slightly out of alignment. This adjustment broadens the tuning curve so as not to cut the side bands. While it is possible to judge this condition by ear, best results are accomplished by the use of special electrical instruments.

Except for the differences already noted, the intermediate-frequency amplifier is similar to the radio-frequency amplifier discussed in Chapter 22.

154. What is the second detector? The second detector following the intermediate-frequency amplifier is similar to the one used in the tuned radio-frequency set described in Chapter 22. A diode detector is customarily used, since the amount of amplification of the intermediate-frequency amplifier is great enough to overcome the loss of amplification that results from using a diode instead of a triode detector.

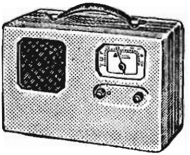
The automatic-volume-control system, the manual volume control, the tone control, and the audio amplifier are the same as those used in the tuned radio-frequency receiver.

155. What is the value of a radio-frequency stage in front of the first detector? Sometimes a stage of ordinary radio-frequency amplification is placed in front of the first detector. While it is not necessary to increase the sensitivity or selectivity of the superheterodyne receiver (which is sensitive and selective enough without it), this radio-frequency stage serves two useful functions.

First of all, it serves to reduce the volume of any unwanted signals from powerful radio stations that may be in the vicinity of the receiver. If this stage were not present, this unwanted powerful signal would be impressed on the first detector and might cause some interference. While the radio-frequency stage may not completely eliminate this interfering station, it can reduce its signal strength to the point where the tuned circuit of the first detector can eliminate it completely.

156. How are image frequencies eliminated? But even more important is the fact that this radio-frequency stage eliminates what are called *image frequencies*. To get the idea of image frequency, assume that we are tuning to the 1000-kc. station. Our oscillator produces a radio-frequency current whose frequency is 1175 kc. A beat-frequency current of 175 kc. results, the same frequency to which our intermediate-frequency transformers are tuned.

Suppose, at the same time, there is a station whose frequency is 1350 kc. This new signal will beat against the 1175-kc. current produced by the oscillator, and once again a beat frequency of 175 kc. will result. This means that for every frequency produced by the oscillator there are *two* frequencies that will produce the desired beat frequency, one 175 kc. *above* the oscillator frequency and one 175 kc. *below* the oscillator frequency. Thus two stations may be passed on to the intermediate-frequency amplifier at the same time.



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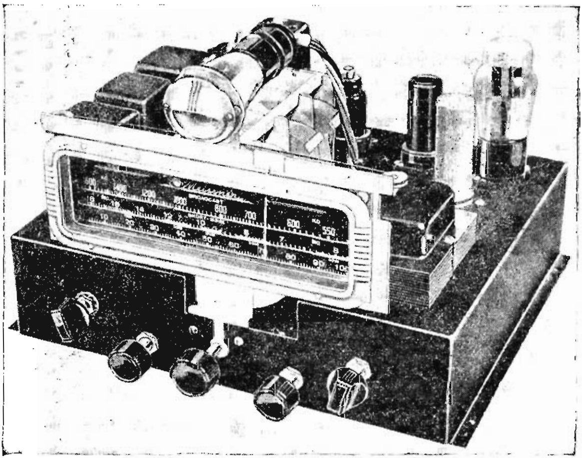
Portable superheterodyne receiver.

This second and unwanted frequency (1350 kc.) is called the *image frequency.* The stage of radio-frequency amplification eliminates the image frequency by tuning it out before it reaches the first detector.



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Superheterodyne receiver chassis.

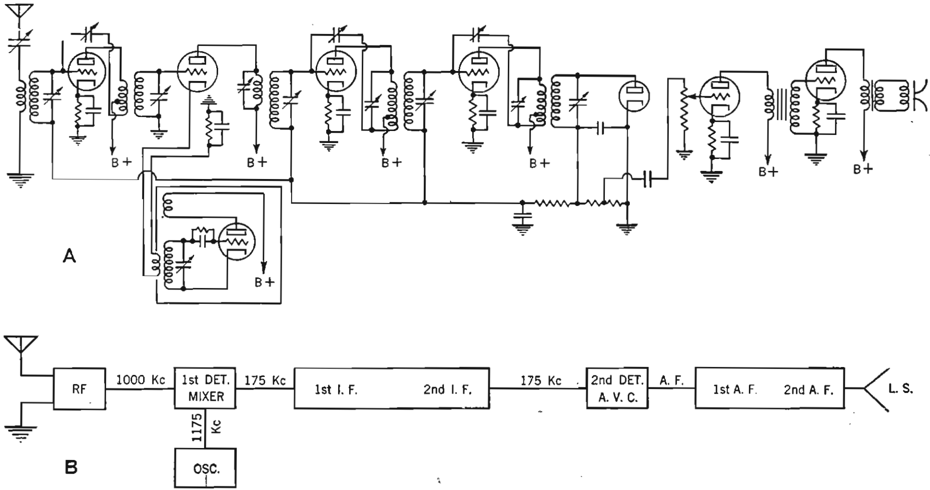


Fig. 166. (A) Circuit of the complete superheterodyne receiver. (B) Block diagram showing arrangement of the component parts.

SUMMARY

1. The tuned radio-frequency receiver cannot be tuned sharply and at the same time remain able to receive stations that have a wide range of frequencies.

2. The superheterodyne receiver provides a means of sharp tuning over a wide range by means of the principle of **beat notes.**

3. Beat is a phenomenon of the alternate reinforcement and neutralization of each other by waves of two frequencies. The number of beats produced by this reaction of two sets of waves is equal to the difference between their vibration frequencies.

4. The **first detector** in a superheterodyne receiver is a tube in which the radio waves from the aerial are mixed with the waves from a local oscillator.

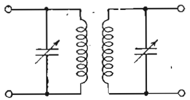
5. The local oscillator is tuned so that the beat note produced by its wave mixed with an incoming radio wave will always be the fixed natural frequency of the intermediate-frequency amplifier.

6. The current from the first detector tube is a beat-frequency current that is of radio frequency, but lower than the broadcast frequencies.

7. The radio-frequency amplifiers are set for this beat frequency and such an amplifying system is called an **intermediate-frequency amplifier.**

8. The superheterodyne receiver is very sensitive and tunes so sharply that if it is to respond to the **side bands,** trimmer capacitors must be used to keep the set a trifle **out of alignment.**

SYMBOL



Intermediate-frequency transformer.

CHECK-UP

If a statement is true, encircle the T. If a statement is false, encircle the F. (Answers are on page 305.)

T F **1.** The chief weakness of the tuned radio-frequency receiver is its lack of sensitivity because one set of tuning circuits must cover the entire broadcast band.

T F **2.** In the superheterodyne receiver the tuned radio-frequency transformers are set at one frequency and we change the frequencies of all incoming signals to this frequency.

T F **3.** When two waves of different frequencies are mixed together, they produce beats whose frequencies are the difference between or the sum of the two original frequencies.

T F **4.** Heterodyning is another name for the production of beats.

T F **5.** In the superheterodyne receiver, we obtain beats of a predetermined frequency by mixing the incoming signal with the output of a local oscillator.

T F **6.** The beat frequency is kept constant by detector tubes, which control the frequency of the tuning circuit and that of the incoming wave.

T F **7.** The first detector is the tube where the radio-frequency current from the local oscillator and the radio-frequency current from the tuning circuit are mixed.

T F **8.** The beat frequency is often called the secondary frequency. For this reason, we call the radio-frequency transformers into which this beat-frequency voltage is fed secondary-frequency transformers.

T F **9.** Unless properly aligned, the superheterodyne receiver may be too sensitive and cut the side bands, thus cutting out some of the lower notes.

T F **10.** An audio-frequency amplifier is sometimes placed before the first detector to eliminate the evil of image frequencies.

T F **11.** If a superheterodyne set is tuned to a 500 kc. station, and the local oscillator is producing a frequency of 575 kc., another station broadcasting at 650 kc. will produce image frequencies.

T F **12.** Capacitors are used in capacitive coupling between the first detector and local oscillator.

CHAPTER 26

Types of Vacuum Tubes

QUESTIONS THIS CHAPTER ANSWERS

1. *What are the functions of the diode and triode tubes?*
2. *What is the nature of power tubes?*
3. *What is the tetrode tube?*
4. *What is the variable-mu tube?*
5. *What is the pentode tube?*
6. *What are multielectrode tubes?*
7. *What are multiunit tubes?*

157. What are the general principles of vacuum tubes? As you have learned, it is possible to have radio without vacuum tubes. Nevertheless, the radio tube has changed what was a scientific toy into one of the world's greatest industries. The vacuum tube has greatly influenced our present civilization.

The basic principles of the vacuum tube are nevertheless extremely simple. Let us study the vacuum tube more attentively. Surrounded by a vacuum, the heated filament or cathode emits a stream of electrons which form a one-way path to a positively charged plate or anode. The more the cathode is heated, the more electrons it sends out. The more positive the charge on the plate, the more of these electrons it attracts. (It should be remembered that these two statements hold true between certain limits. If you heat the filament too much, it will burn up. After a certain limit is reached, the placing of a higher positive charge on the plate will attract no more electrons.)

In some tubes, the cathode is the filament itself. This filament may be a thin wire, as in type 01A tubes. Or else it may be a heavy metal ribbon coated with certain chemicals to permit it to shoot off more electrons, as in the type 26 tubes. In tubes of other types, the filament is merely an electric stove or heater, heating up the relatively heavy metal tube or sleeve that fits over it. This tube or sleeve is the cathode, which, when heated sufficiently, emits the electrons that find their way to the plate. The type 27 tube is an example of this class.

Tubes having thin filaments usually are heated by direct current. Alternating current is generally used to heat the heavy ribbon filaments. The separate-heater types of tubes may be heated either by direct or alternating current.

158. What voltages do tubes require? In practice, tube manufacturers design the filaments and heaters of their tubes to operate at certain voltages. Thus the filament of the 01A tube operates at the 5 volts obtained from a storage battery. For use in portable receiving sets, the 1H5-G type of tube has a filament which operates from the $1\frac{1}{2}$ volts furnished by a single dry cell.

Other types of tubes require different voltages. The type 45 uses $2\frac{1}{2}$ volts on its filament. The heater of the 117Z6 tube uses 110 volts. There are many other types of tubes using other voltages. But the voltage at which the filament or heater of the tube operates does not determine the character or nature of the tube.

159. What is the diode? Simplest of all vacuum tubes is the two-element tube or *diode*. These two elements consist of an emitter of electrons (either a filament or separately heated cathode) and a plate. These two elements are sealed inside a glass bulb from which all air has been evacuated. As described in Chapter 13, the diode makes for an excellent detector. It is also used as a rectifier, changing alternating current into direct current to be used by the B eliminator (Chapter 17) and by the automatic volume-control circuit (Chapter 23).

The 1-V and 12Z3 types of tubes are typical diodes. Sometimes two diodes are sealed into one envelope to make a *full-wave rectifier*. Examples of this type of tube are the 80, 5Z3, and 6H6 tubes.

160. What is the triode? When Dr. De Forest placed a third element, the grid, between the cathode and plate of the diode, he introduced the potent phenomenon of *amplification*. As already explained in Chapter 14, a small voltage placed upon the grid of the tube controls the stream of electrons rushing from the cathode to the plate. This electron stream in turn controls the comparatively large plate current. Since this large plate current varies in step with the small voltage placed upon the grid, amplification results.

The amplifying quality of a tube is called the *amplification factor*, which appears in electrical formulas as the Greek letter *mu* (μ). Here is what it means:

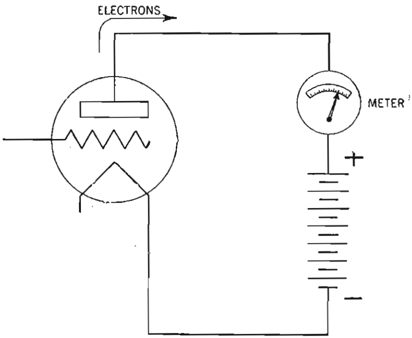


Fig. 167. Meter connected in the plate circuit of the triode to show the flow of electrons.

In Figure 167 we have a triode with a meter in the plate circuit. Electrons flowing from the filament are attracted to the positively charged plate and flow on through the meter, which registers their flow. Assume that you now increase the B battery by 35 volts. The greater positive charge on the plate attracts more electrons and the meter now shows that more are flowing through it.

At this point a negative charge is placed on the grid. This charge will cut down the flow of electrons to the plate, and fewer electrons will flow through the meter. Assume that when you have placed a negative charge of 5 volts on the grid, the meter shows the same number of electrons flowing through it as before the plate charge was raised by 35 volts. This equality means that 5 volts applied to the grid will have the same effect as 35 volts (of opposite charge) applied to the plate of the tube. The amplification factor or *mu* (μ) of this tube is therefore 35 divided by 5, namely 7.

161. What determines the amplification factor of a triode? The amplification factor of a triode is determined by the mechanical construction of the tube. The nearer the grid is to the cathode, the greater is its effect on the stream of electrons flowing to the plate and the greater is the *mu* or amplification factor of the tube. Also, the finer the mesh of the grid, the greater the effect of a charge upon the grid and again the greater the *mu*. If the open spaces in the grid are wide, the electrons are able to rush to the plate without being very much affected by the grid charge. This condition accordingly makes for a smaller amplification factor.

In the triode we are unable to use a grid of very fine mesh because the consequently larger area of the grid would greatly increase the internal grid-to-plate capacitance. This capacitance would increase the feedback and cause the receiver to oscillate, resulting in distortion (see §121). It is partly because of this fact that triodes have a relatively small amplification factor. The type 27 tube has a *mu* of 9 and type 01A a *mu* of 8.

There is another factor that limits the *mu* of the triode. The electrons shot off by the cathode each have a negative charge. Thus they tend to repel each other, and many more are shot out than actually reach the plate. Of these electrons that do not reach the plate, a large number accumulate and fill the space around the cathode inside the envelope of the tube. This accumulation charges the space around the cathode, and is therefore called the *space charge*.

Any new electrons shot off by the cathode must fight their way through this space charge to reach the plate. It is estimated that about 85 per cent of the positive charge on the plate of the tube is used to overcome the repelling effect of the space charge, leaving about 15 per cent for amplification purposes. The space charge, surrounding the grid, also interferes with its action and thus further reduces the *mu* of the tube.

162. What is the amplification outside the tubes? In addition to the amplification furnished by the tube, there is the amplification due to the step-up action of the transformer. Figure 168 shows what is meant by a *stage of amplification.* We may calculate the amplification of this stage by dividing the output voltage by the input voltage. Thus, if the output voltage is 50 volts and the input voltage is 5 volts, the amplification furnished by this stage is 50 divided by 5, or 10.

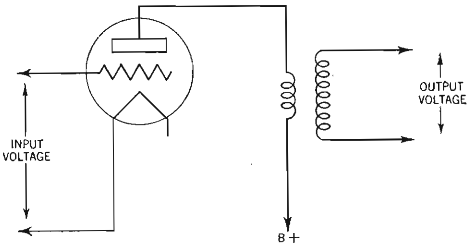


Fig. 168. Diagram showing what is meant by a stage of amplification.

163. How does the power tube function? We must remember that the radio tube is a voltage-operated device; that is, the varying voltage which is fed into the grid controls the current flowing in the plate circuit of the tube. It becomes the function, then, of each stage of amplification to amplify the variations of voltage fed into the grid. Each stage has this function, except the final audio-frequency stage, whose function it is to supply the fluctuating current or power that operates the loudspeaker.

Electrons shot out by the cathode and attracted to the plate circulate through the voice coil of the loudspeaker, which is either in the plate circuit or else coupled to the plate circuit by means of an output transformer (see §115). The frequency of sound coming from the speaker depends upon the frequency of variations in the electron stream. The volume or loudness of this sound depends upon the amplitude of these variations. Thus, to operate our speaker at a loud level, we need a dense stream of electrons flowing in the plate circuit. Therefore, the cathode must be capable of emitting a large quantity of electrons, and the tube must be able to pass them on to the plate.

It is for this reason that the last stage of audio-frequency amplification is called the *power stage* and the tube that operates this stage is called the *power tube.*

If the power tube is of the filament type, this filament is usually made quite heavy and rugged and is coated with chemicals that increase the electronic emission. A power tube may also contain a large number of filaments connected together to give the same effect as one heavy filament. Tubes such as the type 45 and the type 2A3 are examples. Where the tubes have separately heated cathodes, these cathodes are large and are able to emit a large number of electrons. The 6AC5-G is such a tube.

When the electrons strike the plate, they are traveling with considerable speed, and the force of the impact heats up the plate. It is for this reason that the plate of the power tube must be larger and more rugged than for the other types of tubes. It is usually coated with graphite to give it a black surface so that it may radiate away its heat more effectively.

164. Why do power tubes have a small amplification factor? While the grid of the power tube must control the flow of electrons from the cathode to the plate, it must not block off too many of these electrons that are needed so badly in the plate circuit. For this reason the grid of the power tube has an open mesh and is not placed so close to the cathode as in the case of other types of amplifier tubes. This construction, in turn, reduces the amplification factor of the power tube. Thus the *mu* of the type 2A3 tube is only 4.2 and that of the type 45 tube 3.5. Power tubes of the triode class generally have a low amplification factor.

Since the grid of the power tube is of open mesh and relatively far from the cathode, changes in the grid voltage do not affect the flow of electrons in the plate circuit as much as if the grid were of finer mesh and closer to the cathode. In order to create a certain variation in the plate current, therefore, any change in the charge on the grid of the power tube needs to be greater than the change needed by another type of amplifier tube. We say that power tubes of the triode class have low *power sensitivity.*

Because this greater *grid-voltage variation* or *swing* is necessary to operate the power tube, it is important that most of the amplification of the signal should occur before the current is fed into the power tube. For this reason it is customary to have a

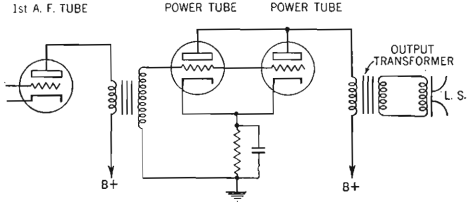


Fig. 169. Circuit showing how two power tubes are connected in parallel to handle greater power.

stage of audio-frequency amplification between the detector and power stage.

165. When may two power tubes be used in parallel? Sometimes the power required for the loudspeaker is too great for a single tube to handle. In such cases we can connect two identical power tubes in *parallel.* The grid of one tube is connected to the grid of the other, the plate to the other plate, and the cathode to the other cathode (Figure 169).

The voltage placed upon the grids of two tubes in parallel is the same as that on the grid of one tube. But because two cathodes are emitting electrons, the current set flowing in the plate circuit of the tubes is twice as large. Thus from two tubes we can get nearly twice the power output that a single tube can deliver to operate the loudspeaker. It is quite obvious that three or more tubes may be connected in parallel. It is not practical, however, to use more than two tubes for ordinary purposes.

166. What is the push-pull system for power tubes? Another method of increasing the output of the amplifier is to connect two power tubes in *push-pull*. Figure 170 shows this circuit. You will notice that the secondary winding of the input transformer is center-tapped. Each end of this winding goes to the grid of one of the power tubes. The center tap is connected to the grid-bias resistor, which in turn is connected to both cathodes.

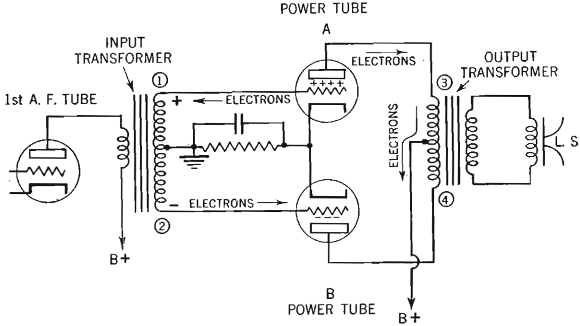


Fig. 170. Circuit showing how two power tubes are connected in push-pull.

Thus a negative bias is placed on the grids of the tubes (see §106). The primary or the output transformer also is center-tapped. Each end of that winding goes to one of the plates, while the B+ terminal is connected to the center tap. Here is how this hookup works: The fluctuating current in the plate circuit of the first audio-frequency tube sets up an alternating voltage across the secondary of the input transformer. Assume an instant when point 1 of the secondary is positive; point 2 then is negative. In this situation a positive charge is placed upon the grid of tube A and a negative charge upon the grid of tube B.

In tube A, the electrons shot out by the cathode are sped on to the plate and flow to point 3 of the primary of the output transformer. They then flow through the coils of the primary to the center tap and out to the positive post of the B supply. As the current flows through the upper half of the primary of the output transformer, a magnetic field is built up. This field, cutting across the secondary of the output transformer, sets up an electrical pressure that sends current flowing through the voice coil of the loudspeaker.

Now let us see what is happening in tube B. The negative charge on the grid cuts off the flow of electrons to the plate. Thus the plate current is reduced, and the current flowing through the lower half of the primary of the output transformer falls off. This falling-off causes the magnetic field to collapse. But a collapsing magnetic field, cutting across a conductor, sets up an electrical pressure across that conductor, just as an expanding magnetic field does. Thus a second electrical pressure is set up across the secondary of the output transformer, and it is in the same direction as the first pressure. As a result, a much greater current flows through the voice coil of the loudspeaker.

Note that while the current flowing in one tube is increasing, the current in the other tube is diminishing, and the output is equal to that of the two tubes. Also notice that we need twice the grid voltage that is needed to operate a single tube in order to operate a pair of tubes in push-pull. Power tubes connected in push-pull produce very little distortion of the signal.

167. What is the tetrode tube? It was stated, earlier in this chapter, that the triode has a low amplification factor because: (1) we cannot use a fine-mesh grid, since this causes too great a grid-to-plate capacitance and thus too much feedback. (2) The space charge within the tube wastes about 85 per cent of the charge on the plate.

To overcome these difficulties, in some tubes a second grid is placed between the original grid, now called the *control grid*, and the plate. This new grid is called the *screen grid*. The screen grid is connected to the B+ terminal, but a dropping resistor reduces the positive charge on it to a value considerably less than that on the plate. Thus, if a positive charge of 250 volts is placed on the plate, 100 volts is placed on the screen grid.

168. What is the action of the screen grid in the tetrode? This new grid acts as a screen between the plates of the capacitor

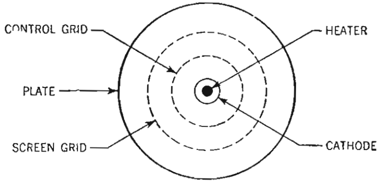


Fig. 171. Looking down on the top of screen-grid tube: the arrangement of the electrodes.

formed inside the tube by the control grid and plate, and thus reduces the internal capacitance of the tube. Thus the amount of feedback is cut down to almost zero, and the evil of oscillation

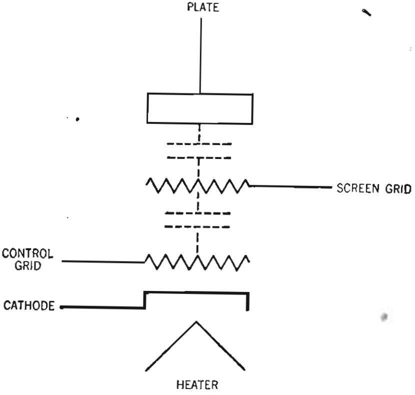


Fig. 172. Arrangement of electrodes within the screen-grid tube showing the internal capacitance between the grids and the plate.

is eliminated. So, while the 01A triode tube has a grid-to-plate capacitance of 8 $\mu\mu$fd., the type 24A screen-grid tube has a grid-to-plate capacitance of about 0.007 $\mu\mu$fd. As a result, we can now use a closely meshed control grid, and this structure gives us a much greater amplification factor.

Another result of introducing the positively charged screen grid is the dissipation of the space charge. The electron cloud which otherwise fills the inside of the tube is attracted to the screen grid. Some of the electrons hit the wires of this grid and go off to the positive post of the B supply. But most of them go through the openings and travel on to the plate, which has a higher positive charge. This electron stream gives a greater

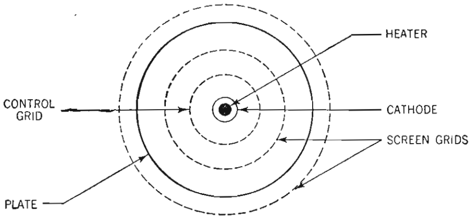


Fig. 173. Looking down on the screen-grid tube. Note the screen grid around the outside of the plate.

plate current and a much greater amplification factor for the tube, because now any new electrons emitted by the cathode need not dissipate themselves battling the repellent effect of the space charge.

We can fully appreciate the effect of the screen grid when we compare the amplification factor of 8 for a triode such as the type 01A with that of 400 for the type 24A screen-grid tube. While losses in the circuit may cut the actual gain down to 40 or 50, nevertheless you can readily see the advantage of the screen-grid tube.

169. How is the tetrode tube used? Because the screen grid forms the fourth electrode in the tube, we call this new type of tube a *tetrode*, meaning four electrodes. In the type 24A tube the control grid is connected to a cap on the top of the tube. Another screen is usually placed around the outside of the plate and is connected to the inner screen grid. This screen tends to shield the entire tube from external disturbances.

Because of the low grid-to-plate capacitance of the tetrode, there is no danger of oscillations being set up as the result of feedback. This condition makes it unnecessary to neutralize the radio-frequency and intermediate-frequency stages of amplification. Figure 174 shows the circuit of a typical radio-frequency stage using the tetrode. Note that the screen grid

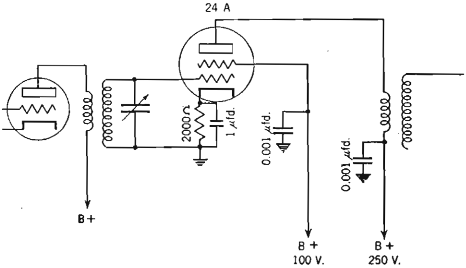


Fig. 174. Circuit of a stage of radio-frequency amplification using the 24A type of screen-grid tube.

is by-passed to ground by a 0.001-μfd. capacitor to eliminate any stray radio-frequency currents.

Since the positive charge on the screen grid dissipates the space charge on the tube, changing this positive charge will affect the space charge in the tube and thus the amplification factor. Because of this, the automatic volume-control voltage may be fed into the screen grid and thus control the amplification of the receiver. In practice, however, automatic volume control is usually maintained by means of variations of the grid bias as explained in Chapter 23.

170. What are other uses of the tetrode? The tetrode may be used as an audio-frequency amplifier, although our study of the power tube shows why the screen-grid tube is not suitable as an output tube.

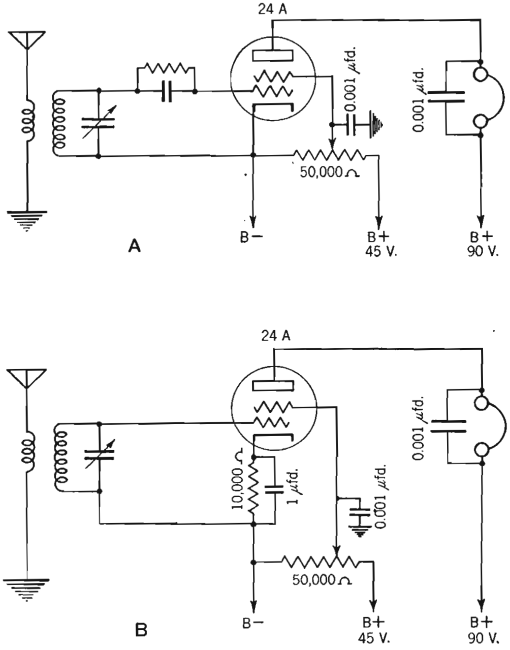


Fig. 175. (A) Circuit of the tetrode used as a grid leak-capacitor detector. (B) Circuit of the tetrode used as a grid-bias detector.

The screen-grid tube may be also used as a detector, as shown in Figure 175. Figure 175-A shows the tetrode hooked up as a grid leak–capacitor detector, while Figure 175-B shows the circuit of a grid-bias detector. The 50,000-ohm potentiometer controls the positive charge placed on the screen grid and thus acts as a volume control by varying the amplifying ability of the tube.

171. What is the variable-*mu* tube? The control grid of the screen-grid tube has a very fine mesh. In consequence, as the electrons stream through the spaces between the wires, they are forced to pass quite close to those wires. A very small charge upon the wires of the grid, then, has a great effect on the electron stream flowing to the plate of the tube. The screen-grid tube is ideal for the purpose of delivering a large voltage from a small one.

The very construction that makes this tube so suitable for handling small voltages prevents it from handling high voltages. It does not require a great negative charge on the control grid to stop entirely the flow of electrons to the plate. Thus, if a large alternating voltage should be fed into the grid, the positive half of the cycle would go through well enough, but most of the negative half cycle would be blocked out, and detection or rectification would result.

If the screen-grid tube is used as a radio-frequency amplifier in a set which is located near a powerful station, the strong signal from that station will cause the automatic volume-control system to send a large negative bias to the control grid of the tetrode. This bias plus the negative half cycle of the incoming signal will cut off the flow of electrons to the plate, and the radio-frequency tube will act as a grid-bias detector (see §69). This phenomenon causes a form of distortion called *cross modulation*.

This interference does not occur if the wires of the control grid are widely spaced. Charges on the grid have little effect on the electrons as they stream through the wide open spaces. But, of course, the amplification factor of the tube is much less.

The ideal condition, then, would be to hook up one tube with a close-meshed control grid and one with an open-meshed control grid in such a way that weak signals would travel through the close-meshed tube where they would be greatly amplified, and the strong signals, that did not need so much amplification, would travel through the open-meshed tube, where they could not cause distortion.

This ideal was achieved in one tube by constructing a control grid that is close-meshed at the ends and open-meshed in the center. When a weak signal comes in, the automatic volume control sends little negative bias to the control grid of the radio-frequency tube, and this tube then acts as a conventional screen-grid amplifier. When a loud signal comes in, the negative bias of the tube is increased. This increased bias means that the electrons cannot get through the fine mesh at both ends of the control grid. But in the center, where the mesh is open, the electrons can get through, and the tube now acts as a low-*mu* amplifier.

Such a tube is called *a variable-mu tube* or *a supercontrol radio-frequency amplifier.* One example of such a tube is the type 35.

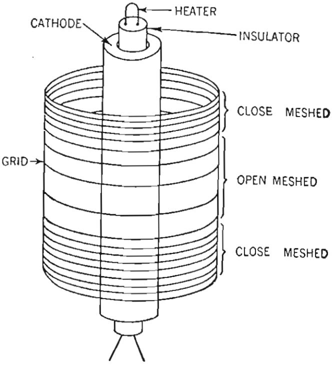


Fig. 176. Diagram showing the construction of the control grid of a variable-*mu* tube.

172. What is the radio-frequency pentode tube? Although the screen-grid tube makes an excellent radio-frequency amplifier, it suffers from one defect. Because the space charge has been overcome and also because of the added pull of the positive charge on the screen grid, electrons leaving the cathode attain a speed as great as 20,000 miles per second and strike the plate with great force.

The force of impact is great enough to knock some electrons off the plate. This phenomenon is called *secondary emission.* These electrons fly about in space and either are pulled back by the positive charge of the plate or else are attracted to the positively charged screen grid nearby. The electrons lost to the screen grid reduce the supply left for the plate circuit of the tube, and amplification falls off.

To remedy this defect a third grid is placed between the screen grid and the plate. This new grid is connected to the filament or cathode of the tube. Since it is connected to the cathode, this new grid has the same charge on it; therefore it will have little effect upon electrons passing through it on their way to the plate. But as compared to the positive charge on the plate, this new grid is negative. Therefore any electrons knocked off from the plate by secondary emission will be turned back by this grid to the

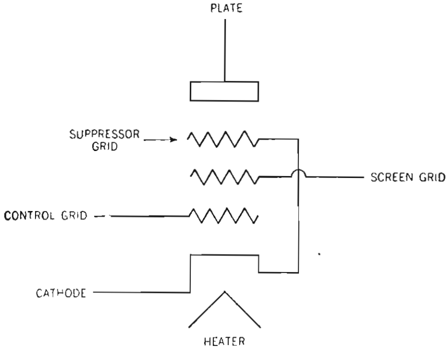


Fig. 177. Arrangement of electrodes in the pentode tube.

plate where they belong. Because of this fact, the new grid is called the *suppressor grid.*

Because they have five electrodes (cathode, three grids, and a plate), tubes of this type are called *pentodes.* They make excellent radio-frequency and intermediate-frequency amplifiers because they have the sensitivity and high amplification factor of the screen-grid tubes plus the ability to suppress secondary emission. They are also known as *radio-frequency pentodes.*

The 34 tube is of this type. The suppressor grid is connected internally to the center of the filament. Sometimes the suppressor grid is led out to one of the base connections. We then must connect it to the cathode externally. The type 58 tube is an example.

173. What is the power pentode tube? Like the screen-grid tube, the radio-frequency pentode is not suited for use as a power tube. Let us see if we can design a good power tube. First of all, it must be capable of handling a good deal of power, hence the cathode must be a very strong emitter of electrons. These electrons must find their way to the plate quite readily, hence we must have an open-meshed grid. The plate must be large and rugged to withstand the bombardment of electrons.

So far we have described our old friend, the triode power tube. Now, let us see if we can step up its amplification factor. We cannot make the grid more fine-meshed because doing so would cut down the flow of needed electrons and thus reduce our power. But we can eliminate the space charge that uses up about 85 per cent of the positive charge on the plate. So between the control grid and the plate we place a positively charged screen grid and the amplification factor shoots up.

But not so fast. We are dealing here with heavy streams of electrons. Without the restraining effect of the space charge, the electrons hit the plate with tremendous impact, knocking off clouds of electrons. A large number of these electrons are attracted to the positively charged screen grid, and down goes our amplification factor.

Well, let us put in a suppressor grid between the screen grid and the plate. Connect this suppressor grid to the cathode, and the electrons knocked off by the impact are forced back to the plate and up goes the amplification factor.

This tube is called a *power pentode*, and one example is the type 47. Compare its amplification factor of 150 with that of the triode type 45, whose amplification factor is 3.5. Because a small grid voltage can control a large amount of power in its plate circuit, the power pentode may work directly from the detector without any need for an intervening stage of audio-frequency amplification.

Like the triode power tube, the power pentode can be connected in parallel and in push-pull circuits to get greater power output. Although they are both pentodes, the radio-frequency pentode and the power pentode are not interchangeable. In reality, they are tubes of two different types.

174. How does the beam power tube work? Although it has only four electrodes, the *beam power tube* is in reality a variation of the power pentode. Here is how it works:

Electrons shot off from the cathode pass between the wires of the control grid and the positively charged screen grid. This screen grid has a higher positive charge than the plate. This charge acts as a brake, slowing down the electrons in their flight to the plate. Deflector plates, connected to the cathode and

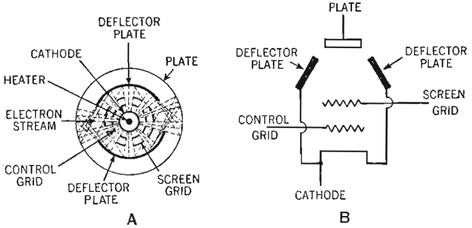


Fig. 178. (A) Looking down on beam power tube showing electron streams threading their ways through the grids. (B) Arrangement of electrodes in the beam power tube.

therefore having the same charge, concentrate these electrons into a cloud or beam, moving slowly towards the plate. Any electrons knocked off by secondary emission are repelled back to the plate by this beam of electrons. Thus it can be seen that the space charge created by the beam of electrons acts just as the suppressor grid acts to overcome the effects of secondary emissions. Examine the diagram in Figure 178.

Another innovation of the beam power tube is the special construction of the grids. In other types of tubes the control grid and screen grid appear as shown in Figure 179-A. Note that a considerable portion of the electrons hit the screen grid and thus are lost to the plate. If a meter were connected in the screen-grid circuit, it would show a considerable flow of electrons from the screen grid to the B+ terminal.

Figure 179-B shows the construction of the beam power tube. Note that the wires of the control grid shade the wires of the

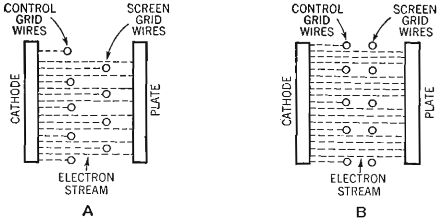


Fig. 179. (A) Arrangement of control grid and screen grid in most tubes. Note that comparatively few electrons get through to the plate. (B) Arrangement of control grid and screen grid in beam power tube. Note that more electrons get through to the plate.

screen grid in such a way that very few of the electrons hit the screen grid. A meter connected in the screen-grid circuit of a beam power tube accordingly would show a very small flow of current.

More electrons therefore strike the plate of a beam power tube, and the efficiency of the tube is raised. Figure 180 shows how the 6L6 tube, a typical beam power tube, is connected in a circuit. Note that the positive charge on the plate is less than that upon the screen grid, since some of the electrical pressure is lost while forcing its way through the primary of the output transformer.

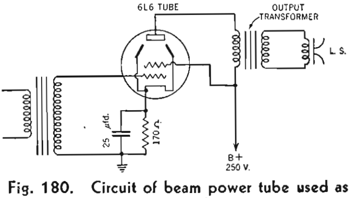


Fig. 180. Circuit of beam power tube used as a power tube.

Some idea of the efficiency of such a beam power tube as the 6L6 can be gained by comparing it with a triode such as the type 45. With a charge of 50 volts applied to the grid, the type 45 tube delivers 1.6 watts of electrical power to the loudspeaker. The 6L6 tube delivers 6.5 watts of electrical power and needs only 14 volts on the grid.

As in the case of other power tubes, the beam power tube can be connected in parallel and in push-pull to deliver greater power.

175. What are multielectrode tubes? Tubes containing more than five electrodes are generally called *multielectrode tubes* Although they may appear quite complicated at first glance, their operation is quite simple if we keep in mind the basic prin-

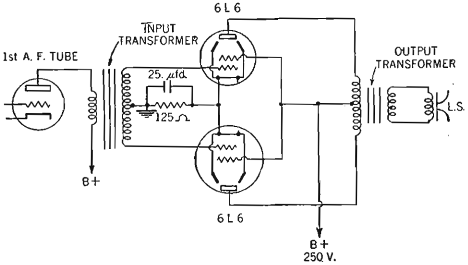


Fig. 181. Circuit showing how two 6L6 tubes are hooked up in push-pull.

ciple of the vacuum tube, that is, that electrons are shot out by the heated cathode and find their way to the positively charged plate.

In their travels the electrons pass between the wires or meshes of a number of grids. These grids either attract or repel the electrons, either speed them up or retard them. The effects that these grids exert upon the traveling electrons depend upon the charges placed upon the grids. A positively charged grid will attract the electrons; a negatively charged grid will repel them. A varying charge upon the grid will produce a varying effect on the electrons. And that is all there is to it.

176. What is the pentagrid converter tube? Let us take a look at the type 6A8 tube. This tube has a cathode (and separate heater), a plate, and five grids, as shown in Figure 182. The grids are numbered from 1 to 5, counting from the cathode toward the plate. This tube is often used as both the mixer (first detector) tube and oscillator tube in a superheterodyne receiver (see Chapter 25). When used for this purpose it is called a *pentagrid* (*five grids*) *converter*. Here is how it works: First consider the cathode and grids 1 and 2 of the tube. If we place a positive charge upon grid 2 and call it the anode or plate, and call grid 1 the control grid, you can readily recognize our old friend the triode. Now let us hook up this triode as an oscillator as described in Chapter 25.

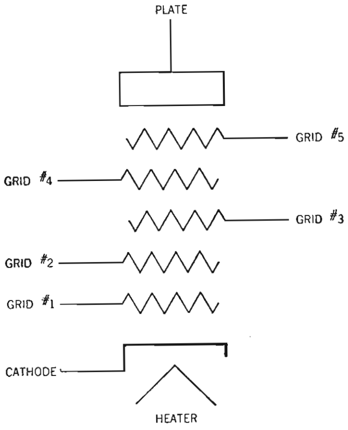


Fig. 182. Diagram showing the arrangement of electrodes in the pentagrid converter tube.

The electrons are shot out from the cathode in a steady stream. In the oscillator circuit, however, the electrons are dashing back and forth at a tremendous rate, at a frequency of 1175 kc. per second if we use the example in Chapter 25. Grid 1 will therefore have a charge on it that will vary 1,175,000 times per second. This variation will cause the steady electron stream from the cathode to vary or fluctuate in step. This fluctuating stream will be attracted to the positively charged grid 2, but since this is a grid and not a solid plate, the electrons will shoot through the meshes on their way toward the real plate of the tube. Thus we may really consider the combination of cathode, grid 1, and grid 2 as a composite cathode, sending out a stream of electrons that are not steady, but fluctuate at the rate indicated by the oscillator, that is. 1175 kc. per second.

We may now consider the entire tube as a screen-grid tube. The cathode and grids 1 and 2 are the composite cathode, grid 4 is the control grid, and grids 3 and 5 are tied together and connected to the B+ terminal to furnish the screen grid and to shield grid 4 from the oscillator circuit.

The incoming signal, the modulated radio-frequency voltage (1000 kc. in our example), is fed into the control grid 4. Thus a

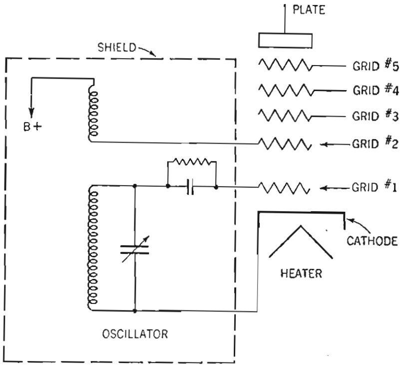


Fig. 183. Circuit showing how cathode, grid 1, and grid 2 of the pentagrid converter are used as a triode for the oscillator section of the superheterodyne receiver.

charge that fluctuates 1,000,000 times per second is placed on this grid 4. Streaming through this grid is a flow of electrons that already are fluctuating at the rate of 1175 kc. per second. Beats result, and out of grid 4 comes a stream of electrons that fluctuate at the rate of 1175 kc. minus 1000 kc. per second, or 175 kc. per second—the exact frequency to which the intermediate-frequency transformers are tuned.

Figure 184 shows the complete circuit for the pentagrid converter.

177. What is electronic coupling? You will recall that when we discussed coupling the oscillator to the mixing circuit in §151, we said that in addition to the inductive and capacity methods there was a third method whereby the two circuits were coupled through the electrodes within the tube. This third method is sometimes called *electronic coupling* for obvious reasons.

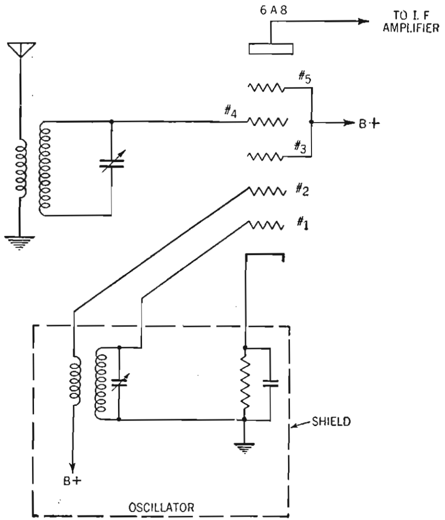


Fig. 184. Complete circuit showing the pentagrid converter as the first detector, mixer, and oscillator tube in the superheterodyne receiver.

178. What are multiunit tubes? It is quite possible to place two or more complete tubes in one envelope. Such tubes are called *multiunit tubes*. All the tubes in the envelope may even share the same cathode, but they differ from the multielectrode tube in one important way. Whereas in the multielectrode tube there is one stream of electrons that is acted on by all the electrodes, in the multiunit tube the stream of electrons flowing from the

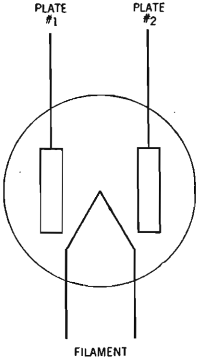


Fig. 185. Diagram of a duo-diode tube. The 80 type is an example.

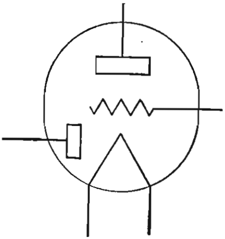


Fig. 186. The 1H5-G tube. One diode—one triode.

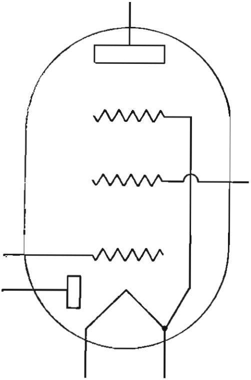


Fig. 187. The 1S5 tube. One diode—one pentode.

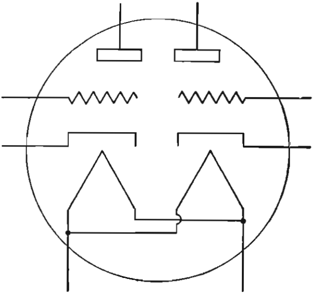


Fig. 188. The 6C8-G tube (two triodes).

cathode divides into two or more parts, and each part flows through its own unit of electrodes. These tubes are constructed so that the electron stream of one unit is not affected by the electrodes making up any other unit, but proceeds to flow from the cathode through its various grids (if any) to its own plate.

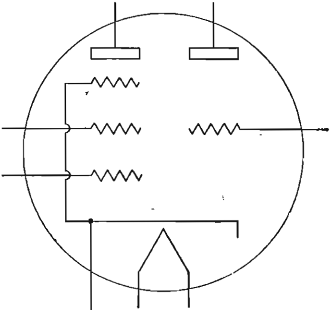


Fig. 189. The 6F7 tube (one pentode—one triode).

One of the simplest of these multiunit tubes is the type 80 shown in Figure 185, which is used as a full-wave rectifier. Here the electrons shot out by the filament follow two paths, one to plate 1, the other to plate 2. Figure 186 shows the diagram for the 1H5-G tube, which has a diode and triode in one envelope.

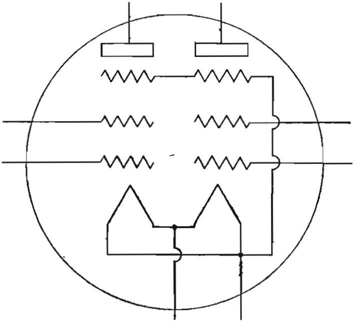


Fig. 190. The 1E7-G tube (two pentodes).

Figure 187 shows a diode and a pentode in the same envelope. This tube is of type 1S5. In Figure 188 we see the 6C8-G tube, which has two triodes in one envelope.

In Figure 189 we see the type 6F7 tube, which has one triode and one pentode in the same envelope. The type 1E7-G tube shown in Figure 190 has two pentodes enclosed in the same envelope.

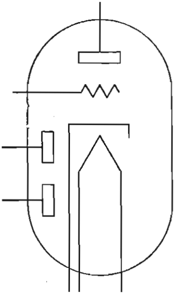


Fig. 191. The 2A6 tube (two diodes—one triode).

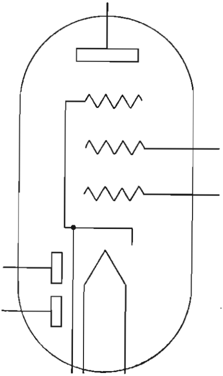


Fig. 192. The 2B7 tube (two diodes—one pentode).

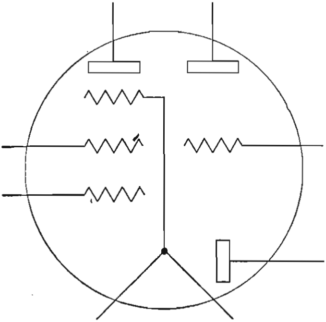


Fig. 193. The 1D8-GT tube (one diode—one triode—one pentode).

The electron stream may be divided into three parts and thus make possible three distinct tubes in one envelope. The 2A6 tube is an example, having two diodes and a triode (Figure 191). Another such tube is the 2B7, which has two diodes and one pentode in the same envelope (Figure 192).

The 1D8-GT tube (Figure 193) contains a diode, a triode, and a pentode in one envelope.

Of course, many other combinations can be designed, and will. But regardless of how complex they seem to be, the basic principle is a simple one. A heated cathode emits a stream of electrons which threads its way through intervening grids to a positively charged plate.

SUMMARY

1. The fundamental principle operating in all vacuum tubes is that electrons emitted by a filament or cathode find their way to a positively charged plate.

2. Tubes with only a filament and plate are diodes; tubes with filament, grid, and plate only are triodes.

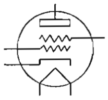
3. Tubes having more than five elements, called multielectrode tubes, are made by adding additional grids with various charges and mesh design.

4. When two or more complete tubes are enclosed in one envelope, the tube is called a multiunit tube.

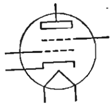
5. In multielectrode tubes only one stream of electrons passes, while in multiunit tubes there may be several different streams of electrons, each one on its way to its own plate.

6. Students of radio must learn the numbers and uses of important commercial tubes.

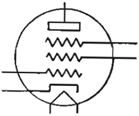
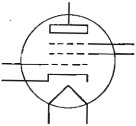
SYMBOLS

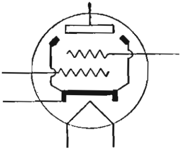
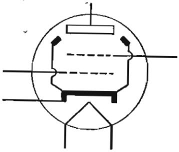


or



Tetrode.

 or  Pentode.

 or  Beam power tube.

CHECK-UP

Each statement below is either true or false. If a statement is false, one or more, but not necessarily all, of the *italicized parts* make it false. If a statement is true, encircle the T and do nothing else with it. If a statement is false in any part, first encircle the F; then correct it by substituting the right word or phrase for the incorrect word or phrase in italics. Write your correction in the blank space at the end of the statement. The samples below show you how: (Answers are on page 305.)

SAMPLES:

(T) F Radio-frequency energy *travels in waves.* ....

T (F) *Direct* currents flow in cycles. **Alternating.**

T F **1.** The diode may be used as either a *rectifier* or a *detector*, but cannot be used as an *amplifier* since it lacks a grid. ....

T F **2.** The amplifying quality of a tube is called its *space charge.* ....

T F **3.** The nearer the grid is to the cathode, the *less* the amplification factor of the tube. ....

T F **4.** The greater the spaces between the grid wires, the *greater* the amplification factor of the tube. ....

T F **5.** The space charge in a tube *increases* the amplifying ability of the tube. ....

T F 6. *Power tubes* generally have larger plates and filaments than do ordinary voltage amplifiers. ....

T F 7. Because the grids of power tubes have a *more open* mesh the amplification factor is *increased.* ....

....

T F 8. To get greater power output, two power tubes may be connected in *parallel* or in *push-pull.* ....

....

T F 9. The screen grid, found in *24 A* and *35* types of tubes, serves to reduce *plate-to-plate* capacitance.

....

T F 10. Another advantage of the *screen grid* is that it reduces the *space charge.* ....

T F 11. A variable-*mu* tube has a grid with *close* spacing to eliminate the evil of *secondary emission.* ....

....

T F 12. Tetrodes suffer from a defect known as *cross modulation* caused by the bombardment of the *grid* by electrons from the cathode. To remedy this defect a suppressor grid is inserted between the *filament* and the plate. The grid is connected to the *plate.* ....

T F 13. The beam power tube is a variation of the *power pentode.* Deflector plates form an electron *cloud or beam* which acts like a *suppressor grid.* ....

....

T F 14. The pentagrid converter is a tube which combines the actions of the *mixer tube* and *oscillator tube* in a superheterodyne receiver. ....

T F 15. The multiunit tube is really a number of tubes in one envelope, each tube or unit doing its work *independently* of the other tubes or units. ....

TEST 3—CHAPTERS 23-26

In the blank spaces write the words, phrases, or numbers needed to complete the statements correctly. (Answers are on page 305.)

1. In battery-operated receiving sets we control the volume by varying the .... from the filaments of the radio tubes.

2. A common method for controlling volume in the electrified receiver is to control the input to the grid of one of the audio-frequency amplifier tubes by means of a ....

3. Automatic volume control is effected by using a portion of the signal current to vary the (*a*) .... on the radio-frequency amplifier tubes. The louder the signal the (*b*) .... the grid bias applied to the radio-frequency amplifier tubes and the (*c*) .... the amplification.

4. Tones are said to be ...., ..., or ...., depending upon the proportions of high and low audio frequencies present.

5. A normal tone can be made high-pitched by removing some of the (*a*) .... audio frequencies. We call such a tone a (*b*) ....

6. (*a*) .... are used to by-pass high audio-frequency currents and (*b*) .... are used to by-pass low audio-frequency currents.

7. In the superheterodyne receiver, the (*a*) .... is mixed with the (*b*) .... from the local oscillator to produce the (*c*) .... fed into the intermediate-frequency amplifiers.

8. The chief advantage of the superheterodyne receiver is the fact that the intermediate-frequency transformers are tuned to a (*a*) .... frequency. This improves the (*b*) .... and (*c*) .... of the receiver.

9. The function of the stage of radio-frequency amplification before the first detector in the superheterodyne receiver is to eliminate the evil of ....

10. To obtain greater power output, power tubes may be connected in .... or .... circuits.

11. The higher amplification factor of the screen-grid tube results from the fact that the screen grid dissipates the ....

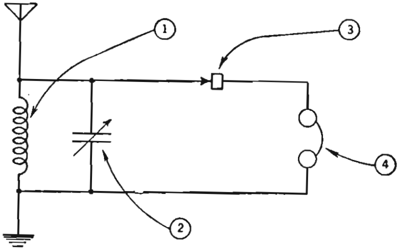
12. The suppressor grid of the pentode is connected to the .... of the tube.

13. The multielectrode tube is a single tube having a large number of ....

14. The multiunit tube consists of .... in a single envelope.

Final Test A

Identify the parts indicated by numbers in the diagram, and state their functions. (Write in the numbered blank spaces below.)



1. ______________________________

2. ______________________________

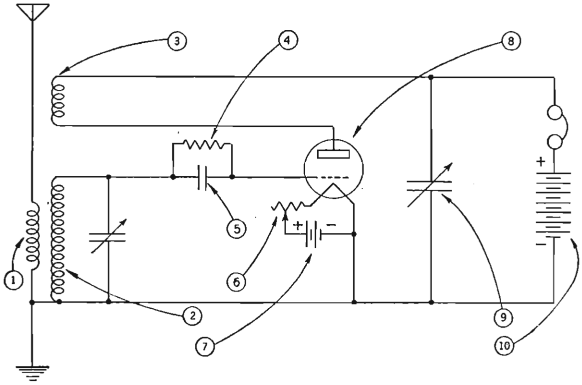
3. ______________________________

4. ______________________________

Answers are on page 305.

Final Test B

Identify the numbered parts of the diagram. (Write in the numbered spaces below.)



1. ....

2. ....

3. ....

4. ....

5. ....

6. ....

7. ....

8. ....

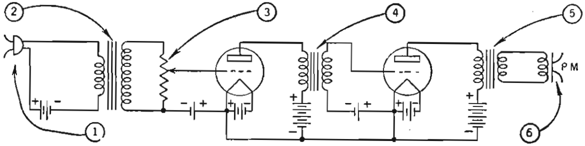
9. ....

10. ....

Answers are on page 305.

Final Test C

Identify the numbered parts. (Write in the numbered spaces below.)



1. ....

2. ....

3. ....

4. ....

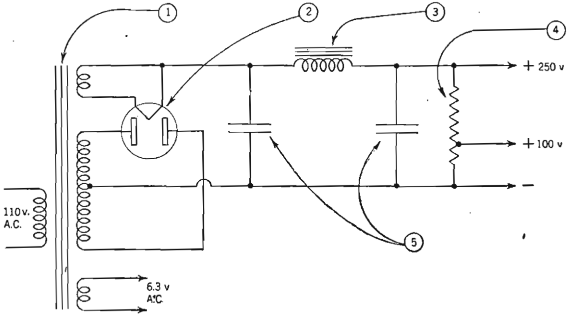
5. ....

6. ....

Answers are on page 306.

Final Test D

Identify the numbered parts. (Write in the numbered spaces below.)



1. ....

2. ....

3. ....

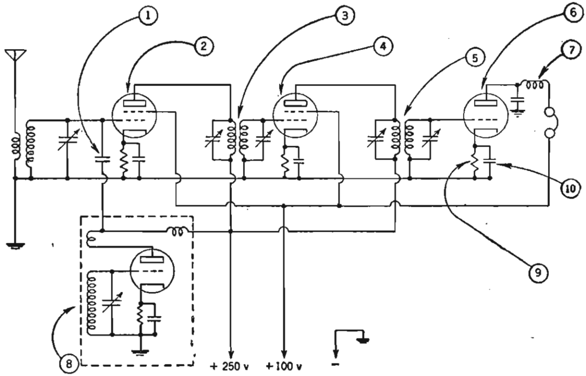
4. ....

5. ....

Answers are on page 306.

Final Test E

Identify the numbered parts. (Write in the numbered spaces below.)



1. ....

2. ....

3. ....

4. ....

5. ....

6. ....

7. ....

8. ....

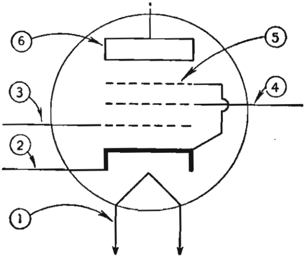
9. ....

10. ....

Answers are on page 306.

Final Test F

Identify the numbered parts. (Write in the numbered spaces below.)



1. ....

2. ....

3. ....

4. ....

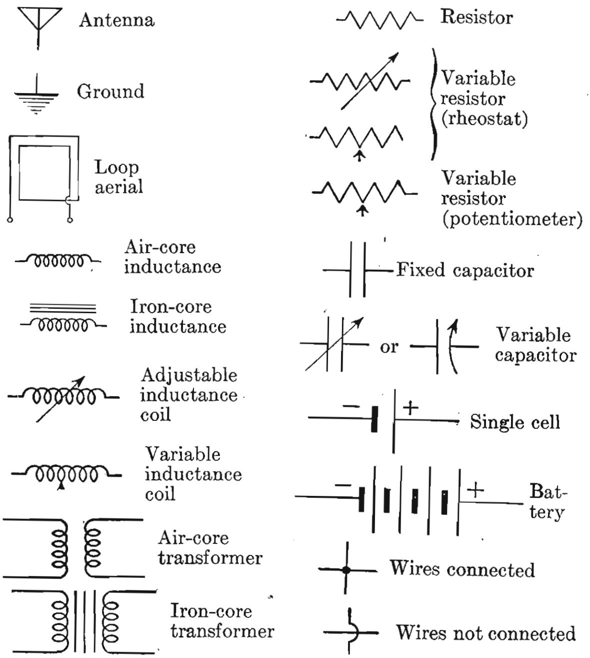
5. ....

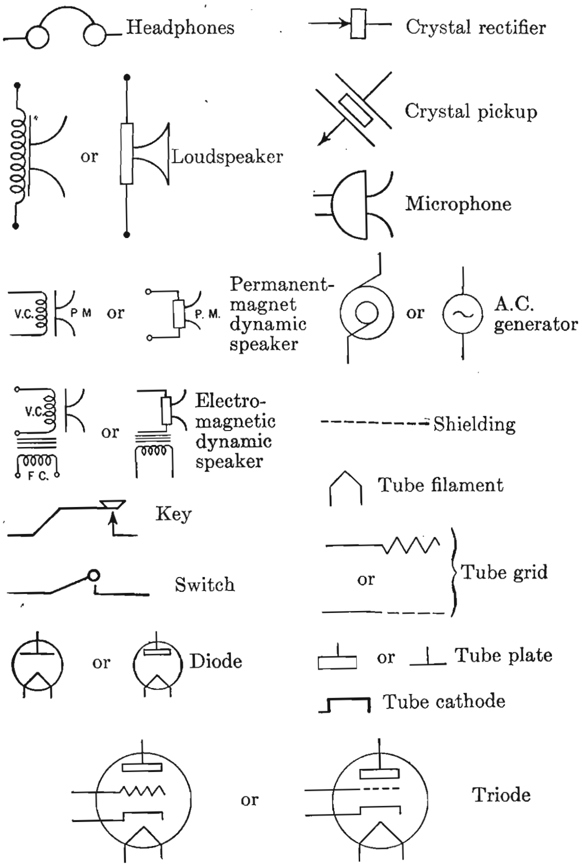
6. ....

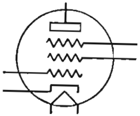
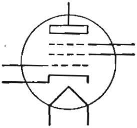
Answers are on page 306.

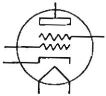
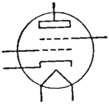
Appendix

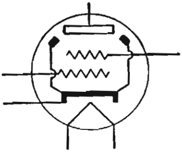
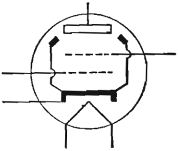
SCHEMATIC SYMBOLS USED IN CIRCUIT DIAGRAMS




Headphones
Crystal rectifier
Crystal pickup
or
Loudspeaker
Microphone
V.C.
P M
or
P. M.
Permanent-magnet dynamic speaker
or
A.C. generator
V.C.
F C.
or
Electro-magnetic dynamic speaker
Shielding
Tube filament
Key
or
Tube grid
Switch
or
Diode
or
Tube plate
Tube cathode
or
Triode


or

Pentode


or

Tetrode


or

Beam power tube

ABBREVIATIONS AND SYMBOLS

Alternating current	A.C.
Ampere	a., amp.
Amplitude modulation	A.M.
Antenna	Ant.
Audio frequency	A.F.
Automatic volume control	A.V.C.
Beat frequency	B.F.
Capacitance	C
Centimeter	cm.
Continuous waves	C.W.
Current	I
Cycles per second	c.p.s.
Direct current	D.C.
Electromotive force	E.M.F.
Farad	fd.
Frequency	f
Ground	Gnd.
Henry	h.
Inductance	L
Intermediate frequency	I.F.
Kilocycles	kc.
Kilowatt	kw.
Mega (million)	M or m
Megacycles	Mc. or mc.
Megohm	Meg.
Meter (measure of length)	m.
Micro $\frac{1}{1,000,000}$	μ
Microampere	μa. or μamp.
Microfarad	μfd.
Microhenry	μh.
Micromicro $\frac{1}{1,000,000,000,000}$	$\mu\mu$
Micromicrofarad	$\mu\mu$fd.
Microvolt	μv.
Microwatt	μw.
Milli $\frac{1}{1,000}$	m
Milliampere	ma.
Millihenry	mh.

Millivolt	mv.	Radio frequency	R.F.
Milliwatt	mw.	Resistance	*R*
Modulated continuous waves	M.C.W.	Tuned radio frequency	T.R.F.
Ohm	Ω	Volt	v.
Power	*P*	Watt	w.

ELECTRICAL UNITS

Capacitance	farad	Resistance	ohm
Current	ampere	Voltage (potential difference, E.M.F.)	volt
Frequency	cycles per second	Wave length	meter
Inductance	henry		

R.M.A. COLOR CODE

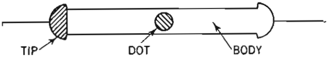
To identify the various connections and values of standard radio components, the Radio Manufacturers Association (R.M.A.) has adopted a color code.

R.M.A. Color Code for Resistors

Numbers are represented by the following colors:

0—black	2—red	4—yellow	6—blue	8—gray
1—brown	3—orange	5—green	7—violet	9—white

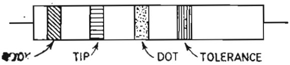
Three colors are used on each resistor to identify its value. The *body* color represents the first figure of the resistance value. One *end* or *tip* is colored to represent the second figure. A colored *band* or *dot* near the center of the resistor gives the number of zeros following the first two figures.



Here is an example. Assume a resistor whose body is yellow, tip blue, and dot red. We thus get yellow, blue, red—which, translated into the code, stands for

4—6—00 or 4600 ohms.

Some resistors are marked with three bands of color. The band nearest the end is the body color, the next band the tip color and the third band is the dot color.



If a fourth band appears, it is the *tolerance* indicator. This indicates the accuracy of the markings. Thus a resistor of 10 per cent tolerance is marked accurately to within ± 10 per cent of its true value. It is seldom that a tolerance of less than 10 per cent is needed for radio work and most resistors used are in this category.

The color code for the tolerance band is as follows:

Per cent	*Color*	*Per cent*	*Color*
1	Brown	6	Blue
2	Red	7	Violet
3	Orange	8	Gray
4	Yellow	9	White
5	Green or gold	10	Silver

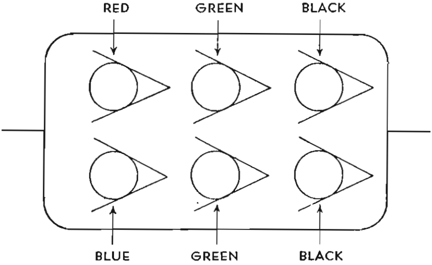
No color usually indicates a tolerance of 10 %.

R.M.A. Color Code for Capacitors

Small mica capacitors may be marked with six color dots, with an arrow or other symbol indicating the sequence of numbers. The color code is the same as for resistors except that the readings are in micromicrofarads instead of ohms.

The first three dots (in proper sequence in the upper horizontal row) indicate the first three digits of the capacitance, and the lower right-hand dot indicates the number of zeros following the third digit. The middle dot in the lower row indicates the tolerance in per cent and the left-hand lower dot, if colored, shows the voltage rating in hundreds of volts. No color for the tolerance dot indicates a tolerance of 20 %.

Thus, if the capacitor were marked as follows:



the value of this capacitor would be:

RED	GREEN	BLACK	BLACK
2	5	0	None

or

250 $\mu\mu$fd. (0.00025 μfd.)
Tolerance—Green or 5 per cent.
Voltage rating—Blue or 600 volts.

R.M.A. Color Code for Power Transformers

To identify the various leads the following color code has been adopted:

1. Primary leads—black. If tapped: common—black; tap—black and yellow striped; finish—black and red striped.
2. High-voltage plate winding—red. Center tap—red and yellow striped.
3. Rectifier filament winding—yellow. Center tap—yellow and blue striped.
4. Filament winding No. 1—green. Center tap—green and yellow striped.
5. Filament winding No. 2—brown. Center tap—brown and yellow striped.
6. Filament winding No. 3—slate. Center tap—slate and yellow striped.

R.M.A. Color Code for Audio-frequency Transformers

Blue—Plate (finish) lead of the primary.
Red—B+ lead (this applies whether the primary is plain or center tapped).
Brown—Plate (start) lead on center-tapped primaries. (Blue may be used for this lead if polarity is not important.)
Green—Grid (finish) lead of secondary.
Black—Grid return (this applies whether the secondary is plain or center tapped).
Yellow—Grid (start) lead on center-tapped secondaries. (Green may be used for this lead if polarity is not important.)

Note: These markings apply also to line-to-grid, and tube-to-line transformers.

R.M.A. Color Code for Intermediate-frequency Transformers

Blue—Plate lead.
Red—B+ lead.
Green—Grid (or diode) lead.
Black—Grid (or diode) return.

Note: If the secondary of the intermediate-frequency transformer is center-tapped, the second diode plate lead is green and black striped, and black is used for the center-tap lead.

R.M.A. Color Code for Loudspeaker Voice Coils

Green—finish Black—start

R.M.A. Color Code for Loudspeaker Field Coils

Black and red striped—start
Yellow and red striped—finish
Slate and red striped—tap (if any)

WAVE-LENGTH–FREQUENCY CONVERSIONS

$$\text{wave length (in meters)} = \frac{300{,}000{,}000}{\text{frequency (in cycles per second)}}$$

Station	Location	Frequency (cycles per second)	Wave length (meters)
WSYR	Syracuse	570,000	526
WEAF	New York	660,000	454.3
KPO	San Francisco	680,000	440.9
WGN	Chicago	720,000	416.4
WJR	Detroit	760,000	394.5
WCCO	Minneapolis	830,000	361.2
WWL	New Orleans	870,000	344.6
KHJ	Los Angeles	930,000	322.4
WAAT	Jersey City	970,000	309.1
KJR	Seattle	1,000,000	299.8
WHO	Des Moines	1,040,000	288.3
WBAL	Baltimore	1,090,000	275.1
KSL	Salt Lake City	1,160,000	258.5
WOAI	San Antonio	1,200,000	249.9
WLAC	Nashville	1,510,000	199.1

Velocity of a radio wave = 300,000,000 meters per second

The Resonant Wave Length

wave length (in meters) = $1885 \sqrt{L \times C}$
L is in microhenries; C is in microfarads.

INTERNATIONAL MORSE CODE TABLE

A ·—	J ·———	S ···
B —···	K —·—	T —
C —·—·	L ·—··	U ··—
D —··	M ——	V ···—
E ·	N —·	W ·——
F ··—·	O ———	X —··—
G ——·	P ·——·	Y —·——
H ····	Q ——·—	Z ——··
I ··	R ·—·	

1 ·————	6 —····
2 ··———	7 ——···
3 ···——	8 ———··
4 ····—	9 ————·
5 ·····	0 —————

Period ·—·—·—	Wait ·—···
Interrogation ··——··	End of message ·—·—·
Break —···—	End of transmission ···—·—

HOW TO SOLDER

There are three essentials to successful soldering: cleanliness, flux, and heat.

1. *Cleanliness.* Be sure that the surfaces to be soldered are perfectly clean. Scrape the surfaces with a knife or rub with sandpaper or steel wool wherever possible.

2. *Flux.* Use a rosin flux. An acid flux may corrode the wires. Use flux sparingly, enough to flow thinly over the surfaces, not to drown them. After soldering, wipe off any excess flux.

3. *Heat.* Heat the surfaces to be soldered until the solder flows over them. If possible, keep the hot iron on the joint even after the solder has flowed so as to be sure there is enough heat. For ordinary radio work a 65- to 75-watt soldering iron is sufficient. Greater soldered surfaces require greater heat.

4. Keep the soldering iron clean by removing any oxide that may form on it. Tin the iron by scraping it clean, dipping the point into the flux and then applying solder to the tip.

PRACTICAL DATA

1. Make connections as short as possible.
2. Shield as many grid leads as you can.
3. The rotor of a variable capacitor is usually grounded to eliminate body capacitance.
4. Pushback wire will be found convenient for wiring.
5. In electrolytic capacitors, the black wire is usually the negative wire, and the red wire usually the positive wire.
6. For shielding purposes, in using paper capacitors, the end which is marked by a black band is usually the grounded or negative end.
7. To calculate a line-cord resistance:

$$R \text{ (ohms)} = \frac{110 - \text{sum of all the filament voltages of the tubes in series}}{\text{current through the tube filaments}}$$

GLOSSARY

A battery: The battery used to heat the tube's filament; also known as the **filament battery.**

A-battery eliminator: A device used to serve the purpose of the A battery by supplying the current needed to heat the filament of the tube from the house mains.

A.C.-D.C. power supply: A battery eliminator that operates from 110-volt alternating or direct current.

Aerial or antenna: An elevated conductor, usually of copper, insulated from its supports and the ground and connected to the receiving set by the lead-in wire.

Aerial-ground system: The wire system which "picks up" radio waves and across which the radio wave produces an electrical pressure.

Aerial trimmer: A small variable capacitor in the aerial circuit used to adjust the length of the aerial electrically.

Alignment: The process of adjusting the tuned circuits of a tuned radio-frequency receiver so that all of them have the same natural frequency. In the superheterodyne receiver, it is the adjustment of the tuned circuits so that they bear the proper relationship to each other—the frequency difference between the incoming signal and the output of the local oscillator should be equal to the frequency of the intermediate-frequency transformers.

Alternating current (A.C.): An electric current in which the electrons periodically reverse their direction of flow.

Amplification factor (*mu*)**:** The ratio between a change in the grid voltage and a corresponding change in plate voltage needed to bring the plate current back to its original value.

Amplification stage: The tube and its accompanying electrical devices serving as an amplifier.

Amplitude: In a graph picturing the flow of alternating current, the amplitude is the maximum distance from the curve to the line of no current flow.

Amplitude modulation: The act of varying the amplitudes of a carrier wave by means of a current of lower frequency or by a fluctuating direct current.

Antenna coupler: An air-core transformer used to couple the energy from the aerial-ground system to the tuning circuit.

Audio frequency (A.F.): A frequency in the range between 30 and 15,000 cycles per second.

Audio-frequency amplifier: A circuit to amplify the electric currents flowing out of the detector, thereby enabling us to use a loudspeaker.

Audio-frequency transformer: An iron-core transformer used to transfer electrical energy at audio frequencies from one tube to another.

Automatic volume control (A.V.C.): An automatic control of volume in the radio receiver which operates by making the receiver more sensitive to weak radio signals and less sensitive to powerful radio signals.

Band width: The range of frequencies of the radio wave sent out by a transmitting station.

Bass tone: The tone resulting when low frequencies are predominant. Also called *low-pitched tone.*

B battery: The battery used to place a positive charge on the plate of the tube. Also known as the **plate battery.**

B-battery eliminator: A device used to eliminate the need for B batteries by supplying plate voltage from the house mains.

Beam power tube: A pentode wherein the suppressor grid action is accomplished by a slow-moving beam of electrons.

Beats: The result of combining two waves of similar nature but of different frequencies. Thus we must combine two sound waves or two alternating currents of different frequencies. The result, in the case of the sound waves, will be a new sound wave whose amplitude variations occur at a frequency equal to either the difference between the two frequencies or the sum of the two frequencies. In the case of the alternating currents, the amplitude variations of the resulting current will occur in the same manner.

Broad tuning: The simultaneous reception of several stations in a radio receiver.

By-pass capacitor: A fixed capacitor that shunts to the ground any unwanted radio-frequency currents, thereby preventing distortion of the signal. A fixed capacitor placed across the cathode-bias resistor which serves to smooth out the current variations in that resistor and thereby supply the grid with a constant negative charge.

Capacitive coupling: A method of coupling electrical energy from one circuit to another through a capacitor.

Capacitor: Two sets of metal plates separated by an insulator or dielectric.

Carrier wave: A continuous wave at radio frequency (very high frequency).

Cathode: A metal sleeve surrounding the filament in a tube and coated with chemicals that shoot off electrons when heated by the filament.

Cathode-bias resistor: A resistor between the B— terminal and the cathode of the tube, which gives the grid a negative bias.

Cat whisker: The thin wire with which we hunt for a sensitive spot on the crystal.

C battery: The battery used to place a fixed negative charge or bias on the grid of the tube. Also known as the **grid-bias battery.**

C-battery eliminator: A device used to eliminate the need for the C battery by obtaining the necessary current from the B-battery eliminator.

Cell: A chemical device used to generate an electron pressure or voltage.

Condenser: A capacitor, *which see.*

Conductor: Any substance, usually a metal wire, through which a current of electricity can flow freely.

Continuous wave: A wave which has an equal amplitude for all cycles.

Control grid: The grid of a tube upon which the signal voltage is impressed.

Coupling: The degree to which electrical energy is handed on from one circuit to another.

Coupling capacitor: A fixed capacitor used in a resistance-coupled amplifier to transfer electrical energy from one tube to another.

Cross modulation: A condition in which a strong local signal comes in with sufficient strength to force the first radio-frequency tube to act as a detector, thus producing distortion.

Damped wave: An alternating-current sine wave whose amplitude gradually and continuously decreases for each cycle.

Detector: The device to change the electrical currents which are produced in a receiver by radio waves into electrical currents which can operate the reproducer. An electrical gate or valve permitting the flow of electrons in one direction but not in the other.

Diaphragm: A thin iron disk which is set vibrating by the flow of the electric current through the coil of the earphone. This disk causes the air to vibrate, thus creating sound waves.

Dielectric: An insulator placed between the plates of a capacitor.

Diode: A two-electrode tube containing a plate and filament.

Direct current (D.C.): An electric current in which the electrons constantly flow in one direction.

Dropping resistor: A resistor connected in a circuit which uses up a part of the electrical pressure, thus leaving less voltage for the remainder of the circuit.

Dynamic speaker: A type of loudspeaker that depends for its operation upon the reaction between a fixed magnetic field and the fluctuating magnetic field produced around the voice coil.

Earphones or phones: Two flat receivers, held on the head by a spring.

Electric current: The flow of electrons through a conductor.

Electrolytic capacitor: A fixed capacitor of high capacitance with aluminum plates and a dielectric of aluminum oxide.

Electromagnet: A magnet made by electric current flowing through a coil of wire surrounding a core.

Electromagnetic dynamic speaker: A dynamic speaker that uses an electromagnet to produce the fixed magnetic field.

Electromotive force (E.M.F.): The electrical pressure or *voltage* that causes electrons to flow in a conductor.

Electron: A minute, negatively charged particle.

Electronic coupling: A method of coupling electrical energy from one circuit to another through the stream of electrons in a tube.

Electron theory: A theory which explains the nature of an electric current, as electrons moving through a conductor.

Envelope: The line joining the peaks of the curve lying on one side of the zero line of the graph.

Ether: The medium, permeating all space, which is *supposed* to carry such forms of energy as light, heat, and radio waves. There is no proof that ether does or does not exist.

Ether wave: A wave of energy which uses ether as a medium.

Fading: An undesired weakening of the radio signal.

Farad: The unit used to measure the electrical value of a capacitor.

Feedback: The transfer to electrical energy from the plate circuit of a tube to a preceding grid circuit. This is usually undesirable and produces distortion of the signal. (But see Regeneration.)

Field coil: The electromagnet of an electromagnetic dynamic speaker.

Filament circuit: The path of electrons from the A battery, through the filament and back to the A battery.

Filament transformer: A step-down transformer used to supply filament current from the house mains.

Filter: An electrical network used to smooth out or eliminate variations from a pulsating direct current, thus changing it to a steady direct current.

Filter capacitor: A fixed capacitor of high capacitance, used in a filter.

Filter choke: A coil of many turns wound on an iron core, used in a filter.

Fixed capacitor: A capacitor whose plates are fixed so that its electrical value cannot be changed.

Fleming valve: A tube ("valve") used as a detector.

Fluctuating direct current: Direct current that is constantly changing in strength or instantaneous amplitude.

Full-wave rectification: Rectification which uses both halves of the alternating-current cycle.

Galena: A mineral crystal, a compound of lead and sulphur, used as a detector in the receiving set.

Ganged capacitors: Variable capacitors, so hooked up that they turn simultaneously from a common shaft.

Graph: A diagram that pictures the instantaneous relationship between two varying factors, for example, temperature at a certain instant of time.

Grid: An open-mesh metal screen, placed between the plate and the filament of the tube, that controls the stream of electrons going from the filament to the plate.

Grid bias: The fixed negative charge placed on the grid on the tube.

Grid capacitor: A small fixed capacitor placed in the grid circuit of the tube and used to hand on the electrical energy from the tuning circuit. This capacitor also blocks the flow of electrons, accumulated on the grid, through the grid circuit.

Grid circuit: The path of electrons from the filament to the grid of the tube, through connecting wires and electrical apparatus and back to the filament.

Grid coil: The coil which is connected in the grid circuit of the tube. As discussed in Chapter 15, the grid coil is the secondary of the antenna coupler.

Grid leak: A resistor placed across the grid capacitor to provide a slight path or leak for the electrons accumulated on the grid of the tube.

Grid resistor: A resistor connected in the grid circuit of a tube.

Grid return: The wire connecting the end of the grid coil with the filament of the tube.

Grid swing: The amount of grid-voltage variation needed to operate the tube.

Ground: A water pipe, or some such arrangement, by which the receiving set makes contact with the earth.

Half-wave rectification: Rectification which uses only one half of the alternating-current cycle.

Heat wave: An ether wave whose wave length lies between 0.00008 cm. and 0.04 cm. (0.00030 in. to 0.01 in.).

Heaviside layer: A layer of electrified air, consisting of charged particles called *ions*, from sixty to two hundred miles above the surface of the earth, which acts as a reflector for radio waves. Changes in this layer are believed to be the chief cause of fading. The layer is also known as the *Kennelly-Heaviside layer* or *ionosphere.*

Henry: The unit used to measure the electrical value of an inductor.

Heterodyning: The producing of beat notes or currents by mixing two waves or two alternating currents of different frequencies.

Image frequency: A frequency that is as much above the oscillator frequency as the desired station frequency is below that of the oscillator. Thus the signals from two different stations may be fed into the intermediate-frequency amplifier at the same time.

Inductive coupling: A method of coupling electrical energy from one circuit to another by mutual induction.

Inductor: A coil of wire wound on a form.

Insulator: Any substance through which a current of electricity cannot flow freely.

Intermediate frequency: The frequency that lies between the radio frequency of the received signal and audio frequency. It results from heterodyning two different radio frequencies.

Intermediate-frequency (I.F.) transformer: A transformer tuned so that its natural frequency falls within the intermediate-frequency range.

***L* × *C*:** The product of the electrical values of the inductor and capacitor of the tuning circuit which determines its natural frequency.

Lead-in: An insulated wire connecting the aerial to the receiving set, or the ground to the receiving set.

Light wave: An ether wave whose wave length lies between 0.00004 cm. and 0.00008 cm. (0.000015 in. to 0.000030 in.).

Line-cord resistor: A resistor in the power line which uses up most of the 110 volts, leaving a small portion for the filaments.

Local oscillator: A generator of radio-frequency currents in a superheterodyne receiver.

Loudspeaker: A reproducer which produces a loud, audible sound.

Magnet: A bar of iron or steel or a coil bearing an electric current that has the property of attracting to it pieces of iron, steel, or other magnetic substances.

Manual volume control: A control of volume, usually a variable resistor, which can be manipulated by the person operating the radio receiver.

Meg-: A prefix meaning 1,000,000.

Micro- (prefix): $\frac{1}{1,000,000}$.

Micromicro- (prefix): $\frac{1}{1,000,000,000,000}$.

Microphone: A device used to change sound waves to a fluctuating electrical current.

Middle-register tone: The tone resulting when high and low frequencies are present in about equal proportions. Also called *normal tone*.

Milli- (prefix): $\frac{1}{1,000}$.

Mixer tube: A tube in the superheterodyne receiver in which the incoming signal current is mixed with the radio-frequency current from the local oscillator to produce the intermediate-frequency current.

Modulated carrier wave: A carrier wave whose amplitude is continuously varied as the result of mixing with a current of lower frequency or with a fluctuating direct current.

Multielectrode tube: A tube with many electrodes, mainly grids, each of which acts on the single stream of electrons flowing from the cathode to the plate.

Multiunit tube: A tube combining several independently acting tubes in one envelope. The electron stream divides into several parts, each part being acted upon by one set of electrodes.

Mutual induction: The method by which electrical energy from one circuit is transferred to another by means of a moving magnetic field.

Natural frequency: The frequency at which a body will vibrate if kept free from outside interference.

Negative charge: A region where there is an excess of electrons as compared with other regions.

Neutralization: The elimination of the feedback due to the inter-electrode capacitance between the plate and grid of the tube.

Neutralizing capacitor: A small capacitor connected in such a way as to neutralize the capacitance between the plate and grid of a tube.

Ohm: The unit in which we measure the resistance to the flow of electrons.

Oscillation: The movement of electrons back and forth through a circuit. The condition under which the electrons flowing in the tuning circuit of the receiver cause it to become a transmitter of radio waves.

Output transformer: A step-down transformer that couples the electrical energy from the plate circuit of the last audio-frequency amplifier tube to the voice coil.

Parallel circuit: An electrical circuit in which electrons have two or more paths to follow.

Pentagrid converter: A tube containing five grids in addition to the plate and cathode. This tube is used in the superheterodyne receiver to perform the functions of local oscillator and mixer tubes at the same time.

Pentode: A five-element tube containing a cathode, plate, control grid, screen grid, and suppressor grid.

Permanent magnet: A magnet that retains its magnetism after the magnetizing force which produced it is removed.

Permanent-magnet dynamic speaker: A dynamic speaker that uses a permanent magnet to produce the fixed magnetic field.

Phonograph pickup: A device used to change variations in a phonograph-record sound-track to a fluctuating electric current.

Piezoelectric effect: The effect whereby pressure on certain types of crystals produces an electric current.

Plate circuit: The path of electrons from the filament to the plate of the tube, through connecting wires and electrical apparatus and back to the filament.

Plate coil or tickler: The coil which is connected in the plate circuit of the tube to produce feedback.

Plate resistor: A resistor connected in the plate circuit of a tube.

Pole (or electrode): Terminal of a cell or battery through which electrons leave or enter.

Potentiometer: A resistance device enabling us to tap off portions of the entire voltage placed across it.

Power sensitivity: A measure of the extent to which small changes in grid voltage control large changes of power in the plate circuit of a tube.

Power-transformer: A transformer used to step up the 110-volt alternating current from the house mains to a higher voltage. It may have several step-down secondaries, which are used to supply current to heat the filaments of the tubes.

Power tube: A tube designed to handle more current than the ordinary amplifying tube. This tube is used in the last stage of the audio-frequency amplifier.

Primary: The input coil of a transformer.

Pulsating direct current: A direct current that periodically changes in strength.

Push-pull: A method of connecting two tubes to supply great power to a loudspeaker with little distortion.

Radio frequency: The frequency of the radio wave. Those in the broadcast band range between 550 kc. and 1600 kc. per second.

Radio-frequency alternating current: Alternating current that makes thousands or millions of changes in the direction of current each second.

Radio-frequency amplifier: An amplifier that amplifies the radio-frequency current from the tuning circuit before feeding it into the detector.

Radio-frequency choke coil: A small inductor, usually with the air core, placed in a circuit to impede the flow of electrons through that circuit. It is called a **radio-frequency** choke coil because its impeding effect, or **impedance,** is greater as the frequency of the current increases. Thus, the impedance is greatest at radio frequencies.

Radio-frequency transformer: A transformer, usually wound with an air core, used to couple radio-frequency electrical energy from one circuit to another.

Radio wave: An ether wave whose wave length lies between 0.01 cm. and 30 km. (about $\frac{1}{250}$ in. to 18 mi.).

Rectified current: An alternating current that has been changed to direct current by a rectifier tube or other rectifier device.

Rectifier tube: A tube whose sole function is that of changing alternating current to direct current.

Regeneration: The action whereby electrical energy in the plate circuit is fed back to the grid circuit to be amplified again and thus produce a louder signal in the earphones or loudspeaker.

Regenerative control: The device by which the amount of electrical energy fed back to the grid circuit is controlled, thus preventing the receiver from oscillating.

Reproducer: A device such as a telephone receiver which changes electric currents to a form which our senses may observe.

Resistance: The opposition a substance offers to the flow of electric current through it.

Resistance coupling: Coupling between the plate circuit of one tube and the grid circuit of the next by means of resistors and a coupling capacitor.

Resonance: In electricity, the adjustment of a circuit that permits the maximum flow of current when a voltage of a given frequency is applied to the circuit. In the radio receiver, when the natural frequency of the tuner is the same as the frequency of the transmitting station, the two are in resonance. Two bodies are in resonance with each other if their natural frequencies are the same.

Rheostat: A variable resistor.

Screen grid: A grid of a tube placed between the control grid and the plate to reduce the space charge and plate-to-grid capacitance.

Secondary: The output coil of a transformer.

Secondary emission: The cloud of electrons knocked out of the plate by the impact of the electron stream sent out by the cathode.

Selectivity: The ability of a tuner to select one radio station signal and reject all others.

Self-induction: The property of a coil whereby it tends to keep out a current coming in and, once in, to prevent it from discontinuing; in short, to oppose any current change through it.

Sensitivity: The ability of a radio receiver to respond to radio waves of very low strength.

Series circuit: A circuit in which electrons have but one path.

Series connection of cells: Cells connected in sequence from + to − to supply a higher total voltage than that of any single cell.

Sharp tuning: The ability of a radio set to receive one station only at a time.

Shielding: The act of surrounding a current-carrying device by a metal container to keep magnetic fields in or out.

Shunt: One of the paths in a parallel circuit.

Side band: The band of frequencies on either side of the fundamental carrier frequency, simultaneously transmitted with it by the broadcast station.

Sine curve: A graph indicating the smooth variations of current flowing in an alternating-current circuit.

60-cycle alternating current: An alternating current that reverses its direction of flow through a circuit 120 times a second.

Space charge: A cloud of electrons filling the space between the cathode and plate of a tube.

Spider: A piece of elastic material that constantly tends to return the voice coil to its normal position.

Step-down transformer: A transformer which develops a lower voltage across the secondary than the voltage impressed across the primary.

Step-up transformer: A transformer which develops a higher voltage across the secondary than the voltage impressed across the primary.

Supercontrol radio-frequency amplifier tube: A variable-*mu* tube.

Superheterodyne receiver: A radio receiver using the heterodyne principle.

Suppressor grid: A grid placed in a tube between the screen grid and the plate to reduce the effect of secondary emission.

Tetrode: A four-element tube containing a cathode, plate, control grid, and screen grid.

Thermionic effect: The throwing off of electrons by a body when it is heated to incandescence.

Three-circuit tuner: A tuner coupled to the plate circuit as well as to the aerial-ground system.

Tone: The sound resulting from the mixture of air waves of different frequencies.

Tone control: An electrical circuit used to emphasize high- or low-frequency notes in a combination of sound frequencies. It usually consists of a fixed capacitor and rheostat.

Transformer: An electrical device consisting of two separate coils, insulated from each other, used to transfer electrical energy from one circuit to another.

Transformer coupling: Coupling between the plate circuit of one tube and the grid circuit of the next by means of a transformer.

Treble tone: the tone resulting when high frequencies are predominant. Also known as *high-pitched* or *soprano tone.*

Trimmer: A small variable capacitor connected across the large tuning capacitor used to adjust the latter (see *Alignment*, above).

Triode: A three-electrode tube containing a filament, grid, and plate.

Tuned radio-frequency (T.R.F.) receiver: A receiver using one or more tuned radio-frequency amplifier stages, a detector, and one or more audio-frequency amplifier stages.

Tuned radio-frequency transformer: A radio-frequency transformer whose secondary is tuned by a variable capacitor.

Tuner: The device in a radio receiver which selects a radio wave of a certain frequency and rejects all others.

"Valve": A tube with a filament and plate which will allow current through it only in one direction.

Variable capacitor: A capacitor whose plates can be moved so that its electrical value can be changed at will.

Variable-*mu* tube: A tube with a specially wound grid producing a change in the amplification factor with signals of different strength.

Voice coil: The small coil of the dynamic speaker through which electrical energy from the plate circuit of the last audio-frequency amplifier tube is fed, setting up a fluctuating magnetic field that reacts with the fixed magnetic field to drive a cone, thus producing sound.

Voltage: The electrical pressure that causes electrons to flow in a conductor.

Voltage divider: A resistor, placed across the output of the filter system, from which we may obtain various voltages by tapping off at points along its length.

Volume control: A resistance device, usually a rheostat or potentiometer, which controls the volume of the radio signal coming out of the earphones or loud-speaker.

Watt: The unit for measuring electrical power.

Wave form: A graph showing changes of direct- and alternating-current flow.

ANSWERS TO TESTS

Chapter 1 (Page 6)

1. T.	**3.** F.	**5.** T.	**7.** T.	**9.** F.
2. F.	**4.** T.	**6.** F.	**8.** F.	

Chapter 2 (Page 12)

1. Meter.
2. 1000.
3. 1,000,000.
4. Wave length; frequency.
5. 186,000; 300,000,000.
6. Heat; light.
7. 200; 660.
8. Millimeter.
9. Megacycle.
10. Velocity; frequency.
11. Magnetic field of force.
12. Current.

Chapter 3 (Page 18)

1. Aerial-ground system, tuner, detector, reproducer.
2. Voltage; electrical pressure.
3. Tuner.
4. Natural frequency.
5. Resonance.
6. Reproducer.
7. Galena.

Chapter 4 (Page 23)

1. (a)	**3.** (i)	**5.** (c)	**7.** (b)	**9.** (g)
2. (d)	**4.** (h)	**6.** (e)	**8.** (f)	

Chapter 5—Part A (Page 29)

1. Inductance; capacitance.
2. Number of turns, length, diameter, core.
3. Henry.
4. Conductors; dielectric.
5. Total area of the plates facing each other, the material of the dielectric, the thickness of the dielectric.
6. Farad.
7. Oscillations.
8. *L*; *C*.
9. The same as or equal to.

Chapter 5—Part B (Page 30)

1. (e)	**3.** (i)	**5.** (c)	**7.** (b)
2. (f)	**4.** (h)	**6.** (j)	

Chapter 6—Part A (Page 37)

1. An electromagnet.
2. Center post of one cell is connected to the side post of another cell.
3. Must vary.
4. Diaphragm.
5. Is larger and thus moves more air.

Chapter 6—Part B (Page 38)

1. Diaphragm. **2.** Field coil. **3.** Permanent magnet.

Chapter 7 (Page 44)

1. Electrons; negative.
2. In one direction.
3. Back and forth.
4. Pulsating direct.
5. Frequency.
6, 7, 8. Radio-frequency alternating.

9. Detector. **10.** Carborundum; galena. **11.** 

Chapter 8—Part A (Page 58)

1. Graph.
2. Strength.
3. Carrier.
4. Damped.
5. Modulated radio.
6. Envelope; the same as.

Chapter 8—Part B (Page 58)

1. (e) **2.** (f) **3.** (g) **4.** (b) **5.** (d) **6.** (a) **7.** (c)

Chapter 9 (Page 67)

1. T. **2.** F. **3.** T. **4.** T. **5.** F. **6.** T.

Chapter 10 (Page 74)

1. Carbon; zinc.
2. Negative; positive.
3. Increased.
4. Repel.
5. Direct.
6. Alternating-current generator; electron tube.
7. 120.
8. Alternating.
9. Electromotive force.
10. Positive.
11. Two.
12. Peak.

Chapter 11 (Page 83)

1. Mutual inductance.
2. An alternating.
3. The same as.
4. Metal plates; a dielectric.
5. Oscillatory.
6. (*a*) Opposes; (*b*) keep the current flowing; (*c*) self-inductance.
7. Coil; capacitor.
8. Inductor; capacitor.

Chapter 12 (Page 89)

1. F.
2. T.
3. T.
4. T.
5. T.
6. T.
7. F.

Answers to Test 1—Chapters 1–12 (Page 90)

1. Energy.
2. Frequency.
3. Ether.
4. 300,000,000.
5. Aerial-ground system; tuner; detector; reproducer.
6. Electrical pressure; voltage.
7. In resonance.
8. Detector.
9. Electrical currents.
10. Coil; capacitor.
11. Capacitor.
12. (*a*) 10, (*b*) 3,000,000.
13. Resistance.
14. Transformer.
15. Electrons.
16. (*a*) Excess, (*b*) deficiency.
17. Series.
18. Parallel.

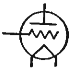
Chapter 13 (Page 98)

1. Electrons; Edison; thermionic.
2. Positive.
3. Positive; current.
4. Pulsating direct.
5. Detector.
6. Diode; plate; filament.
7. 
8. Alternating-current generator.
9. Aerial-ground.
10. Positive.

Chapter 14—Part A (Page 115)

1. Filament; plate.
2. DeForest.
3. Plate; filament; plate.
4. Decreases; increases.
5. Filament; plate.
6. Negative; grid.
7. Capacitor; grid leak; grid.
8. Resistor.
9. Ohm.
10. Million.
11. Resistor.
12. Rheostat.
13. Negative.

Chapter 14—Part B (Page 116)

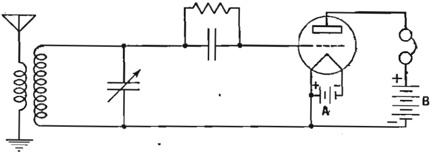
 or  Triode.


Fixed resistor.


Rheostat.

Meter

Chapter 14—Part C (Page 116)



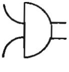
Chapter 15 (Page 125)

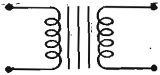
1. T.
2. F; plate to grid.
3. F; Armstrong.
4. T.
5. F; oscillations.
6. T.
7. T.
8. F; tickler coil.
9. F; sensitive.
10. T.
11. T.
12. T.
13. T.

Chapter 16—Part A (Page 143)

1. F; 30 to 15,000.
2. F; grid.
3. F; negative; grid.
4. T.
5. F; B battery.
6. T.
7. T.
8. T.
9. T.
10. T.
11. T.
12. T.
13. T.
14. F; two; three.
15. F; potentiometer; grid.
16. T.

Chapter 16—Part B (Page 145)

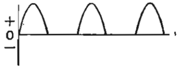

Microphone

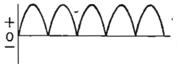

Audio-frequency transformer.

 Potentiometer.

 Crystal pickup.

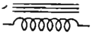
Chapter 17—Part A (Page 158)

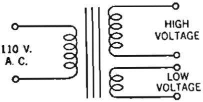
1. 110; 60 cycles per second.
2. Rectified.
3. Filter; filter choke coils; filter capacitors.
4. Up; down.
5. 



; 80.
6. Voltages.
7. Watts.
8. Electrolytic.

Chapter 17—Part B (Page 159)

 Filter choke coil



Power transformer

Chapter 18—Part A (Page 165)

1. Filament.
2. Temperature.
3. Grid; filament.
4. Metal sleeve; cathode; filament.
5. Heater.
6. Negative; sleeve.

Chapter 18—Part B (Page 166)

1. Plate.
2. Grid.
3. Cathode.
4. Filament or heater.

Chapter 19 (Page 172)

1. Negative; filament or cathode.
2. Voltage divider.
3. Filament or cathode; negative; grid.
4. Grid; cathode.
5. Plate.
6. Parallel.
7. Voltage; grid.

Chapter 20 (Page 177)

1. Plate; 110.
2. Series; dropping resistor.
3. Line-cord.
4. Resistor.
5. Resistor; parallel.

Chapter 21 (Page 184)

1. T.
2. F.
3. T.
4. F.
5. T.
6. T.
7. F.
8. T.

Chapter 22 (Page 201)

1. F; detector.
2. F; transformer.
3. T.
4. T.
5. F; aluminum or copper; ground.
6. T.
7. T.
8. F; screen-grid.
9. F; ganged.
10. F; capacitor.
11. T.
12. F; more stable.
13. F; capacitors.
14. T.

Answers to Test 2—Chapters 13–22 (Page 202)

1. (*a*) Filament, (*b*) plate.
2. (*a*) Grid, (*b*) plate.
3. Grid leak; capacitor.
4. (*a*) Plate, (*b*) grid.
5. Oscillate.
6. 30; and 15,000.
7. Transformer; resistance.
8. (*a*) Resistance, (*b*) transformer.
9. (*a*) Rectify, (*b*) filter.
10. Full-wave.
11. Cathodes.
12. (*a*) Resistor, (*b*) capacitor.
13. (*a*) Voice coil, (*b*) field coil.
14. Grid-to-plate capacitance.
15. Ganged.

Chapter 23 (Page 216)

1. Filament; rheostat; A battery.
2. Rheostat; primary; plate.
3. Potentiometer; secondary; grid
4. Rheostat; resistance; grid.
5. The negative charge on the grids of the radio-frequency amplifier tubes.
6. Changed to direct current; grids; radio-frequency.
7. Type 55.

Chapter 24 (Page 223)

1. 30; 15,000.
2. Same.
3. Frequencies.
4. Higher audio.
5. Lower audio.
6. Audio-frequency amplifier; audio.

7. Capacitor; resistor.
8. Higher audio; lower audio; potentiometer.

Chapter 25 (Page 239)

1. T.
2. T.
3. T.
4. T.
5. T.
6. F.
7. T.
8. F.
9. F.
10. F.
11. T.
12. T.

Chapter 26 (Page 268)

1. T.
2. F; amplification factor.
3. F; greater.
4. F; less.
5. F; decreases.
6. T.
7. F; decreased.
8. T.
9. F; plate-to-grid.
10. T.
11. F; variable; cross modulation.
12. F; secondary emission; plate; screen grid; cathode.
13. T.
14. T.
15. T.

Answers to Test 3—Chapters 23–26 (Page 270)

1. Emission of electrons.
2. Potentiometer.
3. (*a*) Grid bias, (*b*) greater, (*c*) less.
4. High-pitched, shrill, or treble; medium-pitched or normal; low-pitched, deep, or bass.
5. (*a*) Low, (*b*) false treble.
6. (*a*) Capacitors, (*b*) inductors.
7. (*a*) Incoming signal, (*b*) radio-frequency current, (*c*) beat-frequency current.
8. (*a*) Single, (*b*) sensitivity, (*c*) selectivity.
9. Image frequency.
10. Parallel; push-pull.
11. Space charge.
12. Cathode.
13. Grids.
14. Several tubes.

FINAL TEST A (Page 272)

1. Tuning coil.
2. Tuning capacitor.
3. Crystal detector.
4. Head phones.

FINAL TEST B (Page 273)

1. Primary of antenna coupler.
2. Secondary of antenna coupler or grid coil.
3. Plate coil or tickler coil.
4. Grid leak.
5. Grid capacitor.
6. Volume-control rheostat.
7. A battery.
8. Triode detector.
9. Regenerative control.
10. B battery.

FINAL TEST C (Page 274)

1. Microphone.
2. Microphone transformer.
3. Volume-control potentiometer.
4. Audio-frequency transformer.
5. Output transformer.
6. Permanent-magnet dynamic loudspeaker.

FINAL TEST D (Page 275)

1. Power transformer.
2. Full-wave rectifier tube.
3. Filter choke coil.
4. Voltage divider.
5. Filter capacitors.

FINAL TEST E (Page 276)

1. Coupling capacitor.
2. First detector and mixer tube.
3. First intermediate-frequency transformer.
4. Intermediate-frequency amplifier tube.
5. Second intermediate-frequency transformer.
6. Second detector tube.
7. Radio-frequency choke coil.
8. Local oscillator.
9. Cathode bias resistor.
10. By-pass capacitor.

TEST F (Page 277)

1. Heater.
2. Cathode.
3. Control grid.
4. Screen grid.
5. Suppressor grid.
6. Plate.

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(Also see Glossary, pages 287–298)