# Understanding Radio

## WATSON · WELCH · EBY

# UNDERSTANDING RADIO

*A Guide to Practical Operation and Theory*

BY

## HERBERT M. WATSON
*Associate Member I. R. E.*

## HERBERT E. WELCH
*Associate Professor of Radio Technology and Engineering*
*Stockton Junior College, Stockton, California*

AND

## GEORGE S. EBY
*Professor of Applied Science*
*Stockton Junior College*
*Stockton, California*

# WHAT DOES THIS BOOK OFFER?

**Who May Study Radio?**    Radio sets have for years been constructed of a simple assortment of parts by persons handy with screwdriver, soldering iron, and drill.    These experimenters have proved that the field of radio is not limited to mechanics or to persons who are already familiar with electrical and radio principles.    This means that you, too, can have the fun of hearing distant stations on a set that you have built or that you can have the satisfaction of being able to operate intelligently equipment you have purchased.

Whether you are a beginner in radio or an experimenter who wishes to round out his radio background and gain experience in the handling of radio apparatus, you will find in this book necessary and valuable radio information. The fundamental radio and electrical facts are explained simply and clearly.    In addition to explanations, each chapter suggests and outlines practical experiences in building, operating, and studying simple and practical equipment.

**The Importance of Fundamentals.**    Radio is essentially simple if its fundamental principles are learned in a logical order.    Such a learning order is followed in this book by combining set construction, practice in operating basic radio circuits, and a thorough study of radio principles.

Many persons have enjoyed building and operating radio sets without knowing the principles on which the operation of the set depends.    You can, of course, build and operate sets by following instructions in radio magazines or other

radio publications. But while you can do much experimenting without knowing the "whys" of a circuit, a knowledge of the principles of radio and their underlying electrical theory and practice is usually desirable for the person who has a permanent interest in radio either as a vocation or as a hobby.

**The Selection and Arrangement of Material.** The subject matter of the book is arranged in the order in which you will need it as you work with each set. As far as possible, each circuit is studied as a single lesson, which is divided into the following parts:

1. The Purpose of the Lesson
2. How to Build and Wire Any Needed Apparatus
3. How to Operate the Set or Apparatus
4. Why the Set Works as It Does

The explanation in "Why the Set Works as It Does" assumes that you have some understanding of common electrical principles. But if you do not know or have forgotten these principles, you will find included in the chapter experiments that demonstrate and help to explain them to you.

The how of set operation is given in the operating instructions. The description of each set is followed by an explanation of the theory involved. Every principle is proved by experiments which use parts found in the average laboratory or shop.

Inexpensive and easily secured parts are suggested for all the sets described in the book. The authors, as teachers, are more interested in circuits that are suited to the demonstration of certain basic radio or electrical principles than in using the most modern equipment. For example, this is the reason for using the type 01A tube to present the principles of the electron tube and to explain its operation. Tubes of later design, which are more efficient, may be

used in place of the type 01A tube, but their filaments are
easily burned out by a small increase in voltage over the
specified value. The rugged 01A tube is little affected
by such overloads.

Questions which serve as a checkup on understanding
are included in each lesson.

In the list of "Technical Terms" at the end of each
chapter, you will find explained the new words that are
used in that chapter.

**How to Study Each Chapter.** Follow a definite pro-
cedure as you work through each chapter to produce the
best results. The following plan is suggested. You may
want to omit some steps, depending upon your previous
knowledge and work.

*Step* 1. Read the purpose of the lesson carefully.

*Step* 2. Then make a copy of each circuit diagram.
(This is an excellent way to learn the connections for each
circuit.)

*Step* 3. Build and wire any needed equipment. If you
are using completed equipment, follow carefully the instruc-
tions for attaching the batteries or the power pack and the
aerial and ground. You will find there is a right and a
wrong way. (Do not omit any experiment or hook-up,
because each is designed to teach you an important prin-
ciple in electricity or radio.)

*Step* 4. Test yourself on the checkup questions. They
are a good test of your understanding of the information
in the lesson.

*Step* 5. Work through the experiments on electrical
and radio principles. (Your understanding of radio is
based on your grasp of these principles.)

*Step* 6. Turn to the list of "Technical Terms" at the
end of the chapter for the meaning of any technical words
that are new to you.

**What to Expect from This Book.**   When you have completed the experiments outlined in this book, you will have a working knowledge of the principles that underlie radio. These principles do not change.   They are the basis on which all radio sets are built, from the lowliest crystal set to the finest de luxe model.   If you wish to keep up with the latest developments in radio, the current radio magazines are your best source of information.   There are many of them on the newsstands.

In them you may find many abbreviations which you do not recognize.   The list of abbreviations at the back of the book will furnish a handy place to find the meanings of these abbreviations.   This list includes the principle ones used at the time it was compiled.   However, radio is still so new, and its terminology is changing so rapidly that you probably will find from time to time abbreviations not listed here.

The authors know that you can achieve a successful and satisfying understanding of radio from your study of this book.   They have been developing and trying out the manuscript in their classes for years, and have incorporated in the book the explanations which their students have found most helpful.   Some of these students have become amateur radio operators, using equipment they have made themselves; some have become marine and broadcast operators; some have gone into radio sales and service. Some other interesting applications you may make of your knowledge of radio are discussed in the last chapter of this book.

# CONTENTS

# CHAPTER I

## RADIO WAVES AND WAVE TRAVEL

**Wave-travel Characteristics.** In this chapter we will study about the way radio waves travel. Many people think the radio music and programs sent out from a broadcasting studio travel as air waves which the receiving set picks up and in some mysterious way changes into music.

We will discuss the facts that are known about these so-called waves and their action in as simple and nontechnical a way as possible. We will use the latest generally accepted explanations for these facts and will avoid the explanations that are in dispute.

Much research is being done concerning the uses of radio waves for industry, for pure science, and especially for the electrical and chemical field. It is interesting to read the results of this advanced research.

**The Many Types of Waves.** Radio waves are used in many fields other than radio. They and their effects are found in places unsuspected by those who have done little reading on scientific topics. The concentrated research on these waves is bringing out new uses for them and is revealing their existence in startling fashion. Few would suspect that light, heat, the X ray, and many other common effects are due to the same type of waves.

**The Many Wave Bands.** We are familiar with the several wave bands used by the broadcast, police, and aircraft radio services. We are not as well acquainted with the amateur band of wave frequencies or with the higher frequency or ultrashort radio waves. Neither are many of

1

us familiar with the very low frequencies used by the commercial "wireless" telegraph companies.

It is a highly fascinating chapter of science that deals with the frequencies far higher than the highest radio frequency. We must delve somewhat into these things in our study of Waves and Wave Travel.

**Wave Length and Frequency.** The use of these two terms is apt to be confusing at first but in reality they prove to be easy to keep straight.

We must learn how each of the terms is used and how to keep them straight in our thinking. We will discover the common uses of the term "wave length" in the older radio language and learn why its use was satisfactory at that time. The newer use of the term "frequency," which is just another way of describing the size of a radio wave, is discussed in this chapter.

### Contents of This Chapter

### 1. WHAT ARE RADIO WAVES

**These Waves Cannot Be Pictured.** If you do not know much about radio waves or do not understand how they act, you need not feel bad about it, because no one at the present time understands them fully. Also, do not think
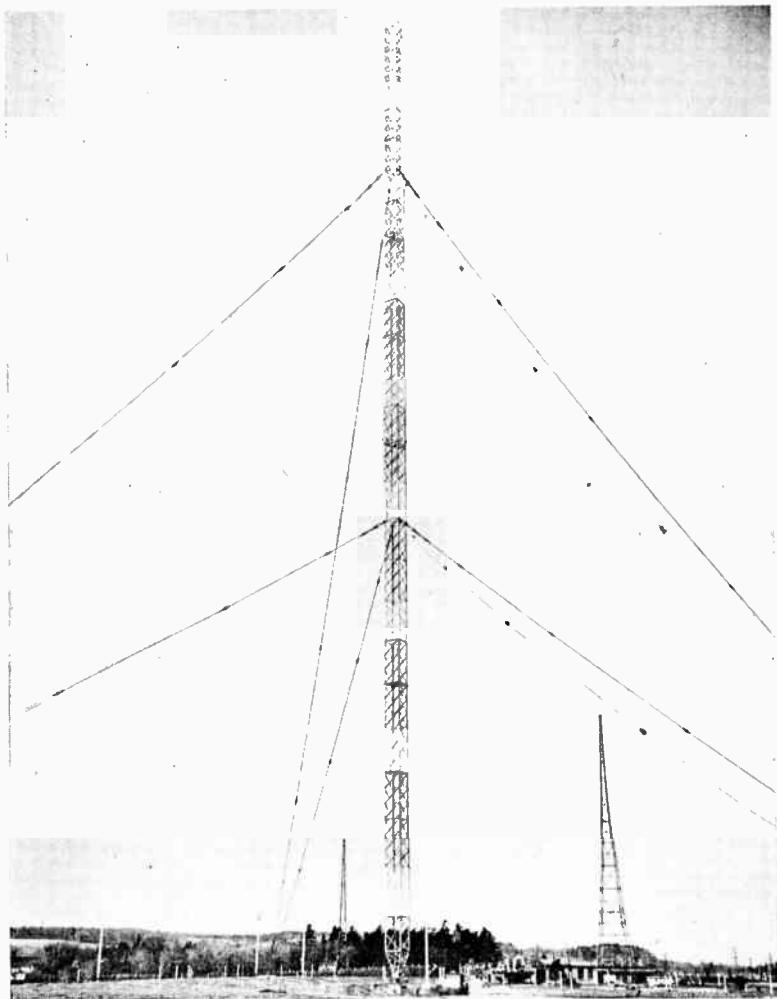
*Courtesy General Electric Co.*

ANTENNA OF A POWERFUL BROADCASTING STATION

This antenna stretches 625 feet into the air. Thirteen miles of grounding wire are embedded in trenches which radiate from the tower base. This antenna replaces the old towers in the background.

that all you have to do is to read an article on "Radio Waves" and then expect to have a definite mental picture of them.

*Many ways are used to describe and to picture radio waves, but all are inadequate and incomplete. If you have a definite picture in your mind of radio waves, you may be sure that your picture is wrong.*

**Electrical Effects Travel through Space.** Many theories have been advanced as a means of explaining the effects that we know occur in radio. From the early experiments of Hertz, Maxwell, and Marconi in the eighteen hundreds, there was evidence that something traveled from the transmitter to the receiver. At first it was thought that this effect was carried by the air, but later experiments proved this not to be the case.

**Only Mathematical Formulas Describe Radio Waves.** So-called radio waves are peculiar. Scientists have found mathematical formulas which will predict every move and twist the waves make, but the scientists so far have been unable to form a reliable mental picture of them. These waves behave like trained seals when they are caged in mathematical formulas, but the instant they are removed from the mathematical cage, they seem to vanish into utter nothingness.

It is fortunate for the radio amateur that he can use and enjoy radio waves without knowing much about them. However, there are general points which the amateur should know.

### Questions

1. Is it possible to understand the action of radio waves without first having a mental picture of them?

2. What is the one sure means that scientists have for explaining the action of the radio waves?

## 2. THE HEAVISIDE LAYER

**Wave Travel.** Radio waves move, are carried, or pass through space some way. No matter what the length or frequency of the wave, it moves at the speed of light: 186,-000 miles a second. The exact form or manner in which this wave motion travels is a matter of much discussion among advanced scientists, and we will not go into it in this book. The speed of wave travel is so great that a wave could flash seven times around the earth at the equator in one second. Radio waves generally travel in a straight line, but they may be bent or reflected like light. Metal interferes with these waves.

**The Heaviside Layer.** For years an effect called "fading" has interfered with reception of programs. This effect is noticed in broadcast receivers, although it is more pronounced in the amateur sets. The amateurs have also known the effect of the waves skipping over their stations. The explanation of fading and skipping is based upon the Heaviside layer theory. This theory was developed by an Englishman named Heaviside and by an American named Kennelly. These men reasoned that there was a stratum or layer made up of electrified or ionized particles of air, enveloping the earth at a considerable height. They also reasoned that this layer of ionized particles must have a reflecting effect similar to that of a mirror.

A beam of light that strikes a mirror at an angle is reflected at the same angle. If radio waves acted like light waves, it would be possible to explain fading and skipping by saying that a layer of some sort in the sky reflected the waves. It is generally accepted at the present time that there is such a layer. It has been studied enough so we

think that we understand its characteristics with reasonable accuracy.

### Questions

1. What effect does the Heaviside layer have upon radio waves?

2. Does a radio wave reflect at the same angle that it strikes the Heaviside layer?

### 3. THE HEAVISIDE LAYER HEIGHTS

The Heaviside layer is formed as the ultraviolet rays from the sun reach the upper layers of air and use their energy in
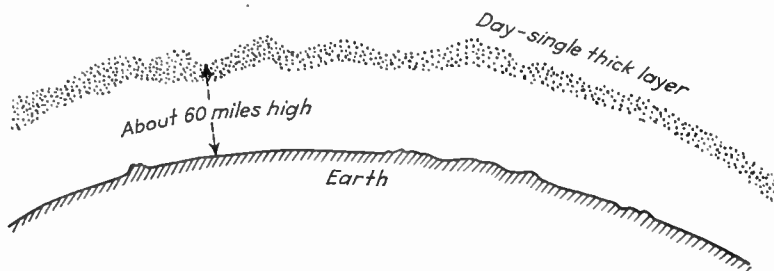


Fig. 1.    The Heaviside layer—day.

electrifying or ionizing the air particles they meet.    When the sun is overhead, the ultraviolet rays penetrate farther through the air layer surrounding the earth.    As a result, the ionization or charging of the air is heaviest and the layer is thickest and lowest at noon.    After sunset the layer not only shrinks but rises and splits into two layers.

The constant change in strength of the flow of ultraviolet rays from the sun causes the Heaviside layer to billow and flow much as a cloud.    Its volume and height changes from hour to hour as the strength of the ultraviolet rays changes. Over the day side of the earth there is a low, dense, billowing cloud of this layer about 60 miles above the earth (see Fig. 1), while over the night side of the earth, there are two

layers which have risen to a height of about 200 miles (see Fig. 2).

### Questions

1. What rays from the sun cause or produce the Heaviside layer?

2. What effect does the position of the sun have on the height of the Heaviside layer?

3. Do all radio waves travel at the same speed? What is this speed?

4. What bends the radio waves around the earth?

5. Of what is the Heaviside layer composed?

6. The Heaviside layer is about how many miles above the surface of the earth during the day? at night?

### 4. THE EFFECT OF SUNSPOTS

A sunpot is a huge hole torn in the surface of the sun by an explosion of gas. An inner layer of the sun, exposed by the
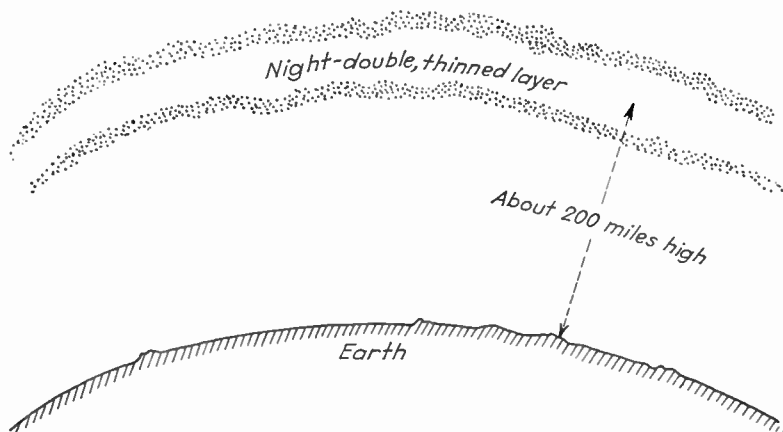


Fig. 2. The Heaviside layer—night.

explosion, is at a temperature of about 30,000°F., or 20,000° hotter than the outer layer. A huge blast of ultraviolet rays rushes to the earth from the sunspot. They may cause the thickness and the strength of the Heaviside layer to increase as much as a third or more in an hour.

The electrified air particles, called ions, drift or flow.
The negatively charged ions drift westward while the
positively charged ions drift eastward.    This ion flow or
current of electricity is the Heaviside layer.    It is not just
an electronic cloud; it is a "river" of electrical power flow-
ing above in the sky.    The flow of this river of ions produces
a tremendous electrical current of about 30 million amperes
of electricity.

The ions of the Heaviside layer spiral around the earth
and accumulate at the north and south poles.    The positive
ions accumulate at one pole and the negative ions at the
other pole.    When the ion clouds become thick enough at
the north pole they are visible as the northern lights (aurora
borealis), or southern lights (aurora australis).    Radio,
cable, and telegraph service in Alaska is often interrupted
by these displays of the aurora.    The effect of the ion cloud
moving at the poles, seen as the aurora, creates a tremen-
dous field of magnetic force which causes this disturbance
in the radio and telegraph communication systems.    Com-
pass magnets are also badly affected by the aurora.

### Questions

1. Describe the motion of the Heaviside layer.
2. Describe the effect of sunspots on the Heaviside layer.

### 5. SKIP DISTANCE

The Heaviside layer acts like a mirror to reflect or bend
radio waves.    A broadcasting station sends out a wave
which strikes the Heaviside layer, reflects back to the earth,
glances from the earth up to the Heaviside layer, then down
again, and so on until its energy dies out.    This process
carries waves for great distances.    (See Fig. 3 and Fig. 4.)

**Waves Reflect over Your Receiver.** Suppose your
receiver is too far from the transmitting station to pick up
its ground waves, which apparently travel for short dis-

tances along the earth (see Fig. 3). Radio waves which
are reflecting back and forth between the earth and Heavi-
side layer may strike the earth 10 miles from your set, then
reflect up to the Heaviside layer, and then strike the earth
again beyond your set. The set will be in a dead space
between the reflected waves, but listeners beyond and
behind you will receive the program. The distance
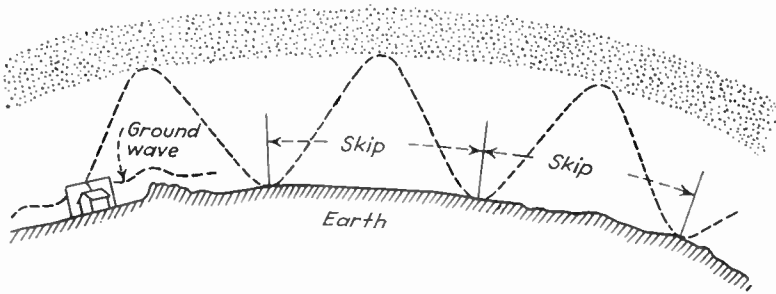between points where the reflected wave reaches the earth
is called the skip distance. The wave that is sent from the



Fig. 3. Skip distance—day.

transmitting station to the Heaviside layer is called the sky
wave to distinguish it from the ground wave.

**Waves Reflect between the Two Heaviside Layers.** At
night two Heaviside layers affect reception (see Fig. 4).
Sometimes these sky waves penetrate the first Heaviside
layer, reflect from the next one, glance back to the first
one, and then bounce along between the two layers. These
sky waves may travel great distances before they finally
break through and get back to the earth. This is the
cause of many freak broadcasts where transmitters com-
monly rated at consistent ranges up to 400 or 500 miles are
heard thousands of miles away at night. Freak trans-
missions also take place in cold weather, during which
listeners far beyond the normal distance of a station hear
it with ease.

This reflection of waves is one reason for the varying difference in volume of signals received from nearby stations and stations located great distances from the receiver. It is not always possible to judge the distance between the transmitting station and the receiving station by the volume of signals. In many cases listeners have noticed that stations located thousands of miles away come in stronger than stations located only a few hundred miles distant.
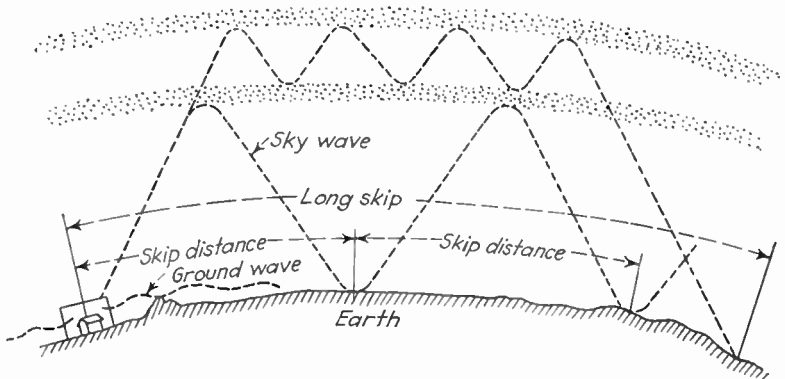


Fig. 4. Skip distance—night.

The shorter the wave length, the greater the skip distance. The skip distance for a 33-meter wave during the day is about 100 miles, and at night about 4000 miles.

The diagrams show why certain angles of sky waves produce fading and loss of programs. It has been proved for certain wave lengths that this angle of reflection is sharp enough so that the wave is lost to the receiving station in a very short distance. Experiments made by a well-known western broadcasting station showed that a portable receiving set placed on a truck would pick up strong signals at certain places, but when the truck was moved forward a distance equal to its own length, the signals would be lost entirely.

### Questions

**1.** What is skip distance?

**2.** Describe two causes for skipping.

**3.** What is the relation between wave length and skip distance?
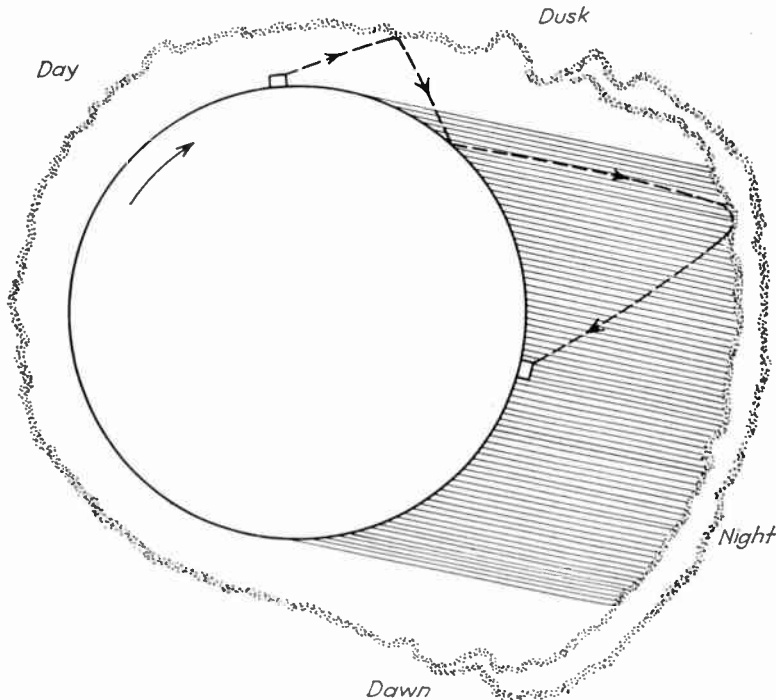


Fig. 5. Skip distance—dusk.

**4.** What is likely to happen to radio waves which are sent nearly straight up?

**5.** What is likely to happen to waves which are sent out in nearly a horizontal direction?

### 6. RECEPTION AT SUNRISE AND SUNSET

**Twilight Zone.** Radio waves that travel over long distances often must pass through zones of sunrise or of sun-

set.   In these zones the two high Heaviside night layers
change to one low day layer.

The reception of short-wave signals and short-wave pro-
grams becomes weak or is lost entirely during the sunrise
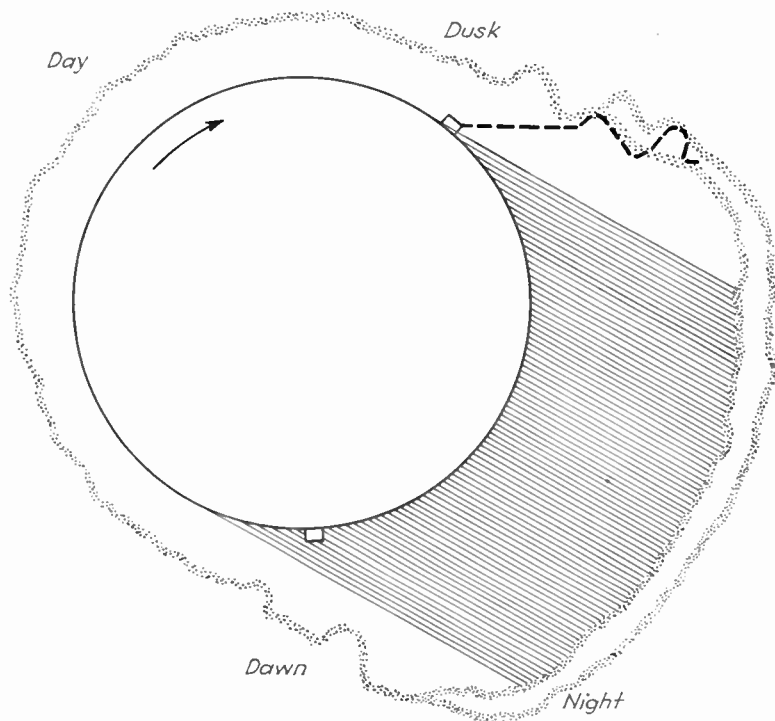or sunset period.



FIG. 6.   Lost signals—dusk.

Let us examine the wave action across the sunrise and
sunset zones more carefully.   When a wave travels from
daylight to darkness as in Fig. 5, the wave has skipped the
twilight area by reflection between the earth and the Heavi-
side layers.   Or perhaps, the dawn or twilight area was
closer to the transmitting station so the wave travel was

as shown in Fig. 6. Here the waves are weakened, distorted, or lost in the change between layers.

Now, if the wave starts in a night zone so it enters the twilight zone, as in Fig. 7, it will be lost in the disturbed
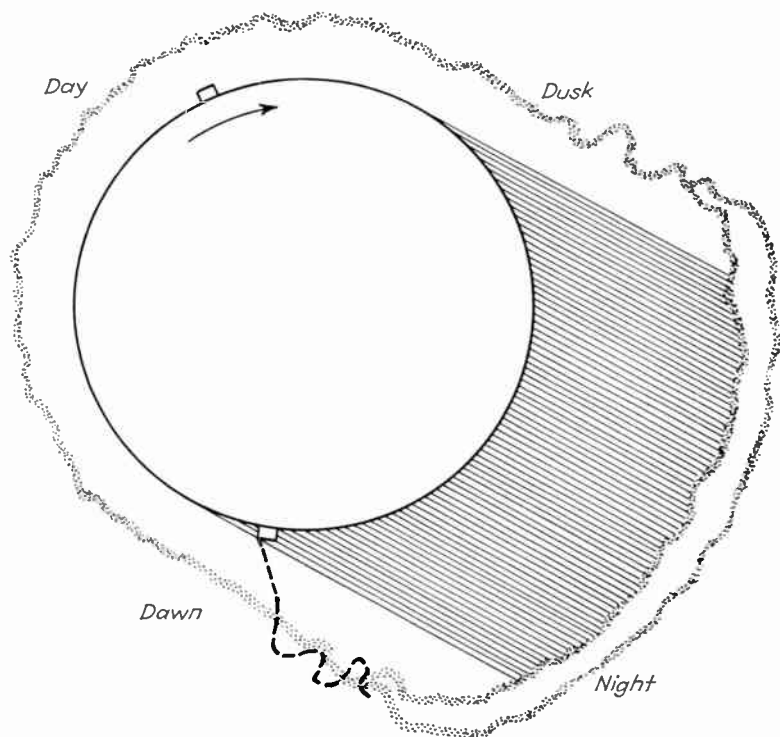


FIG. 7. Lost signals—dawn.

conditions between the different levels of the Heaviside layers.

**Night Reception.** Broadcast reception is greatly improved at night. Greater distances are covered, and the music is stronger. Short-wave reception above 20 meters also works better at night. Below 20 meters or thereabouts the night reception is poorer than day reception.

The amateur uses the 160-meter band for comparatively local work both for day and night operation. The 80-meter band reaches out farther. Operations at 40 meters cover great distances. The 20-meter band covers good distance during the day, but it is very poor at night, while the other wave-length bands seem much improved after dark.

### Questions

1. Make a drawing showing the positions of the Heaviside layers which are east of you shortly before sunset.

2. Show the type of Heaviside layer which is west of you shortly before sunset.

3. Make another drawing to show the types of Heaviside layers east of you shortly before sunrise.

4. Show the type of Heaviside layer which is west of you shortly before sunrise.

5. In what direction is it usually easier to send radio messages shortly before sunset: east? or west?

6. In which direction is it usually easier to send shortly after sunset: east? or west?

7. In which direction is it usually easier to send before sunrise: east? or west?

8. In which direction after sunrise: east? or west?

9. Name the amateur bands which are often best for daylight reception and those which are best for night reception.

### 7. FADING

Of the many interesting explanations for fading we will discuss but three.

**Interference between Ground Wave and Sky Wave Causes Fading.** Assume that you are close enough to a broadcasting station for the ground wave to reach your set. It could be possible for the sky wave to reflect up about 200 miles to the Heaviside layer and back down 200 miles to your set so that you would be able to get waves from either the ground wave or the sky wave (see Fig. 8). But the sky wave has traveled a greater distance than the ground

wave, and, consequently, the waves that come to you over the sky wave arrive a little later than the ground wave. A radio engineer would say the two waves are "out of phase." The result is that two sets of waves interfere and the waves are weakened or completely stopped.

The height of the Heaviside layer constantly changes; and when the Heaviside layer rises, it increases the reflection distance, and the sky wave goes beyond your set. When the Heaviside layer drops, the wave reflects on the near side of your set. Both times you hear the signal over
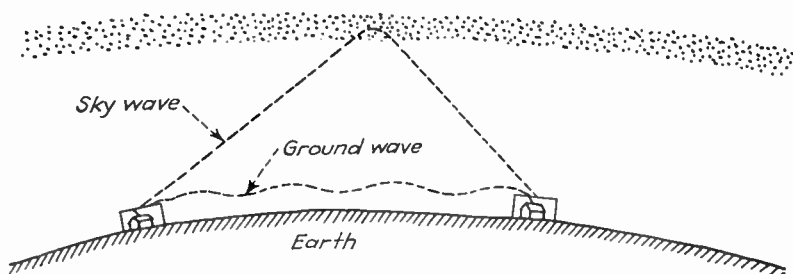


Fig. 8. Cause of fading—day.

the ground wave, but when the sky wave and the ground wave reach your set together, the signal is stopped or distorted.

**Interference between Two Sky Waves Causes Fading.** Another possible type of fading may occur if the set is beyond the ground wave and is receiving signals from two sky waves (see Fig. 9). One wave is reflected directly from the Heaviside layer to your set. Another set of waves from this station may have been reflected back and forth between the two Heaviside layers. If the upper wave should break through and travel to your set, you might receive signals from two different sets of sky waves. The one traveling between the two Heaviside layers may have traveled a shorter or longer distance than the other, and as

a result it brings the signal sooner or later than the first wave.
These two waves are out of phase and weaken the signal.

**Billowing of Heaviside Layer Causes Fading.**    Another
cause of fading is the billowing of the Heaviside layer.
Suppose you are a long distance from the transmitter
and in just the right position for the sky wave to reflect
down from the Heaviside layer and hit your set.    You are
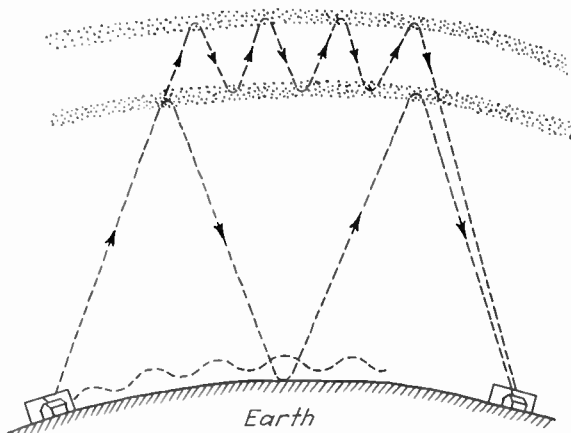far enough away to receive no ground wave.    As the



Fig. 9.    Cause of fading—night.

Heaviside layer rises or billows upward the wave hits the
ground beyond your set and the station fades out.    Then
as the Heaviside layer comes down again, the wave drops
back and the wave falls on the other side of your set.

The Heaviside layer may billow up and down so rapidly
that it is possible for the wave to come in and disappear
several times in a few minutes, or sometimes the fading may
be very slow.

### Questions

1. Describe three causes of fading.
2. What causes a station to fade in and out quite rapidly?

## 8. WAVE LENGTH AND FREQUENCY

**A Way to Compare High and Low Frequencies.**   Let us compare high and low frequencies by the speed of vibration of two sticks.   If we fasten the lower end of a yardstick in a vise, then pull back the upper end and release it, the stick will vibrate back and forth several times at a low frequency. Now, if we move the stick down so that it extends only 1 foot above the vise, pull it back and release it, it will vibrate very much faster or at a higher frequency than the long stick.   From this we see that frequency refers to the number of times the stick vibrates in a second.

Suppose that when the yardstick moves to the right, it sends out a wave crest through space.   Now, such waves travel at a certain fixed speed.   So when the frequency of vibration of the stick is low, the wave crests started by the motion of the stick are far apart.   But if the stick is shortened in length, its frequency of vibration is very much higher (faster) and the distance between waves—which travel at the same speed as before—very much less.   The wave length is shorter, but the frequency is increased.

In a 40-meter wave, or one in which the wave parts of greatest strength are only 130 feet apart, we find that nearly 7,500,000 wave crests (7500 kilocycles) strike the aerial in a second.

We cannot count the number of waves striking the aerial each second, but we can figure out the number from the speed of electron flow and the length of the aerial-ground wire.

**Broadcast and Short-wave Bands.**   Most amateurs are familiar with the difference in the length of short waves and of long waves, but few realize the extreme differences in the lengths of other waves.   They do not realize that the radio wave lengths are only a small part of the many
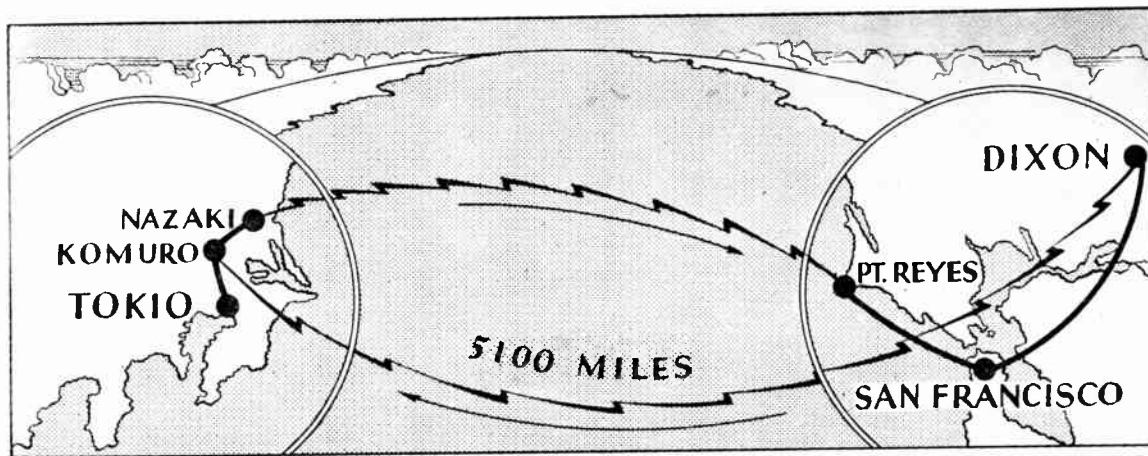
*Courtesy Pacific Telephone and Telegraph Co.*

SHORT-WAVE RADIO CONNECTIONS BETWEEN NORTH AMERICA AND ASIA

The short-wave radio telephone channel shown here is 5130 miles long. Telephones in the United States, Canada, Cuba, and Mexico are interconnected with telephones in Hondo, the principal island of the Japanese Archipelago. Dixon and Nazaki are sending stations. Point Reyes and Komuro are receiving stations.

possible wave lengths.    Also, they do not realize their very interesting uses and applications.

Let us discuss some other commonly used wave lengths. Certain naval services use waves up to 25 miles or about 40,000 meters in length. These are very low-frequency waves. The ordinary broadcast band uses waves of lengths between 550 meters and 200 meters (500 kilocycles to 1500 kilocycles in frequency). The short-wave amateur sets operate on several wave bands. It is possible to use radio waves of any length for radio purposes. The reason they are not all used is that interference is produced between sets if the bands are too close together.

Experiments show that the wave lengths from 20 meters up penetrate buildings, trees, and into the earth or water a certain distance. This fact is interesting here, since we find that the shorter wave lengths act in a very different manner.

**Ultrashort-wave Bands.** The wave lengths below about 10 meters (the ultrahigh frequencies) act much like light waves. These waves do not seem to penetrate objects as do the longer waves, but are reflected from buildings and hills as light is reflected from a mirror. Certain objects stop the waves entirely. It is not always possible to send or receive messages with these waves, unless the stations are in sight of each other, or unless a system can be developed that will permit the wave to be reflected from one station to the other, because the ultrahigh-frequency sky wave is not reflected back by the Heaviside layers in the same manner as ordinary radio waves.

### Questions

1. What do we mean by saying a radio wave is 400 meters in length?
2. Explain the meaning of the term *frequency*.
3. What is the meaning of the word *kilo?*
4. What is the wave length of a radio wave that has a frequency of 1500 kilocycles?

**5.** What is the frequency of a radio wave 500 meters in length?

**6.** What is the range in meters for the broadcast band? in kilocycles?

**7.** What is the range in meters for the short-wave sets? in kilocycles?

**8.** What is one striking difference between a 5-meter wave and a 200-meter wave?

### 9. HOW RADIO WAVES ARE MEASURED

**Wave Lengths or Spacing.** Water waves vary in size or strength and so do radio waves. The size of a water wave is measured by the distance from the crest of one wave to the crest of the next wave. We can measure the
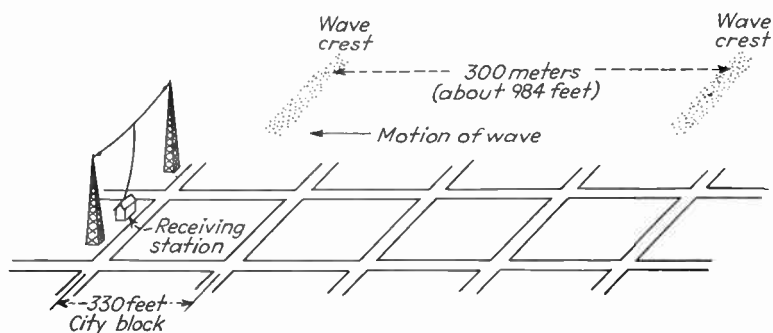


Fig. 10.   Wave length.

length of a radio wave by measuring the distance from one point of great intensity to the next point of similar great intensity (see Fig. 10). This distance is called the wave length. *But no amateur should ever make the mistake of believing that radio waves look like a water wave traveling through the air.*

Wave length is a term used to describe the spacing between like parts of waves, such as shown in the diagram. This distance is generally given in meters. A meter is about $39\frac{3}{8}$ inches or a little over a yard in length. When we say that a wave is 300 meters in length, for example, we mean that the distance between the like parts of the

wave is 300 meters. This is about 975 feet. A 300-meter wave is used in broadcasting. An amateur wave that is very popular is one around 40 meters in length. The strongest part of the 40-meter wave is about 130 feet between corresponding points.

**Another Way to Measure Wave Lengths.** Radio waves may be measured by counting the number of like changes in intensity which strike an aerial in a second. There are no radio waves in a wire. When radio waves strike a wire, they cause electric currents to flow in the wire.

Frequency as applied to these waves means the number of waves which will strike the aerial each second. A radio wave is more commonly described by giving its frequency than by giving its wave length.

We know that radio waves move at a speed of 186,000 miles a second. Now, if the crests of a wave are 300 meters (about 975 feet) apart and are traveling at this terrific speed, approximately 1,000,000 wave crests will strike the aerial in one second. The frequency of this 300-meter wave is 1,000,000 cycles per second. Instead of saying 1,000,000 cycles, we usually shorten it to 1000 kilocycles, or sometimes 1000 kc.

### Questions

1. Explain the term *frequency*.

2. Tune your home broadcast receiver to a station of known wave length. Then estimate how far down the street a wave crest is at the instant when a like crest strikes your set.

### 10. OTHER TYPES OF WAVES

**Heat Waves.** When the wave length is shortened to about an inch or less, it is no longer called a radio wave but is known as a heat wave. The heat waves are shorter and their frequency is greater. Heat waves vary greatly in length. The shorter they are the hotter they feel. When

you feel the heat from a stove on your hands, the stove is "broadcasting" to you on an extremely short wave length. During the World War, heat waves were generated, focused, and controlled so that it was possible to send messages on them.

**Light Waves or Rays.**   Short waves are known as rays. When the heat rays get quite short, they are no longer known as heat rays but are called infrared rays.   If the wave length of these rays is shortened just a little more until their length is 81 millionths of a centimeter, they are visible to the eye and are seen as red light.   As the rays get still shorter, they are seen as orange light, then yellow, green, blue, indigo, and violet.   The violet light is the shortest ray visible to our eyes and is 31 millionths of a centimeter long.   The length of light rays can be pictured easily by imagining an ordinary human hair which has been split lengthwise into 100 pieces.   The thickness of one of these pieces is approximately the length of a light wave.

In other words, the light waves which we see are just the same as radio waves, but they are shorter.   The radio receiver, then, is a machine for "seeing" waves that are too long for our eyes to "tune in" or for the nerves in the skin to feel.   The receiver changes these waves into sound.

As the waves become shorter than 31 millionths of a centimeter, they again become invisible and are known as ultraviolet light.   These rays play a powerful part in making possible long distance reception by short waves, as we have seen.

**X Rays.**   The next shorter wave that is interesting to us is called the X ray.   It has a wave length of 1 billionth of a centimeter; or it is about one $\frac{1}{1000}$ as long as visible light rays.   The X ray has a property similar to that of the radio wave and different from that of the light waves, in that it can pass through wood and other opaque or nontransparent

objects. Dense objects like iron and lead, however, will stop the X rays.

**Cosmic Rays.** The shortest wave known is the cosmic ray. Its wave length, about $\frac{1}{45}$ the length of the X ray, produces such enormous power that it will penetrate over 14 feet of lead. The cosmic ray is the "headliner" at present among the different waves when it comes to getting into the newspapers.

There are many other rays which we have not mentioned, because too little is known about them or they are not commonly used. There seem to be but few breaks or gaps in the wave bands between the shortest (cosmic) waves and the longest (radio) waves.

### Questions

1. What are the wave lengths of light rays?

2. Can radio waves pass through a wooden building? Can light waves? Can X rays?

3. Discuss some newspaper article which you have read on cosmic rays.

4. What are waves a fraction of an inch in length called?

5. Can messages be sent on waves which are a fraction of an inch in length?

### 11. HOW RADIO WAVES ARE PRODUCED

**Electron Motion Starts Radio Waves.** Electrons are set in motion in a wire by a generator, a battery, or a magnetic field. Vacuum tubes may also cause electrons to be set in motion in a wire. The transmitter causes electrons to flow back and forth in the aerial thousands or millions of times a second. The motion of electrons flowing in the aerial produces a magnetic field around the wire (see Fig. 11). This magnetic field of force is the direct result of the motion of the electrons, and it is formed regardless of whether the electrons are moving in a wire or through air. The more electrons in motion, the greater the magnetic field.

The magnetic force surrounds the moving electrons and never gets far from them, but it produces a new kind of energy which flies off into space and leaves the electrons
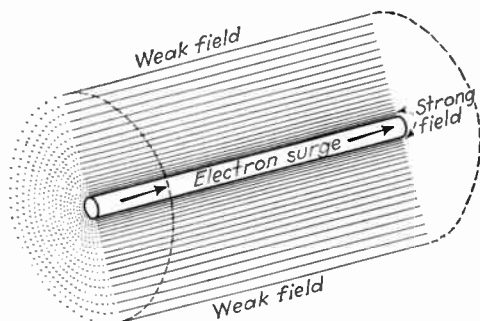


FIG. 11.    Magnetic field around a wire.

forever (see Fig. 12).    This new energy is popularly known as radio waves, and is easily thought of as a "wave" because it does not move with a steady flow, but seems to be pulsat-



FIG. 12.    Magnetic field starts radio waves.

ing.    That is, if we examine the effect created by a radio wave, we find that parts of the wave seem to possess much energy and other parts little energy.

### Questions

1. What determines the strength of a magnetic force in a wire?

2. In order for an aerial to throw off radio waves, what must be moving in the wire?

3. Do all parts of a radio wave possess equal amounts of energy?

### 12. STATIC

**Cause of Static.**    Static is a term that is usually applied to disagreeable hissing, crackling, or popping noises in the

receiver caused by atmospheric electricity. Static may be caused by a running motor, or by a leaky insulator on a power line from which current is leaking off to the pole. These send out radio waves, or static, most of which cover a wide band of frequencies and cannot easily be tuned out.

The radio waves from a spark jumping across an insulator to the power pole may be picked up on neighboring sets regardless of what station is tuned in. This spark will cover the whole band of long and short waves. Sets have been developed, however, with tuning adjustments that cut out most of this interference. Static is no longer the problem it used to be because it can be eliminated in most good receivers at present. It is only strong static from the nearby arcing of current across a leaky insulator, or something of that nature, that interferes with these sets. So-called "light" waves or "strays," invisible to the eye, wander around through the sky and Heaviside layer at night and give much trouble to the older types of sets in the form of static, but most of these can be screened out in new receivers.

**Shielding against Static.** Lightning and northern lights send out powerful waves which interfere with programs. Diathermy machines are considered a serious offender in sending out static.

Sparking at the brushes of washing machine motors causes static. Static is eliminated on a noisy motor by putting grounded condensers across the wires to the base plug or power outlet. A good illustration of this is in auto radios. Each spark plug is shielded and grounded and the car can run with little or no interference to the radio reception. Amateurs operating receivers on the higher frequencies can hear the static from the ignition system on unshielded cars passing their stations.

## Questions

1. Make a list of causes of static.
2. List some ways by which static may be overcome.

## Technical Terms

**aurora borealis**—A beautiful colored display of streamers and lights caused by a thick ion cloud in the sky over the north pole. A similar display at the south pole is called aurora australis.

**broadcast bands**—Wave lengths from 550 meters to 200 meters (500 kc. to 1500 kc.).

**fading**—The decrease in strength or total loss of a received signal.

**frequency**—*See* wave length and frequency.

**ground wave**—The radio wave which travels along the earth for comparatively short distances.

**heat**—Waves from 1 inch to about 81 millionths of an inch in length. These waves cause the sensation of warmth when they fall on the skin.

**Heaviside**—An English scientist who developed the theory of the Heaviside layer at the same time Kennelly developed a like theory in America.

**Heaviside layer**—A stratum or layer of electrified particles of air that blankets the earth at from 60 to 200 miles in height.

**high frequency**—Short waves oscillate at high frequency.

**ionization**—The partial breaking up of atoms or molecules into electrical charges. At the instant of ionization the atoms or molecules either gain or lose electrons.

**in phase**—Waves coming together so as to add like effects.

**light**—Waves of the correct length to affect the eye. Light waves are from 81 millionths of a centimeter to 31 millionths of a centimeter long.

**low frequencies**—Long waves oscillate at low frequency. Short waves oscillate at high frequencies.

**Marconi**—The Italian scientist and inventor who made the first practical application of the principles of telegraphy without wires.

**out of phase**—Waves coming together so as to oppose each other in effect.

**radio waves**—An effect that travels through space at the speed of light (186,000 miles a second).

**short-wave band**—Waves between 200 meters and 10 meters in length.

**skip distance**—The distance between the points where the reflected sky wave returns to earth.

**skipping**—Billowing or raising and lowering of the Heaviside layer causes reflected waves to strike the earth over certain areas and to miss or skip other areas.

**sky wave**—The radio wave which travels to the Heaviside layer and is reflected back to earth.

**sunspots**—Huge holes torn in the sun's surface by explosions of gas.

**twilight zone**—The part of the earth and the sky between daylight and darkness.

**ultrashort waves**—Waves shorter than 10 meters and longer than about an inch.

**ultraviolet rays**—Waves just too short to be seen; waves shorter than 31 millionths of a centimeter and longer than 1 billionth of a centimeter.

**wave bands**—A group of frequencies or wave lengths. Light wave lengths cover a narrow band of frequencies, as do amateur wave lengths, the police wave lengths, and the broadcast wave lengths.

**wave distortion**—Changes in the form of the sky wave in passing through the twilight zone.

**wave length and frequency**—As the frequency of a wave increases, its length gets shorter, provided it continues to travel at uniform speed. Contrariwise, a lower-frequency wave has a longer length. Short waves vibrate at high frequencies.

**wireless**—A word commonly used when referring to radio telegraphy.

**X ray**—Waves about a billionth of a centimeter long. X rays penetrate wood, metal, and many other materials through which light or heat will not pass.

# CHAPTER II

## WAVE-FORM PICTURES

The action of alternating-current surges and the "flow" of direct currents in even simple radio circuits is exceedingly difficult to explain. But we can draw line pictures which show the action of currents that would take many words to explain.

In this chapter we shall learn the appearance of the wave-form pictures of the simple alternating and direct currents and also learn how to read their meaning.

If a cathode-ray oscillograph is available, you can see the actual instantaneous wave shape of a current by a moving colored line. This makes the study of the simple wave forms much more vivid and clear.

We can now study the radio transmitting and receiving process clearly by using wave pictures.

### Contents of This Chapter

28

## 1. A WAY TO STUDY ELECTRON FLOW

**What Are Wave-form Pictures?** It is often extremely difficult if not impossible to explain in words the action of the alternating currents flowing in even the simpler radio circuits.

In some cases this action can be shown clearly by means of electron-flow arrows on a diagram. But to show the action of these currents, it is customary in electrical and radio
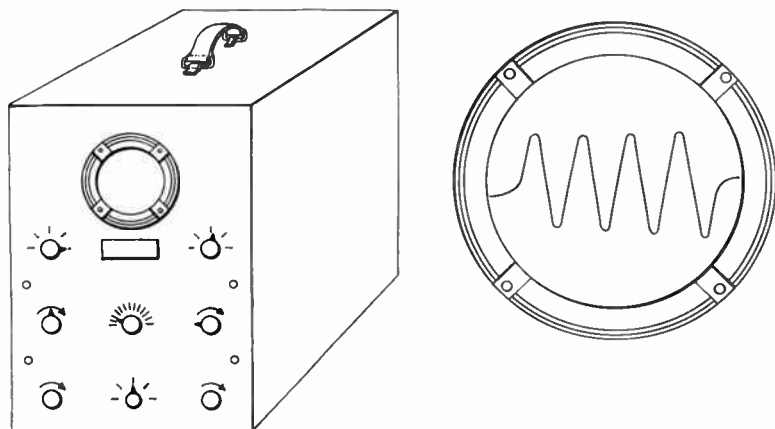


FIG. 13. Cathode-ray oscillograph and wave-form image.

discussions to draw diagrams called "wave-form pictures." An informed student or amateur must be able to read many kinds of diagrams and to understand their meaning.

**How Can the Wave-form Pictures Be Seen?** Of the many explanations used to introduce the nature of electricity to a student none has been as clear and as valuable as the recently perfected cathode-ray tube used in the cathode-ray oscillograph (see Fig. 13). The wave forms shown by the oscillograph make clear the action of electricity as it flows in radio circuits and through the simple circuits of ordinary electrical apparatus used in the home or elsewhere.

In the oscillograph a stream of electrons traces a glowing path on the coated interior of the cathode-ray tube. The stream of electrons is shot from the cathode of the tube at a terrific speed against the coated portion, called the screen, inside the end of the tube. Here the electron stream causes a greenish glow as it strikes the chemical on the inside of the glass. This glow can be seen from the front of the oscillograph. Connections are made from the circuit which is to be studied to the oscillograph. Electrons from the currents flowing in this circuit are led into the cathode-ray tube,
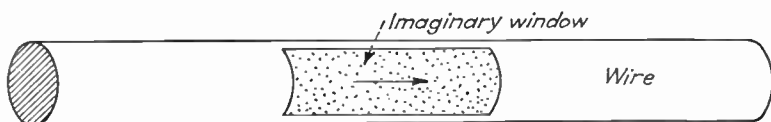


Fig. 14.    Electron flow.

where they affect the stream of electrons flashing off the tube cathode.

When the oscillograph is properly adjusted, the electron stream traces on the screen of the tube lines or curves that show in clear form the action of the electrons as they flow in the circuit that is being studied.

How much simpler than the use of diagrams that have been drawn or the use of wordy explanations! The trace of the line or the curve can be seen and studied at the pleasure of the student.

**How the Oscillograph Wave Pictures Are Used.** The diagrams in this chapter show the actions of electrons flowing in different types of circuits, and also both the direct-current wave shape and the wave shape of the flow of an alternating current traced on the tube screen.

These diagrams are made from the traces of the cathode-ray oscillograph. The traces have been taken apart for study and have been simplified. We shall study, then, parts of

wave-form pictures redrawn from the curves traced on the oscillograph screen by the millions of dancing electrons.

## 2. SYMBOLS USED IN WAVE PICTURES

A symbol is an abbreviation used to show a piece of apparatus in a drawing. Accurate pictures of each piece of apparatus needed in circuit diagrams (hook-ups) would be hard to read and hard to draw. The symbols used here are drawn so as to look somewhat like the part they describe.
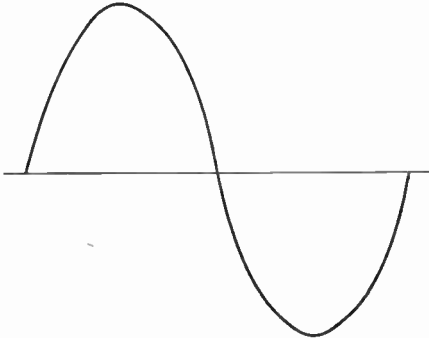
Fig. 15. The sine curve.

**electrons** — Electrons flowing in a wire are shown by dots (see Fig. 14). The strength or amplitude of the current is shown by the thickness of the dots. A strong current is one in which many electrons flow. The arrow shows the direction of the flow of the electrons.

**sine curve** — A curve of the shape shown in Fig. 15 is very common in mathematics, finding many uses in

Amplitude or current-strength measuring line

Time line
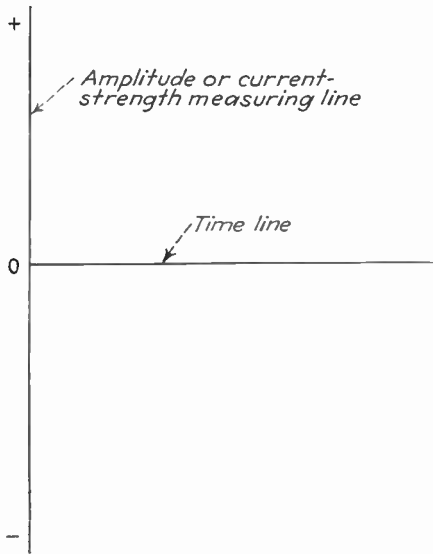
Fig. 16. Base lines for wave pictures.

algebra, trigonometry, calculus, etc.    This curve shape
is much used in the mathematical treatment of electrical
and engineering problems.    The sine curve is useful in
showing variations of current flow in radio and electri-
cal circuits.    The word *sine* has no special radio mean-
ing.    It simply is the name of curves of this shape.

**wave-picture base lines**—The sine curve width is measured
on the time line and the height of the loops is measured
on the amplitude line (see Fig. 16).    These two lines
are the base lines.

### 3. THE ELECTRON FLOW IN AN ALTERNATING CURRENT

**What Is Electricity?**    All atoms are complicated struc-
tures composed of positive, negative, and neutral particles.
The negative particles are called electrons.    Some of these
negative particles can be temporarily driven away from the
rest of the atom.

Let us assume that a current of electricity is some kind of
motion, or surge, of these electrons in a wire.

The individual electron may travel only a short distance
in the wire.    It causes other electrons to move.

A direct current is a steady motion of electrons along the
wire in one direction.    This progressive motion of electrons
in the atoms occurs without any individual electron moving
more than a fraction of an inch.

This is a commonly accepted explanation of the nature of
electricity.

**Compare Electrons to Shot.**    Let us compare the elec-
trons of an alternating current flowing in a wire to something
with which we are familiar.    An alternating current is
made up of surges, or pulsations, of electrons flowing first
in one direction, then in the opposite direction.    If we could
see electrons flowing back and forth in a wire, we should
find that each pulsation looked much like a slow-motion

picture of a charge of shot flying through the air after it had been fired from a shotgun (see Fig. 17).

In the shot picture a few scattered pellets fly ahead of the main group of shot. They break the way through the air for the rest of the group, as it were. The number of shot rapidly increases, until at the middle of the group the shot
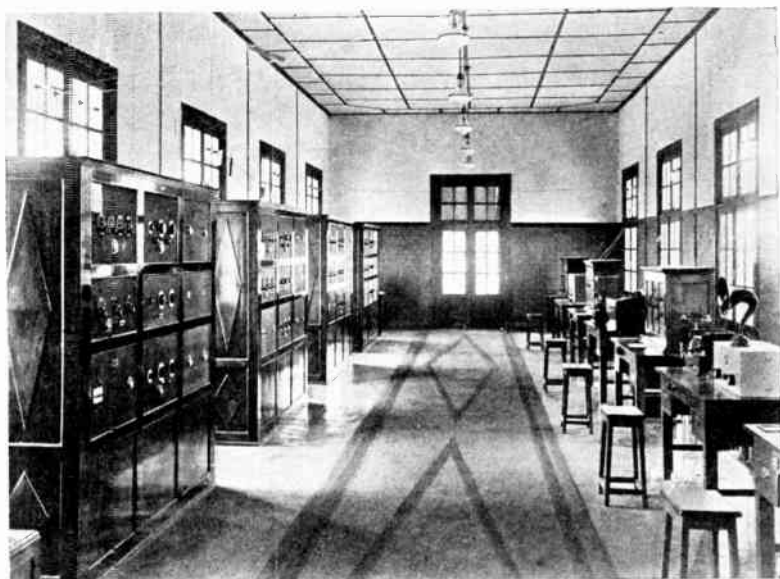


*Courtesy Pacific Telephone and Telegraph Co.*
RECEIVERS FOR SHORT-WAVE AT BANDOENG, JAVA
The equipment shown was all built "on the spot."

are thickly bunched together. Then the shot group tapers out until only a few scattered pellets are seen at the end of the group.

**An Imaginary Window.** Think of an imaginary window through which we can look into the wire and see the motion of the tiny electrons which make up the current of electricity (see Fig. 17). We see each pulsation of alternating current led by a few scattered electrons rushing through the wire.

As in the shot picture, this vanguard of electrons is followed
by a gradually increasing group, until at the center of the
surge many electrons are closely packed together.     The
group then tapers out to a few stragglers, after which no
electrons flow.     The flow now starts in the opposite direc-
tion, gradually increases, then dies away.     This process is
repeated 120 times a second in the house lighting circuit.
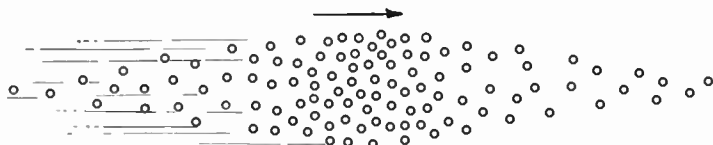


A charge of shot after leaving the muzzle of a gun
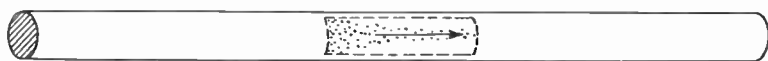


Electrons flowing in a wire
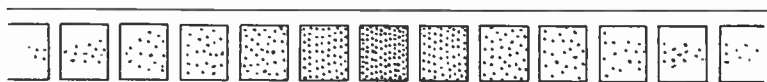


Slow-motion picture of electrons as seen through imaginary windows

Fig. 17.    Electron motions in an alternating current compared to grouping of a
charge of shot.

**Electron Speed.**    It is interesting here to ask: "How far
could one surge of these electrons flow through a wire in $\frac{1}{120}$
of a second?"

The electrons in a wire travel at the speed of light, which
is slightly over 186,000 miles a second.    If this surge of
electricity traveled in a long, straight wire, in $\frac{1}{120}$ of a
second (the time it takes for each pulsation to pass the
imaginary window through which we are looking) the first
electron disturbance would have time to travel 1550 miles
before the last part of the pulsation is seen through the
window.

A pulsation travels fast enough to go from Salt Lake City to Chicago and back in $\frac{1}{60}$ of a second.

### Questions

**1.** Is there a steady flow of electrons in an alternating current?

**2.** Do the electrons in an alternating current always flow in the same direction?

**3.** How does the speed of an electric current compare with the speed of light?

**4.** Are the electrons closely bunched in an alternating current?

**5.** A current starts flowing through a wire stretched around the earth at the equator. How many times could this current flow around the earth in one second?

### 4. A 60-CYCLE ALTERNATING-CURRENT WAVE ON THE OSCILLOGRAPH

*Step* 1. Plug the cord from the oscillograph into an alternating-current outlet. Turn the intensity switch a quarter turn to the right. Set gain 1 at zero.
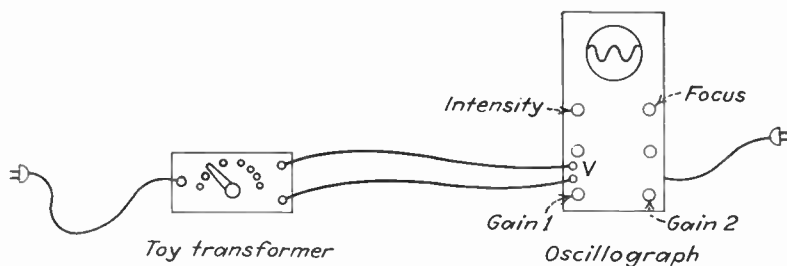


Fig. 18. A 60-cycle wave on the oscillograph.

*Step* 2. Connect wire from the bell or toy transformer to the vertical posts of the oscillograph (see Fig. 18).

*Step* 3. Turn up the intensity until a green line is clearly visible on the screen. Set gain 1 half on.

**Caution!** Set gain 2 full on (turn to left) so a line will show on the screen. If a small dot appears turn gain 2 to spread the dot into a line. A dot will burn the screen and

destroy the sensitivity of the chemical coating over a small area.

*Step* 4.    Turn gain 1 until a moving green line shows on the oscillograph.

*Step* 5.    Adjust the focus control and the intensity control together until a sharply defined narrow line is seen on the screen.    Adjust the two gain controls until a sine curve with an amplitude of an inch (the curve 1 inch high) shows on the screen.

This is the wave picture of the 60-cycle alternating current.    This is the sort of current delivered by many electric light plants.

### 5. THE CONSTRUCTION OF THE WAVE-FORM PICTURES

Let us describe a practical method of picturing an alternating current by making a drawing called a wave-form picture.    Let us see first what each part of the picture means.

**The Time-measuring Line.**    We will draw a horizontal line called the time line (see Fig. 19).    On the time line we will mark off equal spaces which show the time required for each pulsation of the alternating current.    In a 60-cycle current, the first point marked off would be $\frac{1}{120}$ of a second from the zero mark for the first half-cycle.

**The Current-strength Line—Amplitude.**    Now we need a line to use for measuring the strength of the current surges. We will draw a vertical line for this purpose (see Fig. 19). It is called the amplitude or current-strength line, and it too is marked off in equal spaces.

Let us draw a line that will show the number of electrons flowing in the wire at any instant.    We will place this line close to the time line when few electrons flow and move it away from the time line when many electrons flow (see Fig. 20).
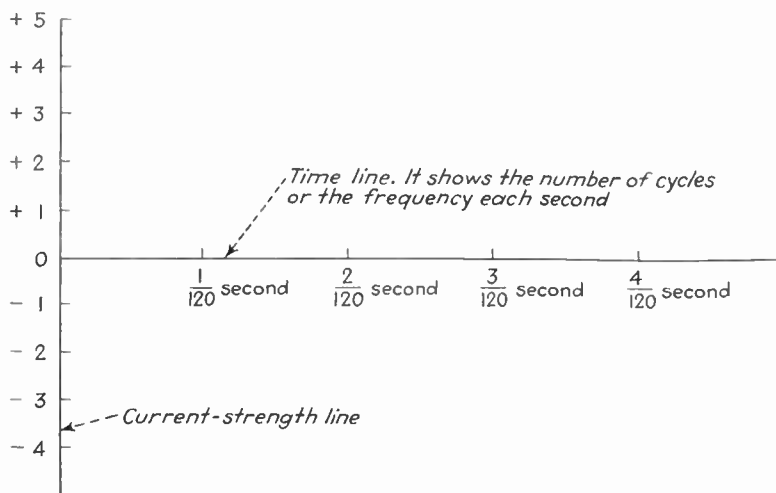
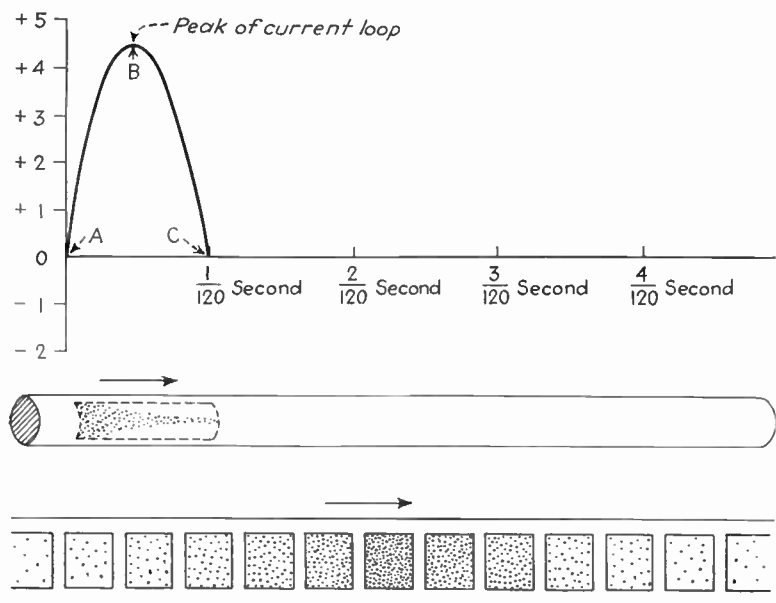FIG. 19.   Base lines for wave pictures, with measurements.



FIG. 20.   A current loop.

A curving line shows a changing current. When the line slopes *away* from the time line, the current is getting stronger. When the line is drawn *toward* the time line the current is getting weaker.

**The Current Loops.** While watching a surge of current through the imaginary window in the wire, at first we see only a few electrons passing. The number increases rapidly until at the center of the surge a great many electrons flash past. They then thin out until only a few and finally no electrons are seen. The wave-form picture of this current flow is a curved line. The strength or amplitude of the current is shown by the height of the current-strength curve and is measured on the vertical amplitude line.

The picture of our alternating current is drawn as a curve which crosses the time line at regular intervals. When no current flows, the curve touches the time line (see *A*, Fig. 20). As the current strengthens, the curve is drawn farther away from the time line (at *B*, Fig. 20). As the current decreases in strength, the curve draws nearer *C* (Fig. 20). Each curve is called a current loop.

**Positive and Negative Loops.** Let us agree that electron flow in one direction in a wire will be called *positive*, and a flow in the opposite direction *negative*. A loop is drawn above the time line to represent a positive direction of electron motion, and a loop below for a negative motion.

It has become standard practice to draw the positive loops above and the negative loops below the time line. This is done only as a matter of convenience.

**The Positive Loops.** The wave picture in Fig. 20 shows a positive loop of current. At point *A* the electron flow has just begun. At point *B*, the peak of the curve, the greatest number of electrons are flowing. At point *A* on the curve the current has almost stopped flowing.

**The Node—a Point of No Current.** At the $\frac{1}{120}$-second point on the time line, no current curve can be drawn on the wave-form picture, since the current flow has momentarily stopped. This is shown in Fig. 21. The action of the electrons here is somewhat similar to that of a pendulum at the end of its swing. It stops for just an instant before
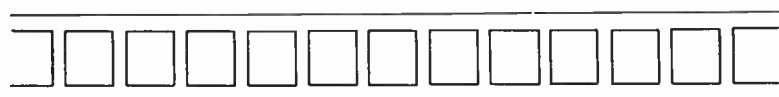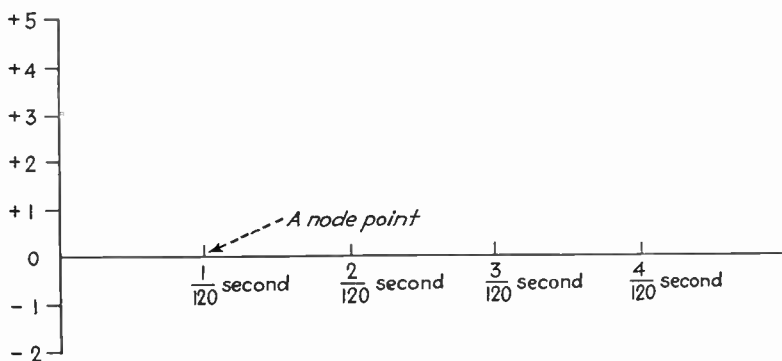


FIG. 21. The node; no current is flowing.

starting the back swing. The electrons, too, stop for just an instant before starting their return journey in the opposite direction. The point on the time line where no electrons are flowing is called a node.

**The Negative Current Loop.** Now, in the wave picture in Fig. 22, we see the same electron travel occurring as we saw in Fig. 19. But here the current flow is in the opposite

direction.    We draw the curve as in Fig. 19, but the loop is
now below the time line instead of above.    This curve is
called a negative loop, or a negative alternation of current
(see Fig. 22).
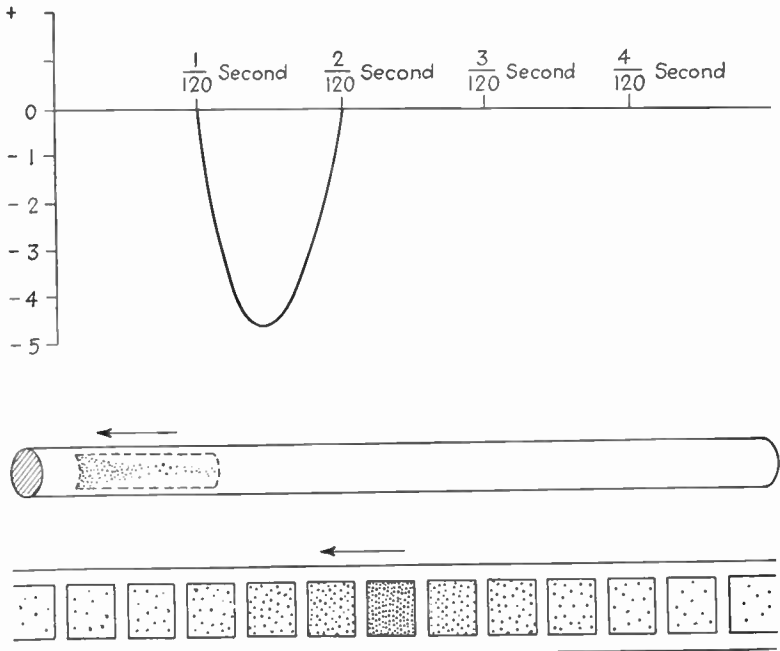


FIG. 22.    The negative loop; the second alternation of current.

**The Cycle.**    In the wave picture shown in Fig. 23, we
will combine a positive loop of current, where the electrons
flow in one direction; a node, point where no current flows;
and a negative loop, where the current flows in the opposite
direction.    The three parts combine to form a picture of
one complete cycle of alternating current.

Two alternations, which make one complete electron-
surge round trip, are called a cycle.
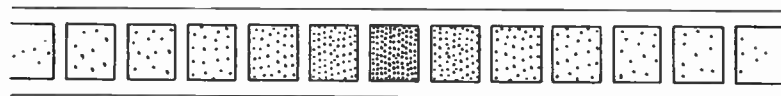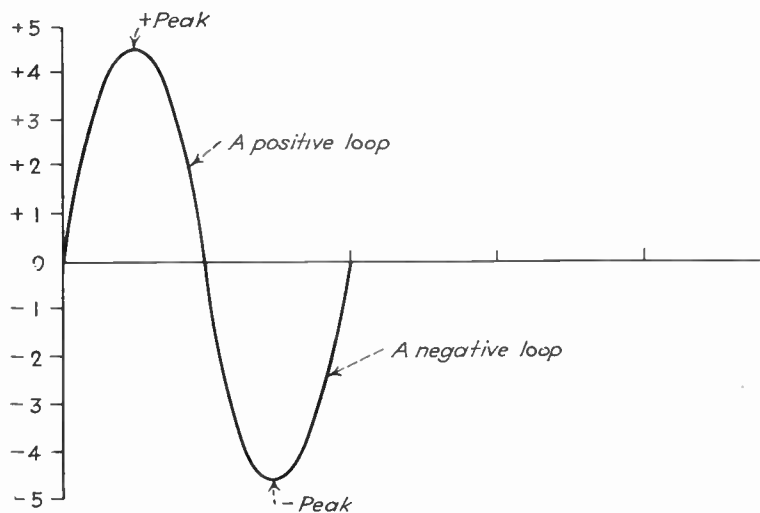
Direction of Electron Flow During Positive Loop
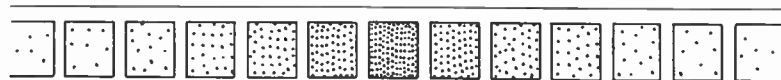
Direction of Electron Flow During Negative Loop

Fig. 23. A cycle of alternating current.

The mathematical name of this curve is a sine wave. The sine wave shape happens to follow the average shape of the curve drawn to show the electron flow in a wire.

### Questions

**1.** What is the purpose of the straight horizontal line in a wave-form picture?

**2.** What is the purpose of the straight vertical line in a wave-form picture?

**3.** Is a positive current represented above or below the horizontal line?

**4.** Where is the negative part of the cycle represented?

**5.** One loop above the line represents what part of an alternating current?

**6.** A wave-form picture including a loop above a line connected to one loop below the line represents what part of an alternating-current wave picture?

**7.** What are electrons doing at the instant shown by the node in a wave-form picture?



Toy transformor          Oscillograph
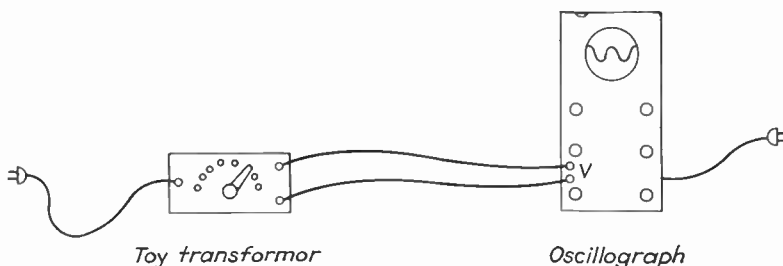
Fig. 24.   Current strength on the oscillograph.

### 6. CURRENT STRENGTH OR AMPLITUDE SHOWN ON THE OSCILLOGRAPH

The amplitude or current strength is shown by the height of the curve on the tube.   This is shown by the following experiment.

*Step* 1. Connect the 6-volt terminals of a toy transformer to the vertical posts on the oscillograph, as shown in Fig.

24. Plug the cord from the transformer into an alternating-current outlet.

*Step* 2. Adjust the height of the sine wave to $\frac{1}{2}$ inch by the vertical gain control.

*Step* 3. Reset the toy transformer to 12 volts. Measure the height of the loops. They should be exactly twice as high. (Do not change the setting of the gain control.)

*Step* 4. Repeat for different voltages. Check the height of the loops for each voltage.

### 7. AMPLITUDE—STRONG AND WEAK CURRENT PICTURES

**Current-strength Line—Amplitude Line.** Let us try out our wave-form picture now and see if we can use it to show
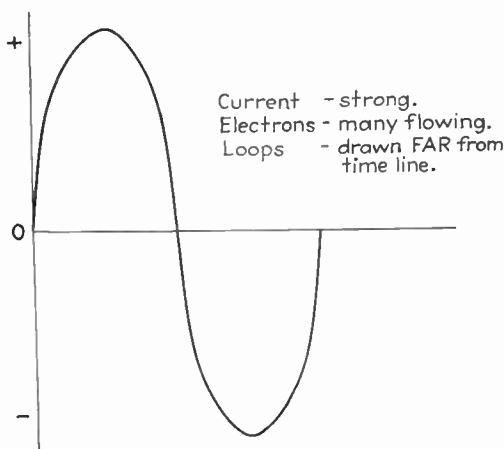


FIG. 25. Strong current, high amplitude.

current flow of different strengths. In Fig. 25, we can show a strong current by the use of this wave diagram.

**What Does a High Loop Mean?** Let us go back to our imaginary window in the wire. As we look through the window when a strong current is flowing, we find that many electrons are flowing through the wire. A high loop shows many electrons.

Now, the same scheme is used for showing a weak current. We find that the sine wave of a weak current

Current – weak.
Electrons – few flowing.
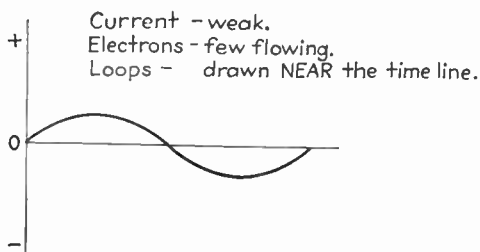Loops –    drawn NEAR the time line.

+

0

–

FIG. 26.    Weak current, low amplitude.

may be drawn as easily as for a strong current by making the loop low (see Fig. 26).    Looking through our imaginary window again, we see that now only a few electrons flow. Apparently our wave-form picture will be very useful.
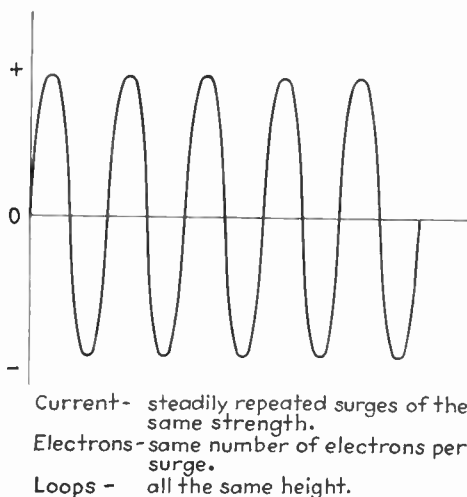
+

0

–

Current –  steadily repeated surges of the
                same strength.
Electrons – same number of electrons per
                surge.
Loops –     all the same height.

FIG. 27.    A 60-cycle alternating current of even amplitude.

Now, let us turn on the light in the room in which we are sitting and use our imaginary window to look into the

wires leading to the light. We can now watch the current
flow that lights the lamp overhead. We see the current
surging back and forth rapidly. If we could time each
surge, we would find that it moved past us and stopped,
then returned. The rate would be 120 surges per second,
or 60 round trips or cycles per second. We would notice
that the strength of each surge was the same. Figure 27
shows the wave-form diagram for the 60-cycle alternating
current.

## 8. HIGH AND LOW FREQUENCY SHOWN ON THE OSCILLOGRAPH

The frequency of a wave can be shown by the circuit
given in Fig. 28. The frequency is shown by the space
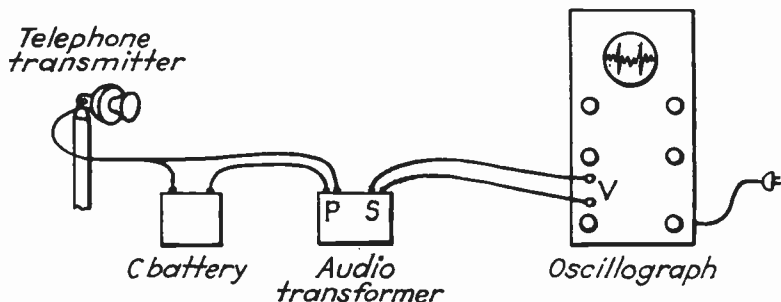


FIG. 28.   High and low frequency on the oscillograph.

between the loops on the time line. (No time line shows
on the oscillograph.)

*Step* 1. Connect a microphone, a C battery, and an
audio or microphone transformer as shown in Fig. 28.
Connect the secondary of the transformer to the vertical
posts on the oscillograph.

*Step* 2. Hum, whistle, or sound a sustained note into the
microphone. Adjust the two gain controls until the wave
is about $1\frac{1}{2}$ inches high and well spread on the imaginary
time line.

*Step* 3. Whistle into the microphone, starting at a very low pitch and gradually increasing the pitch as high as you can. Watch the spacing of the loops along the time line.

*Step* 4. Repeat with the voice.

### 9. WAVE SHAPES OF HIGH- AND LOW-FREQUENCY CURRENTS

**Frequency.** Now, let us try a new thing with the waveform picture. Let us slow up the time required for each surge and see how this current picture will be drawn. If we keep the same space on the time line for each hundredth of a second and we use a current changing direction or surging at only 10 cycles a second, we shall find that the



Current — weak.
Electrons — few flowing.
Loops — drawn far apart on the time line.

$\frac{1}{10}$ sec.  $\frac{2}{10}$ sec.

One cycle
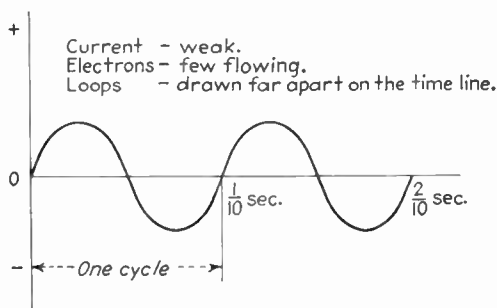
FIG. 29. Ten cycles a second; low frequency.

loops are much flatter and the distance between the nodes much greater.

The frequency of an alternating current is the number of cycles, or electron round trips, that occur in one second.

**Low-frequency Picture.** The picture in Fig. 29 shows a current having a frequency of 10 cycles a second. Ten round trips or cycles have occurred in 1 second. One surge of current has taken only $\frac{1}{10}$ of a second. This is known as a low-frequency current.

**High-frequency Picture.** It is easy then to see that a current having a frequency of 20 cycles a second would be

drawn as in Fig. 30, where we must bunch the number of cycles more closely together along the time line to show that many round trips occur each second. *High* as used here means fast—high rate of speed.
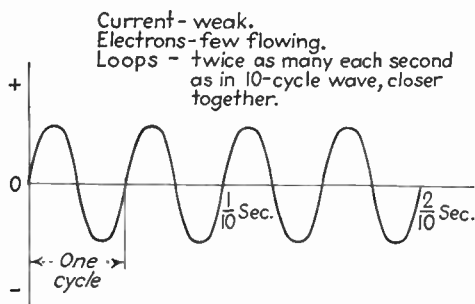
Current - weak.
Electrons - few flowing.
Loops - twice as many each second
          as in 10-cycle wave, closer
          together.



Fig. 30.  Twenty cycles a second; higher frequency.

Current - twice as strong as shown in Fig. 30.
Electrons - twice as many flowing.
Loops - drawn twice as far from time line,
         same spacing as for any 20-cycle wave.
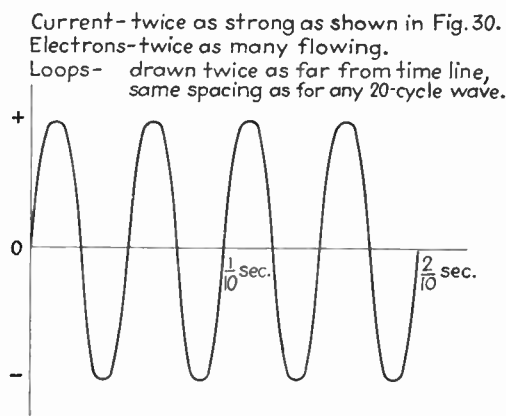


Fig. 31.  Twenty cycles a second; higher frequency, stronger current.

Frequency has nothing to do with the current strength. We may draw the loops either high or low depending upon the current strength for either high- or low-frequency currents. A 20-cycle alternating current is shown in Fig. 31. This current has the same frequency as the current in Fig. 30 but it is stronger, as is shown by the higher ampli-

tude of the current loops above and below the time line.
The current must build up and die out very quickly in high
frequency surges.

### Questions

1. There are two wave pictures in Fig. 32.   Which represents the
stronger current?
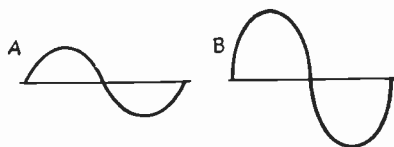


Fig. 32.

2. Explain in terms of direc-
tion of electron flow the meaning
of the terms *plus* and *minus* in
an alternating current.

3. What is the frequency of
the current the power companies
use for ordinary lighting and power circuits?

4. If this line _____ represents a wire in your
house circuit, how many times per second do the electrons flow from
left to right?   How many times
per second do they flow from
right to left?
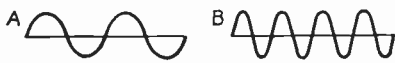


Fig. 33.

5. There are two wave pictures
in Fig. 33.   Which represents the current with the higher frequency?

6. On what line is current strength measured?

### 10. A PULSATING DIRECT CURRENT SHOWN
### ON THE OSCILLOGRAPH

*Step* 1. Set up the oscillograph and turn on the intensity
control.

*Step* 2. Connect a tungar bulb to a battery cell as shown
in Fig. 34.   Plug in the cord from the rectifier.

*Step* 3. Connect the test point to the V binding posts on
the oscillograph.

*Step* 4. Connect a toy transformer to an alternating-
current outlet.

*Step* 5. Attach the test points to the output of the toy
transformer, set for 6 volts.

*Step* 6. Adjust the gain controls until the sine wave
shows about 2 inches high.   Attach the test points to the
terminals of the battery which is being charged.

The sine curve you see when the test points are on transformer terminals shows a 60-cycle alternating current. When you change the test points to the output of the tungar rectifier, half of the current has been stopped by the rectifier tube, and you see remaining a pulsating direct current. By connecting the test points to the output of a receiving circuit across the phones or the primary of an audio transformer, you can see a pulsating direct current
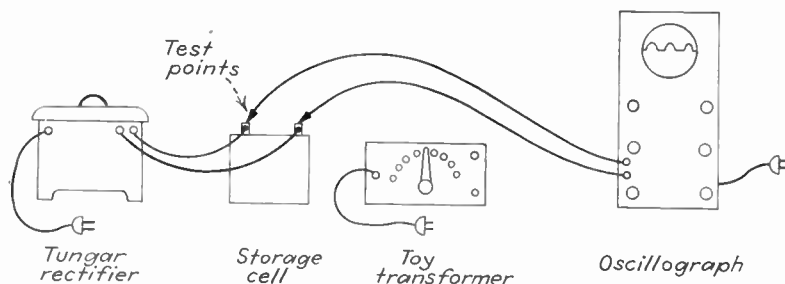


Fig. 34. A pulsating direct current.

which is in the form of an alternating current (called the A.C. component of a direct current).

Inside of the oscillograph, a condenser is connected to the $I^r$ binding post. This condenser charges and discharges with the pulsations of direct current, producing a sine wave on the screen which looks like an alternating current.

When you attach the test points to 6-volt battery, this condenser charges, and you see the green line jump sharply upward. Then it settles back to zero again when the charging current flow stops.

## 11. WAVE FORMS OF RECTIFIED ALTERNATING CURRENT— ALTERNATING-CURRENT COMPONENT—A PURE DIRECT CURRENT

**Pulsating Direct Current.** All of the wave-form pictures we have seen so far have been used to show the pulsations of alternating current which flows in opposite directions in

the wire. Now, let us see if we can use the wave-form picture to show a direct current, in which the direction of electron flow does not change.

We shall study the use of the vacuum-tube rectifier to change an alternating current to a current where the electrons move in separate, spaced surges along a wire, always moving in the same direction. This is called a pulsating direct current. Its wave shape is shown in Fig.
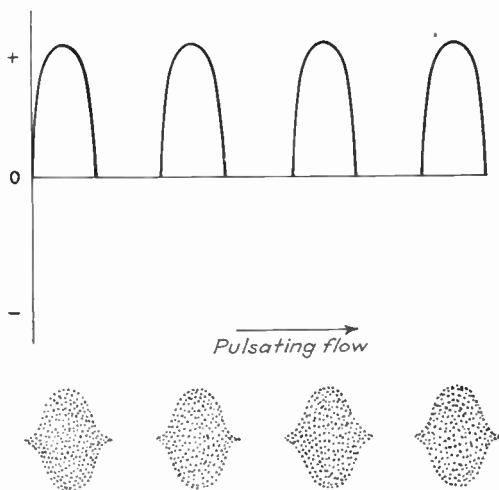


FIG. 35. A pulsating direct current.

35. This wave is like an alternating-current picture showing only the loops above the time line. It is evident that the rectifier has cut off the current flow or the loops below the time line.

Below the wave picture in Fig. 35 is the current flow we would see through our imaginary window in the wire. We would see electrons flowing in one direction during one alternation. During the next alternation no electrons would flow at all. But, during the third pulse we would again see the electron stream rush by the window.

**Alternating-current Component of a Direct Current.** In a direct current the electrons always flow in the same direction. The wave form picture of the direct current flowing in a detector plate circuit is drawn as if it were an alternating current. That is, the sine wave which shows the increase and decrease of current strength is drawn above the time line as was the pure direct-current wave picture.
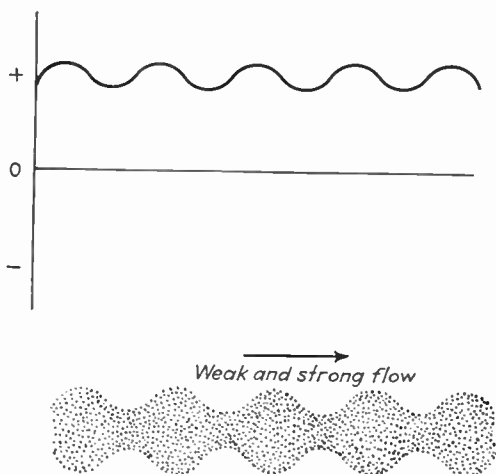


FIG. 36. A direct current with an alternating-current component.

It is possible to have a direct current which changes in strength at regular intervals. Its wave form is shown in Fig. 36. The direct-current surges are shown below the wave-form picture.

*Note.* The lines shown are not seen on the oscillograph as ordinarily connected. The alternating-current-component wave shape appears above and below the zero line like an alternating current. When a direct current is connected to the oscillograph terminals, the green line on the screen jumps sharply upward, then returns to a straight line as the direct current charges a condenser

*in* the oscillograph. The sharp upward motion of the line is seen as the condenser charges.

The whole curve form is drawn above the time line since the current flow in this circuit is assumed to be in a positive direction. We know now that this is a direct current. We call this type of current flow the alternating-current component of a direct current.
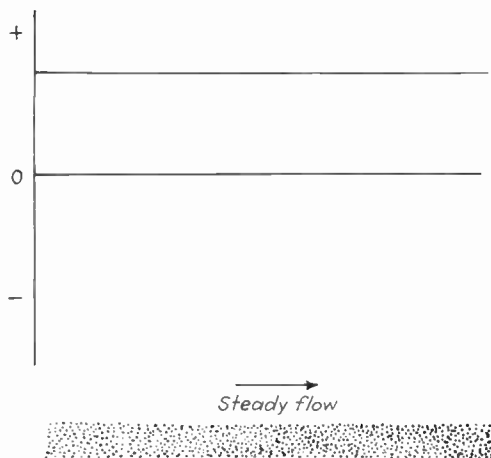


Fig. 37. A pure direct current.

An alternating-current component of a direct current is drawn as a direct-current wave which looks and acts like an alternating-current wave.

**Pure Direct Current.** Now, we can readily understand what the wave picture of a pure direct current would be. Dry batteries, storage batteries, B batteries, and the filtered output from power packs deliver a current in which the strength remains the same and in which the flow is always in the same direction.

The picture of a pure direct current is shown in Fig. 37, as a straight line that remains the same distance from the zero line.

## Questions

**1.** Is the motion of electrons in one pulsation of a pulsating direct current any different from the motion of electrons in one pulsation of an alternating current?

**2.** Is anything happening in the wire between pulsations of a pulsating direct current?

**3.** State in your own words the meaning of the term *pulsating direct current*. Does the electron flow in a pulsating direct current change direction?

**4.** Does the flow of electrons ever stop in a direct current which has an alternating-current component?

**5.** Is it ever correct to draw the alternating-current component so that the bottoms of the curves touch the time line? Try drawing it.

**6.** Does the quantity of electrons ever increase or decrease when a pure direct current is flowing through a wire?

**7.** Is it possible to picture a pure direct current either above or below the time line? Do you draw both a plus and a minus direct current above the time line?

**8.** Can the curve representing a pure direct current ever cross the time line?

## Technical Terms

**alternating-current component**—A direct current which acts like an alternating current. The current strength increases and decreases, making the wave picture look like that of an alternating current, yet electrons flow in only one direction.

**alternation**—An electron surge in one direction; half of an alternating-current cycle.

**amplitude**—The strength of a current is called its amplitude. Amplitude is shown by the distance of the current loop above or below the time line.

**audio transformer**—A small transformer used to couple receiving detector and amplifier circuits.

**current loops**—The curved line which shows how the strength of the current surge grows and then dies away.

**cycle**—Two alternations, which make one complete electron-surge round trip.

**electrons**—The negatively charged particles in an atom.

**frequency**—The number of electron round trips that occur each second. The frequency of the house lighting current is 60 cycles.

**intensity**—A control which increases or decreases the brilliance of the line on the oscillograph screen.

**kilocycle**—1000 cycles.

**meter**—A little over a yard (about 39⅜ inches). The length of radio waves is measured in meters.

**negative loops**—Loops drawn below the time line.

**oscillograph**—An instrument that uses a cathode-ray tube to make visible the flow of current in electrical circuits.

**positive loops**—Loops above the time line are called positive. Loops below the time line are called negative.

**pulsating direct current**—A direct current flowing in one direction in regular pulses. Between pulses no current flows. A pulsating direct current may be thought of as half of an alternating current, the other half having been stopped by a rectifier.

**pulsation**—The surge or rush of electrons in one direction during an alternation of an alternating current.

**sine wave**—A curve of the form ∿∿ is known in mathematics as a sine curve.

**60-cycle alternating current**—An alternating current that changes direction 120 times a second or 60 cycles a second.

**surges**—A disturbance of the electrons in an atom. This disturbance affects nearby atoms. The effect or surge travels rapidly along a wire or other conductor. The electrons may move only a fraction of an inch, but at extremely high speed, while the surge travels along the wire at the speed of light.

**tungar bulb**—A commercial form of vacuum tube used to rectify an alternating current for charging storage batteries.

**wave-form picture**—A diagram showing changes of direct and alternating current flow. A line used to show the action of the current.

# CHAPTER III

## PRINCIPLES OF THE VACUUM TUBE

The tests and experiments in this chapter are made with an early type of three-element direct-current vacuum tube which is simple for the student to use while he learns the theory and actions of the electron tube. If no type 01A tubes are available, other direct current tubes of similar characteristics may be used. The theory and the operation of these tubes is the same.

**Tube History and Construction.** Only enough history is presented to familiarize the student with the development of the vacuum tube. Its internal appearance and construction are studied by breaking up burned out tubes. Get some discarded tubes from the local radio store. Break off the glass. Examine their construction thoroughly. Cut the different elements off with nippers and examine the metal of each. Dig into the tube base. Learn about the parts of as many different makes of tubes as you can obtain. Knowing the construction of the tube helps to explain its operation.

**Electron Flow in a Vacuum Tube.** We shall run tests with the three-element tube to show how a current of electricity may be made to flow through a vacuum. This makes it necessary to study electrons again and to learn new facts about them especially their action in a vacuum. After this, we shall study the effect of the grid on the flow of electrons and learn how the grid can control the action of the tube.

The amplifying effect of the tube will be studied in Chapter V when the audio-frequency amplifier is studied.

55

Tube Tests.   We shall learn a simple form of the
standard methods used in laboratories for running tube tests
and keeping records of each test.   After the test has been
performed, we shall learn to gather up what we have found in
the tests and to show our conclusions in the form of a

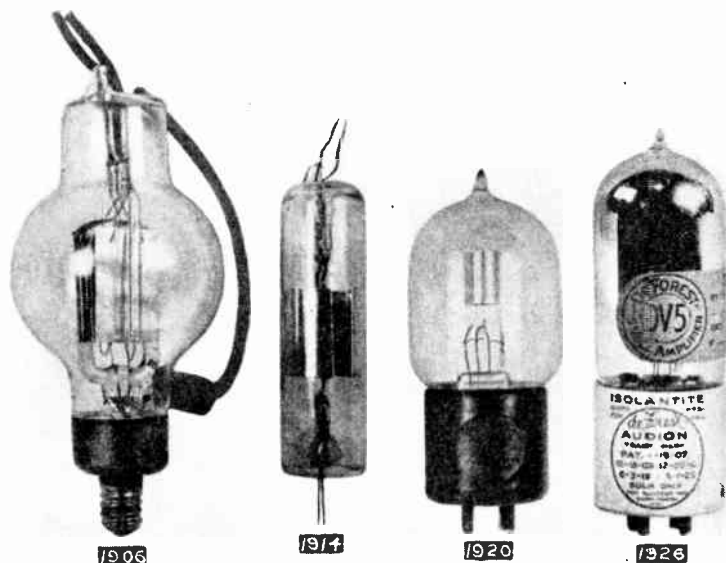

Courtesy Lee de Forest Laboratories

LEE DE FOREST

He added the grid to the vacuum tube and made possible modern broadcasting.

graph, or curve, which tells certain things about the tube.
We shall learn how to read these curves as well as how to
make them.   Curves show the action of the electrons
flowing through particular kinds of tubes under different
conditions of operation.

Electrical Principles.   At the end of the chapter, in parts
6 to 9, are grouped the explanations of the electrical princi-

ples used in explanations of the vacuum tube and its action.
There are many suggested experiments you may perform to
give more meaning to the explanations. Or you may find
it more convenient simply to read the explanations.

As you study radio circuits, you are constantly dealing
with the surge and flow of electrons. You will find the



1906 1914 1920 1926

Courtesy Lee de Forest Laboratories
TWENTY YEARS OF VACUUM TUBE DEVELOPMENT
As the tube developed, it became more rugged and more efficient.

radio information much clearer if you understand the
way direct and alternating currents act under standard
conditions.

This action of electrons in radio circuits follows laws well
known to electrical engineers. We have selected the
electrical facts and principles you should know in order to
gain a working knowledge of radio from this chapter.

*Courtesy Pacific Telephone and Telegraph Co.*

VACUUM TUBES USED IN TRANSPACIFIC RADIOTELEPHONE TRANSMISSION

The tubes shown in this picture are used in Dixon, California, at the sending station which communicates with points such as Nazaki, Komuro, and Tokio. The girl is holding a 10,000-watt water-cooled output amplifier tube and a 75-watt harmonic generator. Lying on the table in the foreground are, left to right, 250-watt radio-frequency stage; 250-watt-audio-frequency stage; 5-watt crystal oscillator; 10-watt crystal amplifier; 50-watt speech amplifier; 10,000-watt rectifier tube, used in 10,000-volt water-cooled six-phase rectifier.

Refer to this electrical information as you need it while you are studying the radio part of the chapter. Take time to set up and work the experiments suggested here. You will understand the principle more clearly by working the experiment than by reading about it.

### Contents of This Chapter

### 1. NEW SYMBOLS USED IN THIS CHAPTER

These symbols are illustrated in Fig. 38 (pages 60–61).

**vacuum tube**—The symbol for a three-element tube such as the type 01A is shown at the top of Fig. 38. The shapes of the grid, filament, and plate used in the symbol are roughly those of these parts in the tube.

**meters**—A meter is drawn as a circle inside of which is a letter to show the kind of meter. The milliammeter is lettered $MA$. The voltmeter is indicated by $V$. An ammeter would be shown by an $A$. Numbers and initials are sometimes shown under the symbols to tell the meter range and whether the meter is used on alternating current or direct current.

**rheostat**—The rheostat or adjustable resistor is shown by zigzag straight lines with an arrow. A resistor whose resistance may not be changed or adjusted has no arrow.
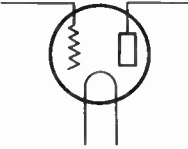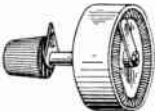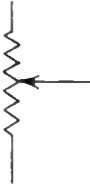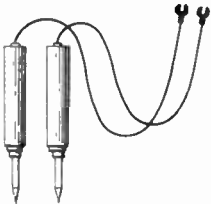
| PICTURE | | SYMBOL |
|---|---|---|
| | Vacuum tube | |
| | Milliammeter | MA |
| | Voltmeter | V |
| | Ammeter | A |
| | Rheostat | |
| | Test points | |

FIG. 38. Symbols used in Chapter III.

PICTURE                                    SYMBOL

A Battery
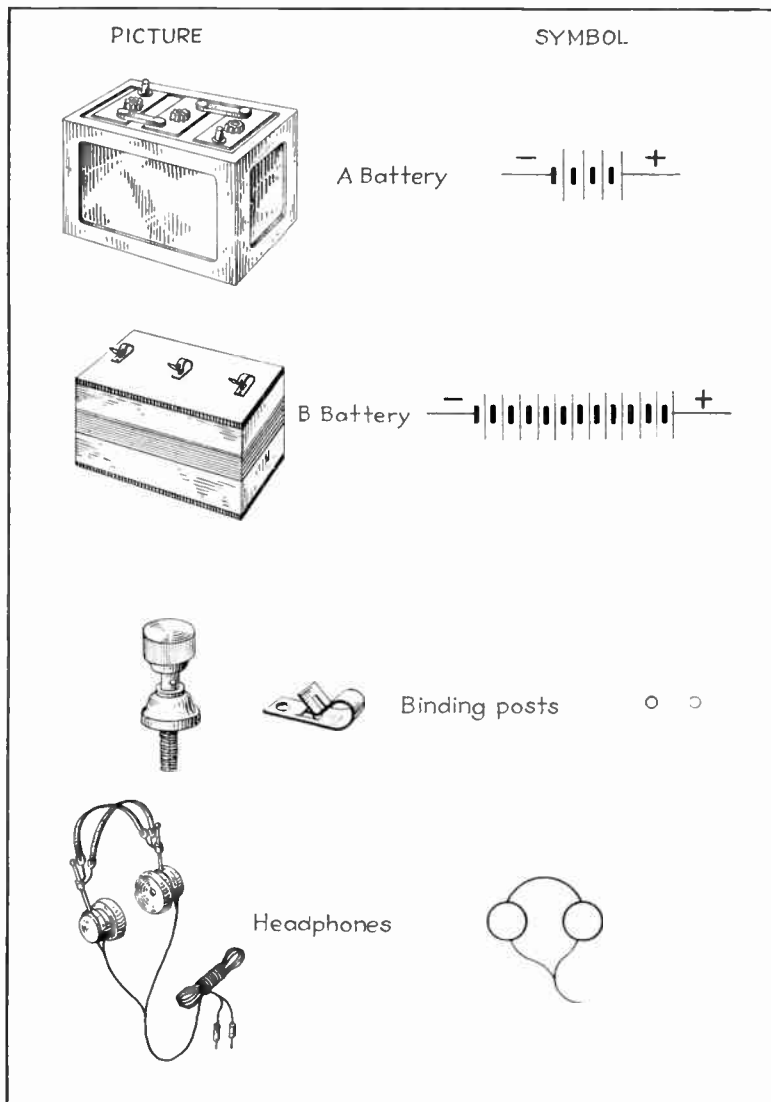
B Battery

Binding posts

Headphones

Fig. 38 (*continued*).   Symbols used in Chapter III.

**test points**—Test points are much used for testing circuits and apparatus where only a good touch connection is needed. The connecting wire runs through the insulating handle to a sharp needle point that is pushed into the metal or the binding post to make a temporary yet satisfactory contact.

**batteries**—The A battery is either a 6-volt storage battery or several dry cells in series. The B battery is a block battery of 45 volts. A power supply may be used instead.

**binding posts**—A screw or spring attachment on a piece of apparatus to which connecting wires are attached.

**phone receivers, headphones**—A pair of telephone receivers or headphones; phones attached to a spring headband which holds the phones on the head, thus leaving the hands free.

### 2. THE HISTORY AND DEVELOPMENT OF THE EARLY DIRECT-CURRENT TUBES

## Tubes Used in Early Broadcast Sets

**The Type 01A—a Good All-around Tube.** The type UV 01A tube was once widely used as a general purpose tube (see Fig. 39). It was also used as a detector and as an amplifier tube. The type 01A filament used 5 volts and $\frac{1}{4}$ ampere of current. A storage battery was needed for its operation. Charging storage batteries was quite an expense, since the operation of the set depended upon having the correct battery voltage. The low filament current used by these tubes made for economy of batteries.

**Early Direct-current Power Tubes.** The demand for greater volume of signals caused the development of the type 71A tubes that were used in the last stages of the audio amplifier. A large increase in the volume of the signals could be had by using these tubes to amplify them before

delivering them to the speaker. The type 71A was used to supply amplification to operate the speaker. If enough power was put on the type 01A tube to get the same volume, the music was unpleasant. This effect was called distortion and was caused by the type 01A tube being loaded beyond its working capacity.

These tubes are in use in only the older sets at the present time, but we shall study them since their construction is simple. Their operation is easy to understand, and the circuits in which they are used are convenient to wire.

## The Construction of Direct-current Tubes

Secure a half dozen or so type 01A and type 71A tubes from a local radio store or from discarded sets. We shall study these tubes first by examining their construction.

**The Glass Bulb.** Break off the glass bulb, and try to rub off the silver coating on the inside of the glass. The bulbs in early tubes were of a soda glass, used since it was quite common in electric lamps. This glass did not prove satisfactory



Fig. 39. An early tube.

because it broke easily, and later tubes were made of a better quality glass.

Cut off the tube elements with nippers or a pair of tin snips.

**The Tube Base.** Now, examine the tube base. Molded bakelite, which is a good insulator is used for the tube bases. The four prongs are of different sizes and are molded into the tube base (see Fig. 40). The two small prongs are connected to the grid and plate respectively. The glass bulb is cemented into the tube base. Wires from
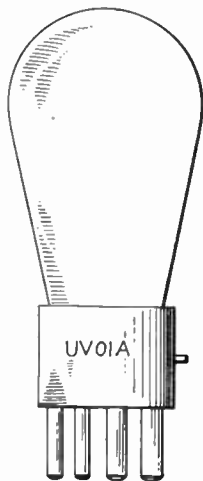
the elements pass through the hollow prongs and are
fastened at their lower ends with a drop of solder. Wiping
contact is made on the sides of the prongs by contact
springs in the sockets. Poor contact between the spring
and the tube-base prong causes much noise in the signal.

The wiping contact cleans both the springs
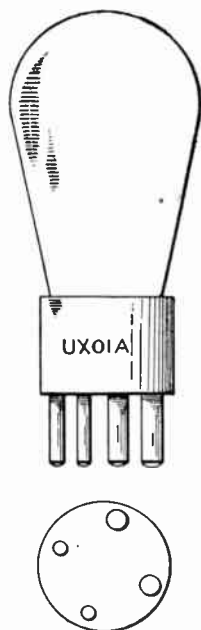and the prongs as the tube is put into the
socket.

### The Tube Parts or Elements

**Triodes or Three-element Tubes.** Each
of the tubes that we are studying, the type
01A and the type 71A has three parts or
elements sealed in a glass bulb (see Fig. 41).
These tubes are known as three-element
tubes or as triodes. What are the three
elements or electrodes? There is a V-shaped
*filament*, a *grid* of light wire surrounding the
filament, and a solid metal *plate* which
surrounds both the grid and the filament.

**Kinds of Filaments.** *The Type* 01 *Fila-
ments—Pure Tungsten.* The early filaments
were made of tungsten. The filament is
used only as a source to supply electrons.
The tungsten filament which was first used
gave off electrons only at a brilliant white heat, used much
current, and was short lived. These tubes were called the
UX01 series. They were replaced by the UX 01A series.

*The* 01A *Filaments—Thoriated Tungsten.* Later a tube
was developed with a filament which threw off a good
supply of electrons at a lower temperature. How Dr.
Langmuir of the General Electric Company discovered this,
quite by accident, is one of the romantic stories of science.
A filament, supposed to be of pure tungsten, had apparently



UX01A

Fig. 40. Tube base.

been spoiled, since it contained traces of thorium. In testing this tube Langmuir found to his amazement that a very high electron emission occurred at much lower temperatures than in the old-type tubes.

He knew, of course, that the tungsten filament had to be operated at white heat in order to produce a sufficient
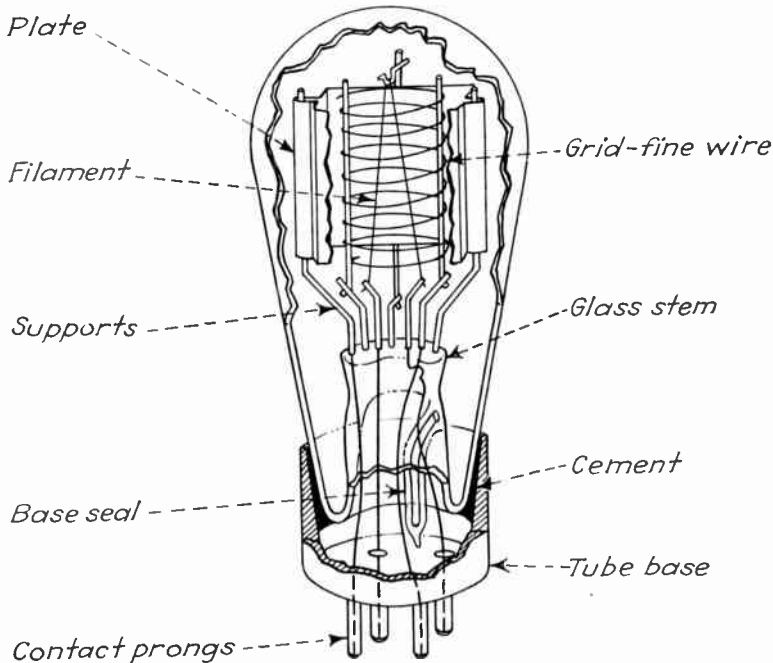


FIG. 41. Tube elements.

supply of electrons. He found that the thoriated filament would supply more electrons at a dull red heat. At the same temperatures, a thoriated filament gives off hundreds of times as many electrons as tungsten. This means a great saving in the current demand on the A battery. This in turn means that batteries last longer and that they

will run longer between chargings, two very desirable improvements for the many users of direct-current sets. So the thoriated tungsten filament was used, since it operated at a lower temperature, a bright yellow heat, and gave off more electrons than the pure tungsten filament. Tubes that use the thoriated filaments include the types 01A and 71A.

*Oxide-coated Filaments.* At the present time many tubes are made with some form of thorium-coated filaments. In rural districts not supplied with electric power, receivers are equipped with modern and more efficient forms of the early direct-current tube. These tubes have a very low current drain, and permit the use of dry cells for A power.

We know that if too low a filament voltage is used, especially with a high B voltage, the filament must supply too many electrons and it wears out rapidly. The B plate voltage tends to force electrons out of the filament. When we study transmitters later in the book, we shall find that sparks may be seen in a tube as the electrons are pulled off the oxide-coated filament by too high a plate voltage.

The tube manufacturer recommends a certain filament and plate voltage which has been found by extended tests to be best for this particular tube. When either the A- or B-battery voltage drops, the action of the set will become poor.

**The Grid and Plate.** The grid is a spiral coil of fine wire surrounding the filament; it is supported by wires fastened in the glass stem. The plate is a round or rectangular tube, formed either of a fine mesh or of sheet metal, surrounding both the grid and filament. The metal used in the grid and plate is molybdenum, nickel, or tungsten, sometimes coated with chromium or magnesium oxide to fill the pores of the metal and keep out air during manufacture. These coatings also act as getters to absorb any free gases

boiled out of the metal or glass during the operation of the tube.

### Questions

1. What was a cause for distortion in type 01A tubes?

2. For what could the type 01A tube be used?

3. What was the main purpose of the type 71A tube?

4. What effect does poor contact between the prongs and the sockets have upon the operation of a set?

5. Where is the filament placed in a three-element tube?

6. Which element is placed around the filament and next to it?

7. Which element is placed around the other two elements?

8. What is the shape of the grid?

9. What is the shape of the plate?

10. What two kinds of material were used in the filaments of the type 01A series tubes?

11. What are some advantages of the material used in the filaments of type 01A tubes?

## Removing the Air from the Tube

**No Gas May Remain in the Tube.** The operation of the tube depends upon a very high degree of vacuum and upon this degree of vacuum remaining unchanged. If any air or gas remains in the tube, its operation becomes so poor that the tube must be discarded. Gas may sometimes be noticed in the power tubes by a purplish glow around the elements. This glow results from ionization of the air molecules by the electrons thrown off from the filament.



The getter cup
Cement
Base seal

FIG. 42. How gases are removed.

**How Air Is Removed.** The early method of exhausting or removing the air from a tube was by means of a mercury suction pump. When the tube was exhausted to the highest degree possible, it was sealed at the tip. The easily broken tip seal was soon discarded for a safer base seal (see Fig. 42). Any air enclosed in the glass or adhering
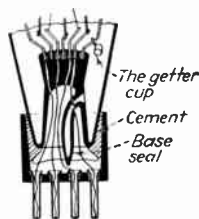
to the surface of the metal elements of the tube was driven off gradually by the heat of the filament. This caused the tube to become gassy and faulty in its operation.

**The Action of the Getter.** In modern practice, after the tube is exhausted and sealed, the remaining air is driven off by placing the tube in a high-frequency furnace, consisting of coils of wire carrying a high-frequency alternating current. All remaining air is driven off the surface of the tube elements by the heat generated in the metal while it is in the field of the coils. At the end of the heating or degassing process, the heat is increased enough to ignite or flash a getter; this is a small quantity of magnesium in a small metal cup attached to the grid or plate supports. The magnesium, in burning, takes up all the remaining air in the tube and deposits a silverlike coating on the inside of the glass.

### Questions

1. How do gassy power tubes appear in operation?

2. What steps are used by manufacturers in removing gases from radio tubes?

### 3. ELECTRON FLOW THROUGH A VACUUM TUBE

In this part of Chapter III we shall begin the study of the action of electrons in a vacuum tube. Modern radio theory and practice is based on this principle, which we are now taking up. You will need a clear and vivid understanding of the ways and habits of the electrons under different conditions in order to operate the sets you will study later in the book.

We shall now learn more about the strength of the currents flowing through the tube. We shall learn how to operate the tube to get the best results from our circuit. We shall learn under what conditions the electron current will flow.

.

Then we shall draw a graph or curve which will show the number of electrons that flow through the tube under normal operating conditions.

## How to Build and Wire the Set

**The Parts Needed for this Test.** *The Tube.* Use a type 01A direct-current tube for this test. If it will not give a
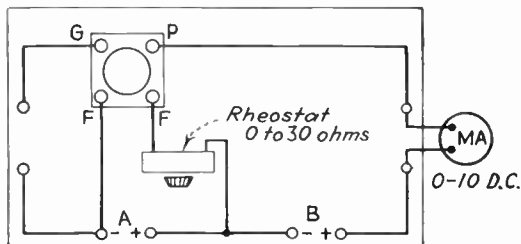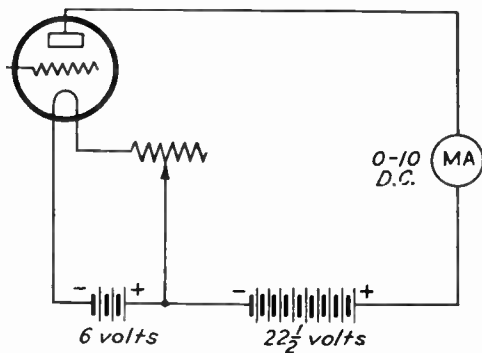


FIG. 43. Board layout for electron-flow tests.



FIG. 44. Circuit diagram for electron-flow tests.

good reading on the meter you have, substitute a type 71A tube. Any of these tubes will fit in the four-prong tube socket.

*The Socket.* Use any four-prong tube socket. The various forms of molded sockets are easier to mount than a wafer socket, but the wafer will work satisfactorily.

*The Rheostat.* Use a rheostat that has a resistance of from 0 to 30 ohms.

*The Meter.* Use a direct-current milliammeter with a range of from 0 to 10 milliamperes.

*The Position of the Parts.* Mount the parts on a board, as shown in Fig. 43. A convenient size for this baseboard is $9\frac{1}{2}$ inches by 12 inches, since sufficient space is available so that the wiring will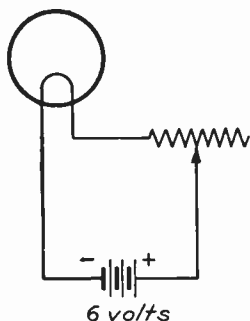 not be crowded. When the parts are well spaced, the wiring of the circuit is plain and is easier to understand. You will notice that the parts are arranged so the wiring looks like the circuit diagram shown in Fig. 44.

Mount the rheostat on a bracket made from a heavy piece of aluminum or brass. The binding posts at the left end of the board, marked *G* and *A* negative are used in later experiments.



FIG. 45. Filament circuit.

**How to Wire the Parts.** *The Filament Circuit.* The filament circuit consists of the tube filament, some kind of battery for heating the filament, and a rheostat which controls the battery voltage across the filament (see Fig. 45). The rheostat can be used as an on-and-off switch. The battery, the rheostat, and the filament are connected in series, as shown in Fig. 45.

When you have finished, check the wiring of the board with the sketch of the board layout.

*The Plate Circuit.* The plate circuit includes the filament, the plate, the meter, and the B battery (see Fig. 46).

Run a wire from the *P* post of the tube socket to the milliammeter. Connect a wire from the positive terminal of the meter to the positive $22\frac{1}{2}$-volt connector on the B battery. Use either a B battery or a B eliminator for B power. A better curve will be obtained from a B battery

since the voltage does not change. The eliminator voltage will drop as the filament heat is increased.

B eliminators may be used by adjusting the voltage before taking each reading. Connect a direct-current 0–50 voltmeter across the B positive and the B negative terminals of the B eliminator. Set the B voltage at $22\frac{1}{2}$ before taking each reading of the milliammeter for each change of filament voltage.
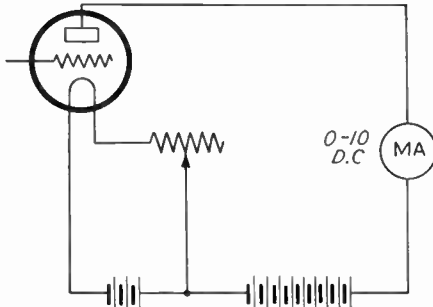


Fig. 46.    Plate circuit.

*Be Careful with Your Meters.* Connect the voltmeter in *parallel* across the two *F* socket terminals. Tap wires to the meter connections to test polarity and to see if the right size of meter is being used. If the hand swings backward, the connecting wires must be reversed. If the hand swings violently across the scale, a meter with a higher range must be used. Cheap meters may be used for this test. Better meters must be used if highly accurate results are wanted.

### Questions

**1.** How should the voltmeter be connected for this experiment?

**2.** How do you test to see if the connections to a meter are correct?

**3.** What is the advantage of B batteries over B eliminators for the tube-test experiments?

## How to Operate the Test

**Test 1. The Electron Flow with the Filament Cold.** *How to Run the Test.* Turn the rheostat so the arm is off the resistance wire. This turns off the filament-heating current.

Plug the type 01A tube in the socket. The B battery is on when the tube is plugged into the socket.

Does the milliammeter hand move?

*Why It Works.* Why does the milliammeter hand not move? Read part 7 of this chapter on meters.

You learn in Part 7 that a current must flow through the coils of the meter to make the hand move. The hand of this milliammeter does not move because no current flows through the meter.

Why does no current flow through this circuit?

This test shows that even with the strong B battery on no electrons flow through the circuit. Why is this?

When the A battery is off, the filament is cold. The purpose of the A battery is only to heat the filament. Cold metals do not give off electrons under these conditions. Therefore, no current flows through the tube.

**Test 2. The Electron Flow with the Filament Hot.**

*How to Run the Test.* Turn the rheostat arm to about two-thirds full on. The current from the A battery now flows through the filament. What happens?

Notice that the filament heat increases as the voltage from the A battery is increased by moving the rheostat arm. How can you tell that the heat of the filament increases?

Watch the milliammeter hand as you change the filament heat. What does the meter hand do as the filament heat increases?

*Why It Works.* The filament lights or glows when a current from the A battery flows through it. We can tell how hot the filament is from the intensity of the glow. As the voltage across the filament is increased by moving the rheostat arm, the heat of the filament increases.

As the heat of the filament increases, the meter hand moves farther over the scale, showing that more current is

flowing through the circuit. Where does the current come from?

The filament gives off electrons when heated. It gives off more electrons as its heat increases. A flow of electrons is called an electric current, so the filament is the source of the electrons causing the meter hand to move.

But how do the electrons get from the filament to the meter?

**Test 3. The Electron Flow with the Plate Positive.** *How to Run the Test.* There is no change in the wiring of the board. The plate of the tube is connected to the positive side of the B battery through the meter.

Move the rheostat arm and watch the meter hand. What happens?

*Why It Works.* The meter hand moves farther as the filament voltage is increased, as it did in Test 2 for a hot filament. We know that the filament gives off electrons when heated. We also know that the electrons are negative.

Now the B battery acts as an electric pump and pulls the electrons from the plate. When there are not enough electrons on the surface, we say it is positive. Unlike charges attract, so the positive plate, which wants electrons, attracts the electrons thrown off by the hot filament.

The electrons reaching the plate flow through the meter to the B battery, causing the meter hand to move. The electrons are returned by the B battery to the filament through the plate return wire.

**Test 4. The Electron Flow with the Plate Negative.** *How to Run the Test.* Turn off the tube filament.

Reverse the two wires in the plate circuit connected to the B battery. The negative terminal is now connected to the plate.

Read the plate milliammeter with the filament cold. Is a plate current flowing?

Heat the filament gradually and again read the milliammeter. Does the meter hand move? Do electrons flow from the plate to the filament?

*Why It Works.* There is no meter reading either with the filament cold or hot. No electrons flow through the tube either time. Why is this so?

We expect no meter reading with a cold filament. No electrons are attracted to the plate.

Perhaps we expect a meter reading when the filament is heated. But there should be no reading because the plate is now negative.

The plate is negative because it has too many electrons. The electrons on the plate repel the electrons in the space charge around the filament. No current will flow under these conditions.

The current will not flow from the plate to the filament because no electrons are thrown off the cold plate.

*Now Summarize the Tube Action.* Let us now collect the facts we have just learned about the action of the tube in a brief summary.

1. A cold filament will not throw off electrons and a hot filament will.

2. Electrons will flow from the filament to the plate only when the plate is positive and the filament is hot.

3. The plate is made positive by the action of the B battery in "pumping" off the electrons.

4. Electrons will flow through the tube in only one direction.

### 4. THE FILAMENT-EMISSION CURVE

### How to Wire the Apparatus

**Wire the Filament Circuit First.** The board layout is the same as that shown in Fig. 43. Add a direct-current 0–10 voltmeter as shown in Fig. 47.

Connect the positive post of the 6-volt A storage battery to one $F$ post of the tube socket.

Connect a 30-ohm rheostat to the positive post of the A battery.

Run a wire from the other connection of the rheostat to the other $F$ post of the tube socket.

Connect the voltmeter across the two $F$ terminals of the tube socket to read the voltage drop across the filament.

**Tubes to Use.** Use a type 01A tube.

**B Power.** Use either

FIG. 47. Circuit diagram for filament-emission tests.

several blocks of B batteries, a B eliminator, or a power-supply unit.
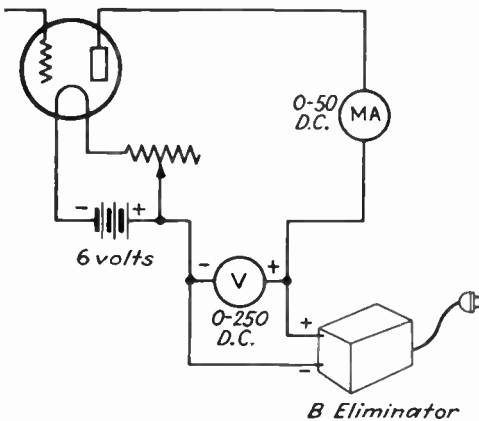
FIG. 48. Filament-emission test circuit with B eliminator.

**Caution!** *B Eliminator Voltages Change.* The voltage of many B eliminators drops as the load caused by increas-

ing the filament voltage becomes larger.    More electrons from the filament put a greater load on the source of B power.

Connect a direct-current 0–250 voltmeter across the terminals of the B eliminator.    Adjust the B voltage each time you change the filament voltage before you take the meter reading (see Fig. 48).

No meter is needed if a B battery is used.    The voltage of a B battery does not change as the load changes.    Test the A voltage before each reading.

### How to Operate It

**Draw a Record-sheet Form.**    Figure 49 shows a sample of the record-sheet form.    It is a place to write down the

| 22½ Volts | |
|---|---|
| Filament Volts | Plate Milliamperes |
| 0 | |
| ½ | |
| 1 | |
| 1½ | |
| 2 | |
| 2½ | |
| 3 | |
| 3½ | |
| 4 | |
| 4½ | |
| 5 | |
| 5½ | |
| 6 | |

FIG. 49.

plate current which is read on the milliammeter for each change in filament voltage as you run this test. These readings are used later in preparing a characteristic curve for the tube being tested.    Prepare a form like the one shown before running the test.

The plate voltage is not changed in this test.    Write the B voltage used above the top of the two columns.    This is done because you may want to make several tests with different B voltages.

**Now Run the Tests.**    *Step* 1.    Set the filament voltage to zero.

First, turn the rheostat to the off position.    The filament voltmeter should read 0 volts.

Second, read the milliammeter.    Write the reading in the Plate Milliamperes column opposite the zero filament voltage.

*Step* 2. Set the filament voltage to $\frac{1}{2}$ volt.

First, adjust the filament rheostat until the meter reads $\frac{1}{2}$ volt.

Second, read the milliammeter. Write down the plate current flowing in the Plate Milliamperes column.

*Step* 3. For the other filament-voltage readings, continue as in Step 2. Increase the filament voltage $\frac{1}{2}$ volt for each test. Write the milliamperes of current flowing in the plate circuit for each voltage increase.

You may get no current readings in the milliammeter for the first two or three settings of filament voltage. There probably is a very small amount of current flowing, but it is not great enough to operate an inexpensive meter. A sensitive meter would give a reading. You should get plate-current readings for settings of over 1 volt on the filament.

When you complete this test, step up the B voltage from $22\frac{1}{2}$ to 45, $67\frac{1}{2}$, 90, 135, and 180 volts. Run a test for each voltage. The results will be interesting and will furnish information for several curves. The same tests may be made with the type 71A tubes. Compare their results with those for the type 01A tube.

## Graphs or Curves—What They Are and How to Draw Them

**What a Curve Is and What It Shows.** It is hard to describe in words what has been happening in the tube during the test we have just completed. Some other method to show the action is helpful. The standard method in radio testing, as well as in engineering analysis, is to use a graph, or curve. An old Chinese proverb has it that "a picture tells more than a thousand words." We shall find that the curve does just this.

You will recall in the filament-emission test that only two things were allowed to change. When the filament voltage was changed, the plate current changed. Everything else

was carefully watched to keep any other changes from occurring. The curve will show this resulting plate current change.

**How to Draw a Curve.** *Step* 1. Draw the base lines. Draw the curve on a piece of cross-section paper (10 squares
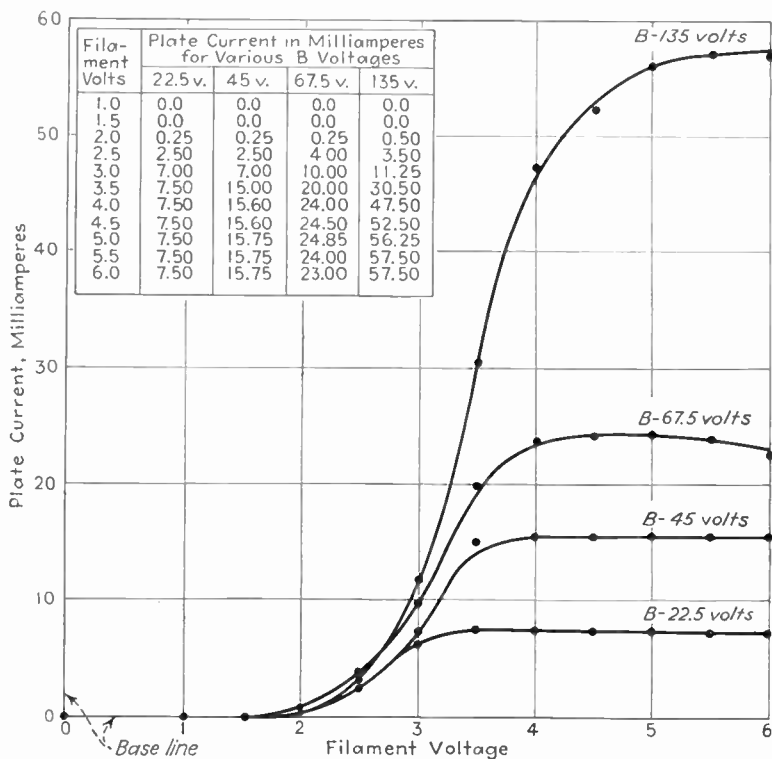


| Fila-ment Volts | Plate Current in Milliamperes for Various B Voltages | | | |
|---|---|---|---|---|
|  | 22.5 v. | 45 v. | 67.5 v. | 135 v. |
| 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.0 | 0.25 | 0.25 | 0.25 | 0.50 |
| 2.5 | 2.50 | 2.50 | 4.00 | 3.50 |
| 3.0 | 7.00 | 7.00 | 10.00 | 11.25 |
| 3.5 | 7.50 | 15.00 | 20.00 | 30.50 |
| 4.0 | 7.50 | 15.60 | 24.00 | 47.50 |
| 4.5 | 7.50 | 15.60 | 24.50 | 52.50 |
| 5.0 | 7.50 | 15.75 | 24.85 | 56.25 |
| 5.5 | 7.50 | 15.75 | 24.00 | 57.50 |
| 6.0 | 7.50 | 15.75 | 23.00 | 57.50 |

Fig. 50.    Sample curves of filament emission for type 01A tube.

to the inch).    Draw a heavy base line near the bottom of the sheet (see Fig. 50).    Measure the changes in filament voltage on this base line.    Mark off the line in equal divisions.    Number each division below the line, one division for each volt.

Draw the other base line upward from the zero mark on the filament-voltage base line. Measure the changes in plate current on this base line. Mark it off also into equal divisions, starting at the lower end of the line for zero current. Use one division for each milliampere of current.

The number of squares for 1 volt may be different from the number used for 1 milliampere.

*Step* 2. Locate points for the curve. We now use the numbers we kept on the record sheets (Fig. 49). Reading the sheet, we see that for zero filament voltage, no plate current was flowing. Make a heavy dot at zero-zero at the corner where the base lines met.

At $\frac{1}{2}$ volt and also at 1 volt on the filament, still no plate current flowed. Make a heavy dot at 1 on the voltage base line.

At $1\frac{1}{2}$ volts there was a slight movement of the meter needle. Make a dot just above the base line at $1\frac{1}{2}$.

At 2 volts the current was $\frac{1}{4}$ milliampere. Make a heavy dot as high above the base line as $\frac{1}{4}$ milliampere is on the current base line.

At $2\frac{1}{2}$ volts the current was $2\frac{1}{2}$ milliamperes. Make the heavy dot $2\frac{1}{2}$ squares above the $2\frac{1}{2}$-volt mark.

Repeat this process for every reading shown on the record sheet.

The curves shown in Fig. 50 are samples prepared by the authors from a test run on an old type 01A tube. The reader should run a test on his own tubes, then plot curves for each tube.

*Step* 3. Now draw the curve. First sketch a light line connecting the heavy dots together in a smooth curve. There should be no uneven bumps in this line if the test was run carefully and if the curve was drawn as directed. After the curve has been checked over and found to be correct, it should be drawn in heavier. If several curves

are drawn, as shown in Fig. 50, the plate voltage should be lettered near each curve.

### Questions

**1.** What were the two varying quantities in the filament-emission tests?

**2.** What quantity is represented on the horizontal base line of the graph?

**3.** Does a movement to the right on the base line indicate an increase in filament voltage or in plate current?

**4.** What quantity is represented on the vertical base line?

**5.** Does a movement up this line indicate an increase in filament voltage or in plate current?

**6.** In Fig. 50 why did we draw the curve so as to miss several dots?

## The Story Told by the Filament-emission Curve

**How Is the Curve Read?**   There are several things to look for when you wish to read the story told by this curve. The steepness means something; where the curve starts and where it stops are important; how high it rises and what it does at the top of the rise are important.   Now, how may we interpret these things?

**The Steepness of the Curve.**   The steepness of the curve tells the ease with which the filament may be caused to give off electrons.   It would be better to call the filament-voltage base line a filament-heat line, for we increase the voltage only to increase the heat of the filament and so to drive off more electrons.   There is no easy way to measure the filament heat, so we measure instead the voltage across the ends of the filament.   This will do, because the heat increases as the voltage gets higher.   A steep curve shows that we only need to increase the filament heat a part of a volt to get, say, an increase of 10 milliamperes of plate current.   A flat curve means that we may have to increase the heat by more than a volt to get the same amount of plate-current increase.   The tube with a steep curve is a

better electron emitter. It will use less A-battery power and will be cheaper to operate.

**Saturation—the Top of the Curve.** We know that the hotter the filament gets the more electrons are thrown off. This is shown by a rising curve. But we notice that the curve stops rising and runs parallel to the voltage base line at from 4 to 5 volts. This means that even when the filament temperature is raised by increasing the voltage we get no more electrons through the tube and through the meter. The tube has reached its saturation point. The sharp bend at the saturation point is called the knee of the curve. There is also a knee at the lower end of the curve.

At the saturation point the filament is emitting electrons faster than the pull of the positive plate can take them away. The electrons crowd around the filament. Some of the electrons that have been forced off return to the filament, since the plate voltage is too weak to draw the whole supply of electrons to the plate. There is a certain saturation point for each plate voltage and filament heat.

**The Space Charge.** When the filament is heated, electrons boil off its surface, instantly forming an invisible electron cloud around the wire. This electron cloud is called the space charge. These electrons dart about inside the tube at a speed of many miles a second. Some electrons strike other electrons, then fall back to the filament, which is negative. Others fly farther away from the filament. The number of electrons in the space charge depends on the heat of the filament. A hot filament throws off more electrons than one which is cooler. When the electrons are being drawn from the space charge by the positive plate, other electrons must come from the filament to the space charge to replace those that have been taken away. Few electrons return to the filament under this condition.

At the time the tube was made, an efficient type of vacuum pump removed as much air as possible. When tubes were being developed, it was soon discovered that any tube in which some gas or air was left by the then imperfect vacuum pumps was very uneven in its action. A high degree of vacuum is necessary in the vacuum tube for good operation. If any air is left in the tube, electrons leaving the filament bump into the air molecules, and the operation of the tube is poor. The electrons boiled off the filament must not be hindered as they fly about inside the tube. Moreover, the oxygen in air would combine with the hot filament and would rapidly burn it in two.

**The Effect of Higher Plate Voltages.** If you increase the voltage on the plate, the plate is more positive and so has a stronger attraction for the electrons in the space charge and for those given off by the filament. Fewer electrons return to the filament, and the space charge is lessened. Fewer electrons wander around in the space between the filament and the plate. The result is that more electrons reach the plate and flow through the plate circuit. A higher plate-current reading is indicated on the meter.

The saturation point is raised, and the curve rises higher before flattening out beyond the saturation point. With higher plate voltages the curve is steeper due to the greater pulling power of the plate.

**How Can We Use These Facts on Our Set?** We would not use a tube with a very flat characteristic curve. It would use far too much A-battery power for its operation. We would look for a tube with a steeper curve and a higher saturation point. This curve would give us louder and better signals for the amount of storage-battery charge it used up.

The curve shows that in using the tube tested we should set the filament rheostat at from 4 to 5 volts. It should

be set at the filament voltage where the saturation begins. If we had a new tube, we would set this voltage at the value recommended by the tube manufacturer.

### Questions

1. What does the steep part of the curve indicate about the electron-emitting power of a tube?

2. What does a flat curve tell you?

3. What is the meaning of the term *saturation point?*

4. After a given number of volts have been put on the filament, is there any advantage in turning on more volts?

5. What is a space charge?

6. What determines the number of electrons in the space charge?

7. What two harmful effects do traces of air in a tube have upon the action of the tube?

8. What effect does an increase in plate voltage have upon the space charge?

9. What is meant by the expression *the knee of the curve?*

10. What use can be made of a filament-emission curve in the operation of a radio set?

### 5. THE PURPOSE OF THE GRID IN A VACUUM TUBE

**The Purpose of This Test.** So far we have not used the third element, the grid, in any way. The grid did not affect the results of the filament-emission tests because nothing was connected to it. But the grid can change the flow of electrons from the filament to the plate. It can increase the flow, or it can entirely shut off the flow.

In this test we shall learn how the grid can have such a powerful influence on the plate current. We shall use a battery of flashlight cells to force electrons on the grid or to draw electrons off the grid while we study the resulting effects on the plate current.

This test is run to secure data for drawing a curve which gives us a sort of slow-motion picture of what occurs in the tube when an alternating current makes the grid negative and positive.

Then we will see how use is made of this curve in studying the action of a tube when connected in a radio circuit.

## The Board Layout

Use the same circuit board that was used in parts 3 and 4. You will need a direct-current 0–10 voltmeter for reading
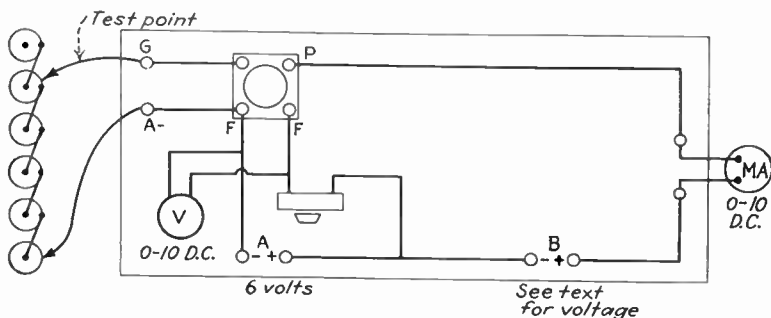


FIG. 51.    Board layout for grid tests.
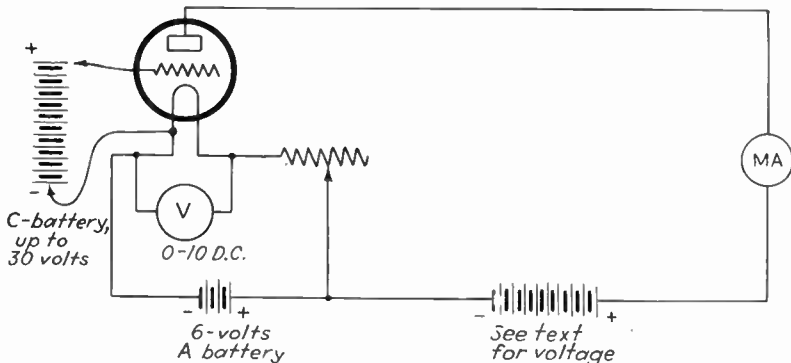


FIG. 52.    Circuit diagram for grid tests.

filament voltage and a direct-current 0–150 voltmeter for B voltage readings (see Fig. 51).

Connect the 0–10 voltmeter as in Fig. 51.    See that the positive side of the meter is connected to the positive board terminal, or the meter will read backwards.

There is no change in the filament circuit on the board.

**Wire the Plate Circuit.** Connect the 0–150 voltmeter to the B positive and the B negative binding posts on the baseboard only if a B eliminator is used (see Fig. 52). No voltmeter is needed if B batteries are used.

Check to see that the B positive wire is connected to the positive post.

**Wire the Grid Circuit.** Attach the end of the wire from a test point to the grid post of the tube socket.

Connect a wire from the $F$ negative post to the negative end of the C or bias battery. It may be necessary to leave this wire disconnected to take the zero reading.

**The C or Grid-bias Battery.** Connect enough dry cells, flashlight cells, or storage cells in series to make a 20-volt battery. If convenient, wire up enough cells to produce 30 volts.

Place this battery near the circuit board so the test point can be handled easily when running the test.

**Check over the Circuit.** Check the board wiring to see that it is the same as shown in the circuit diagram in Fig. 52.

Go over the connections to see that none are loose or broken. Soldered connections sometimes break on account of handling. Test the binding posts to see that they are screwed down tight. Loose connections will spoil the results of this test.

Check the meters. Be sure the polarity of the connections is right so the meter hand does not swing backward and ruin the meter.

**Connect the A and B Batteries.** Connect the A battery to the A binding posts. Turn the rheostat to heat the filament and test the voltage with the 0–10 voltmeter.

Run the first test with a $22\frac{1}{2}$ volt B supply. Then run other tests with 45 volts, $67\frac{1}{2}$ volts, and on up to 250 volts.

Touch the wire from the B battery to the B binding posts. Check the reading of the plate milliammeter to see that the hand moves in the correct direction. If correct, fasten the wire to the binding post.

### How to Run the Test

*Step* 1. Take readings with grid positive.

Touch the test point to the positive post of the first C battery. There should now be $1\frac{1}{2}$ volts on the grid. If a storage battery is used, there should be 2 volts on the grid for each cell in the circuit.

Read the current flowing in the plate circuit on the milliammeter. Write this reading on the record sheet opposite $1\frac{1}{2}$ (or 2) grid voltage. See Fig. 53 for sample curves of a test in which grid bias was increased in steps of 1.4 volts.

Now move the test point to the next C-battery cell. Touch the positive post. There are now 3 volts on the grid.

Write the reading of the milliammeter opposite 3 volts in the Plate Milliamperes column on the record sheet.

Take a reading for each cell added to the C battery as the test point is touched to its positive terminal.

What effect does increasing the positive voltage on the grid have on the plate current?

*Step* 2. Take readings with grid negative or negative bias.

Connect the wire from the *F* negative post on the tube socket to the positive terminal of the C battery.

Touch the test point to the negative terminal of the first cell from the positive end of the C battery. Write the plate-current reading in the Positive section on the record sheet.

Take readings, one cell at a time, until a C voltage is reached where no current flows in the plate circuit. This is the cutoff point.

| Grid Bias | Plate Current in Milliamperes for Various B-Voltages | | | |
|---|---|---|---|---|
| | 22.5 v. | 45 v. | 67.5 v. | 90 v. |
| 14.0 | 10.50 | 14.10 | | |
| 12.6 | 9.25 | 12.75 | | |
| 11.2 | 8.00 | 11.50 | 14.50 | |
| 9.8 | 6.90 | 10.00 | 13.00 | |
| 8.4 | 5.50 | 8.15 | 11.50 | 15.00 |
| 7.0 | 4.50 | 7.00 | 10.00 | 13.25 |
| 5.6 | 3.50 | 5.75 | 8.50 | 11.50 |
| 4.2 | 2.50 | 4.50 | 7.00 | 10.00 |
| 2.8 | 1.50 | 2.25 | 5.75 | 8.25 |
| 1.4 | 0.50 | 2.10 | 4.50 | 7.00 |
| 0.0 | 0.50 | 2.00 | 4.00 | 6.50 |
| 1.4 | 0.10 | 0.60 | 2.00 | 4.00 |
| 2.8 | 0.00 | 0.10 | 1.10 | 3.00 |
| 4.2 | | 0.00 | 0.50 | 2.00 |
| 5.6 | | | 0.05 | 1.00 |
| 7.0 | | | 0.00 | 0.25 |
| 8.4 | | | | 0.05 |
| 9.8 | | | | 0.00 |
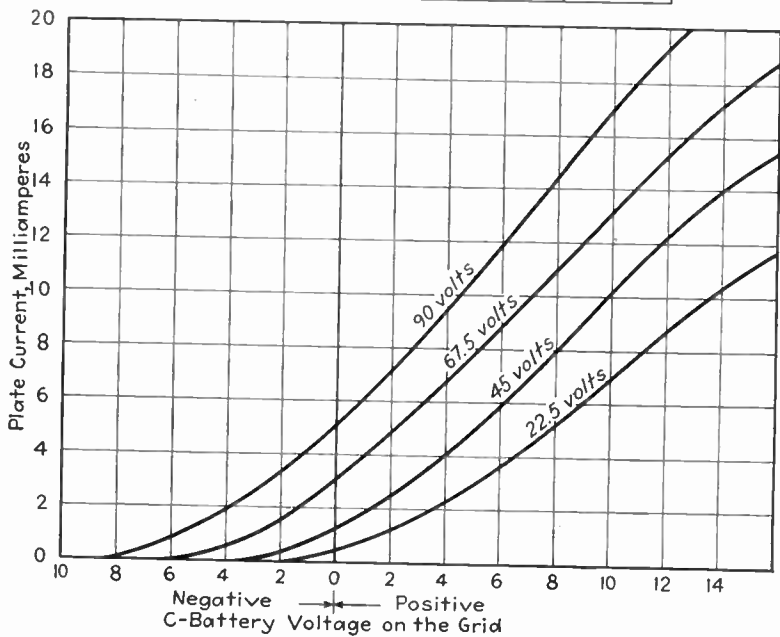


FIG. 53. Sample curves showing grid control of plate current for Type 01A tube.

Does the plate current decrease an equal amount for every volt of negative bias added to the grid?

*Step* 3. Take the zero reading.

Disconnect both the wires from the C battery. Lay the wires and the test points on the table.

Read the milliammeter to get the zero grid-voltage reading. If either wire is connected to the C battery or if the hands are touching either wire, the reading will be inaccurate.

*Step* 4. Draw the curve.

Draw the base line for the grid voltages at the bottom of the graph paper (see Fig. 53). Draw the zero grid-voltage line as shown.

Draw the plate-current base line at the left of the graph paper. Locate the points and complete the curve as you did for the filament-emission curve.

Draw a separate curve for each plate voltage.

## Why It Works

**We Allow Only One Voltage to Change.** During this test we have carefully kept the same filament voltage. We did this so the supply of electrons would be the same all through the test. We also kept the same plate voltage. This meant that the pulling power on the plate did not change.

The only voltage we allowed to change was the voltage on the grid. This we changed in even increases, adding $1\frac{1}{2}$ volts between each reading.

In this way we were able to watch the effect on the action of the tube as each change of grid voltage occurred.

Any changes of plate or filament voltage during the test would be very confusing because we would not be able to tell what had caused any certain result.

**How a Positive Grid Affects the Electron Flow.** What effect will making the grid positive have on the electrons flowing from the filament to the plate?

When we say that the grid is positive, we mean that the electrons on the grid have been pumped away by the C battery. The grid has too few electrons. But the grid is placed between the filament and the plate in the path of the streams of electrons.

The positive grid then will attract electrons from the filament and will add its pull to that of the plate. The pull of the grid is weak, since the C voltage is small, but it is enough to attract electrons. This adds to the speed of electrons in the space charge so that more fly toward the plate.

The fine wires of which the grid is made allow many of the electrons it attracts to fly onward and reach the plate. We know this is so because the reading of the plate milli-ammeter shows more current in the plate circuit as the pull of the grid is made stronger by the positive C battery.

The curve in Fig. 53 shows that 5 milliamperes of current flowed through the tube with no voltage on the grid (see the curve with 90 volts on the plate). But when you make the grid 5 volts positive, the plate current increases to $10\frac{1}{2}$ milliamperes. As you make the grid more positive, the plate current becomes stronger.

This part of the curve is nearly straight. A straight-line curve shows that each volt added to the grid increases the plate current the same amount. A tube with a straight-line curve is a good amplifier. If the line is not straight, signals will be distorted.

**The Effect of Making the Grid Negative.** When we change the connection of the grid circuit so the negative side of the C battery is connected to the grid, electrons are pumped on the grid from the C battery.

Electrons are negative charges of electricity. The electrons on the grid now repel the electrons from the filament. Not as many electrons can reach the plate on account of the pushing-back or shutting-off action of the electrons on the grid.

The curve shows that as the grid becomes 5 volts negative only $1\frac{1}{2}$ milliamperes of current are flowing.

In fact, we find that when enough electrons are forced on the grid by the C battery, no more electrons from the filament are able to pass through the grid. The pushing-back action of the grid stops them entirely. This is the cut-off point where the grid is negative enough to stop the action of the tube. Eight volts on this grid stopped the current flow with 90 volts on the plate.

### Questions

1. Why do most of the electrons fly on past the positive grid?

2. What effect will making the grid negative have upon the flow of electrons to the plate?

3. What is meant by the term *grid cutoff point?*

## Other Effects of the Grid on Tube Action

**The Saturation Point.** We find, when we take more and more electrons off the grid by making it more positive, that the flow of electrons from the filament to the plate increases. The attraction of the grid adds to the pull of the plate, so more electrons are drawn through the tube.

Perhaps this plate-current flow can be increased if we can make the grid still more positive by adding to the number of cells in the C battery. Try doing this.

More plate current flows up to a certain point, but the increase is less for each cell added until finally there is no increase in plate current even when we add several cells, making the grid highly positive. We have reached the saturation point.

The pull of the positive grid added to the pull of the positive plate takes all of the electrons possible from the space charge around the filament. The only way to pull more electrons across is to add to the pulling power of the plate. You can do this by increasing the plate voltage.

**The Effect of Higher Plate Voltage.** When we connect a B battery to the plate circuit so the voltage is raised, we find at once that the amount of current flowing through the plate milliammeter has increased. The higher voltage on the plate makes a stronger pull on the electrons. More electrons are swept away from the whirling cloud of the space charge and from the filament.

The upper knee of the curve is higher, and more plate current is flowing at saturation. More current is flowing for the same C bias.

We also find that more negative bias is needed to overcome the stronger plate pull and to stop the electron flow. More negative voltage is required to cut off the flow.

**Tube Action with an Alternating Current on the Grid.** In the test just run we have placed both positive and negative charges on the grid, but the changes from positive to negative have occurred very slowly. The changes in polarity of the grid have an important effect on the plate current.

When the grid was positive, the plate current was stronger. When the grid was negative, the plate current was weaker.

Suppose you insert a 5-volt 60-cycle current source between the grid and filament of our circuit board, as in Fig. 54. Let us see how this will affect the plate current.

Draw the zero grid-voltage line downward (see Fig. 55). We shall use this line as the time line for the 60-cycle alternating current. Draw vertical lines through each 1-volt mark on the grid base line until five lines are drawn.

Draw each line up to where each line touches the curve,
and from this point draw a line to the right, parallel to the
grid voltage base line.

Draw a plate-current half wave on these lines.    The time
from $O$ to $X$ on the grid curve is the same as the time from
$O'$ to $X'$ on the plate-current wave.

Figure 56 shows how the second half wave is drawn.
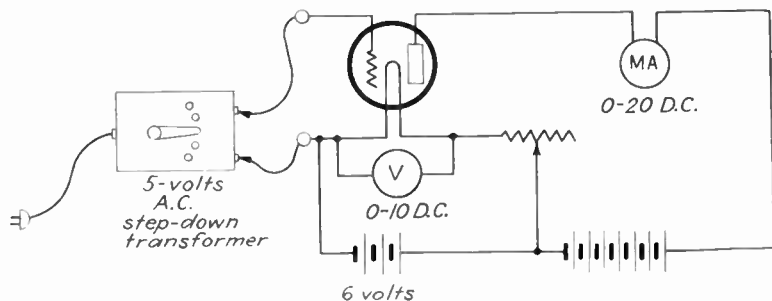


Fig. 54.    Alternating current on grid.

**How to Read the Curve.**    An alternating current on the
grid simply increases and decreases the strength of the
direct plate current.    This is amplification.    The ampli-
tude of the plate curve is higher.    When the zero grid-
voltage line is at the center of the straight part of the curve,
the plate-current wave will be of the same shape as the
grid wave.    There is no distortion of signals.

When the curve is steep, the tube is a better amplifier
than when its curve is flat.    Some types of tubes have a
steeper curve.    High B voltages increase the steepness of
the curve.

**Some Uses of This Grid-control Effect.**    An interesting
and useful effect is the grid's controlling action on the plate
current.    A few electrons at low voltage on the grid can
control a very strong electron flow on the plate.    An
alternating current on the grid increases and decreases

Milliamperes of Plate Current

.Wave form of
pulsating
direct-current
on plate

e
d
c
b
a
f
g
h
i
j
X'
O'

− 0 + Grid Volts

O j i h g f
e
X a b c d

Wave form of alternating-
current voltage on grid

This is the first
voltage loop
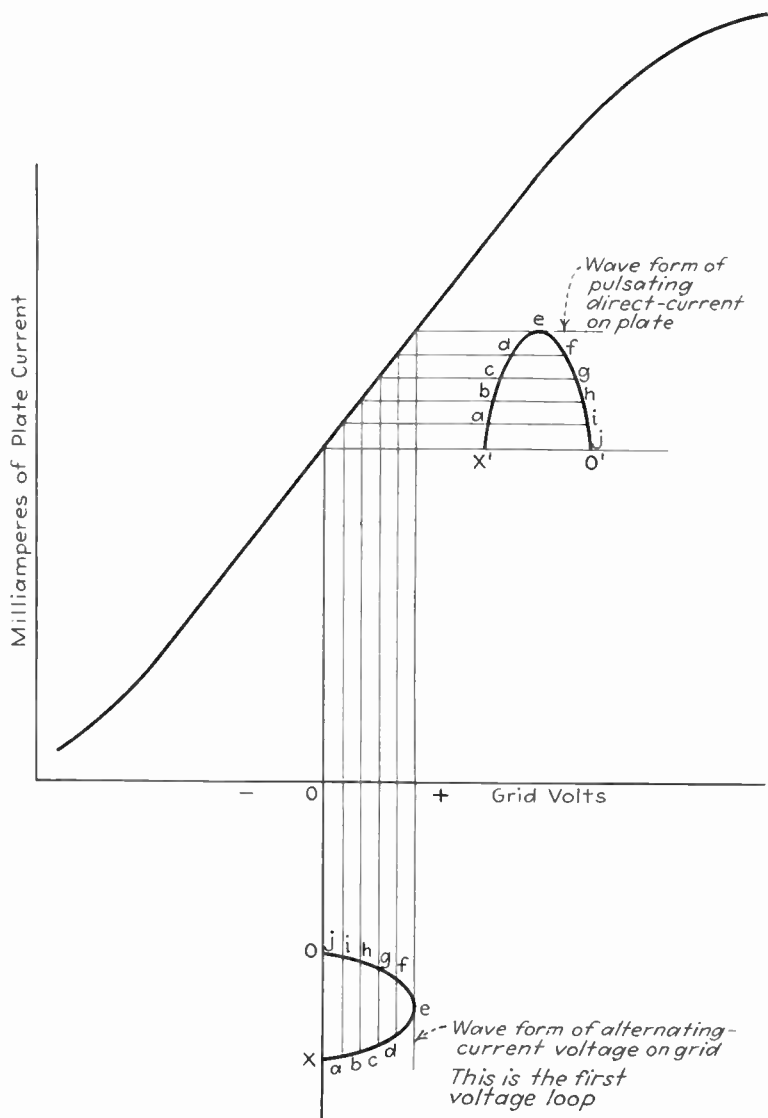
FIG. 55. Plate and grid half waves.
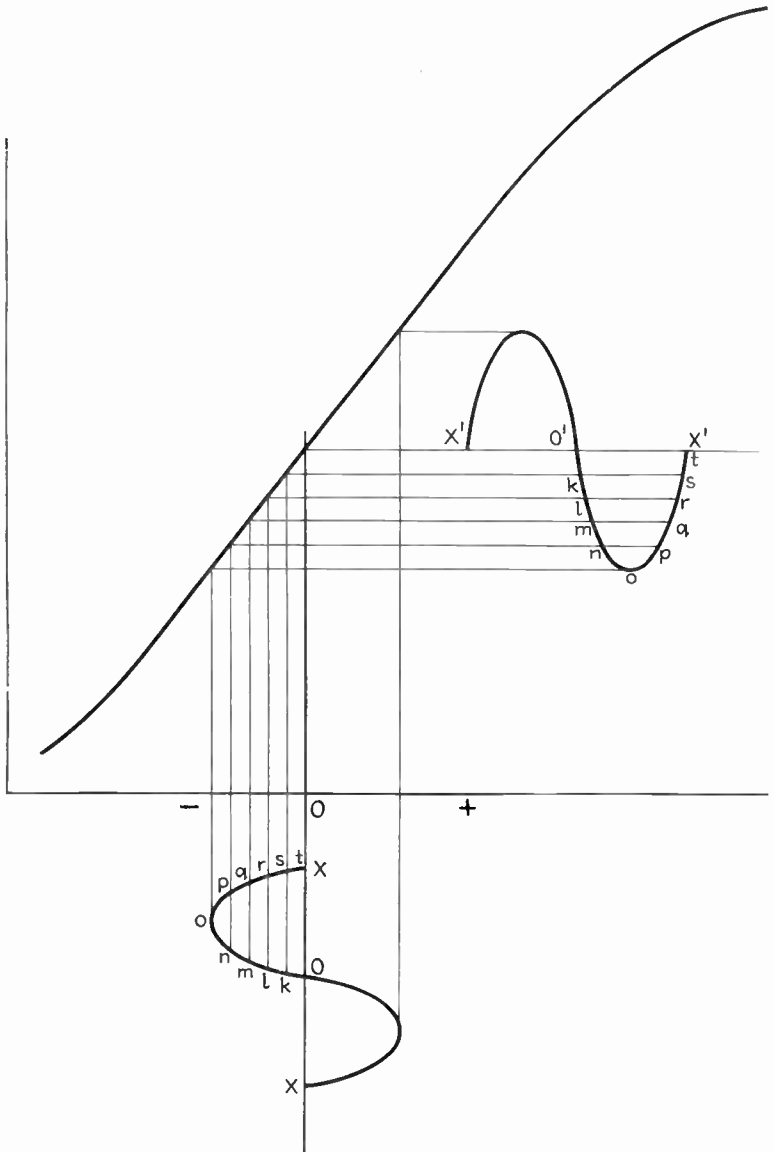
FIG. 56.   Plate and grid waves.

the amplitude of the plate current. If the grid becomes negative enough, the plate current will be stopped. This effect is used in audio amplifiers as well as in oscillator circuits described later in the book. Only a few volts on the grid are needed to control the flow of the plate current at 250 volts. This is the amplifying or leverage action of the vacuum tube. We shall study the amplifying action in the chapters on alternating-current and direct-current receiving sets. The same principle is used in nearly all radio circuits in some way or other.

**Current Flow in the Grid Circuit.** We have found that the current in the plate circuit was a pulsating direct current. What happens when the polarity of the grid is changed?

When electrons have been pumped on it by the C battery, the grid is negative. These electrons repel the electrons from the filament and in the space charge.

But when the electrons have been pumped off the grid by the C battery, the grid is positive. There are too few electrons on the grid so it attracts electrons from the space charge around the filament and a current will flow through the C battery and back to the filament. The result is a weak direct current flowing from the grid to the filament only when the grid is positive. This is a pulsating direct current. We shall learn in Chapter V how this grid current is used to make the receiving set more sensitive and better able to receive weak signals.

Other principles of tube operation, such as radio frequency, amplification, and oscillation, are taken up in the later chapters of the book.

### Questions

1. What is meant by the term *saturation point?*

2. Why cannot an increase in grid voltage continue to increase the plate current?

**3.** When you have reached the grid saturation point, how can you increase the plate current?

**4.** How does the voltage on the grid compare with the plate voltage?

**5.** What effect does an alternating current on the grid have upon the plate current?   .

**6.** When does an electric current flow from the filament to the grid?

### 6. AMPERAGE AND VOLTAGE

## An Explanation of Amperage

**Definition of Ampere.** *Ampere* is the word used to describe a flow of electricity. An ampere is the amount of current which will flow through a resistance of 1 ohm under a pressure of 1 volt. A more practical definition of an ampere is used by students of physics or chemistry. They know that in electroplating under standard conditions, one ampere of current always deposits exactly .001118 grams of silver per second. The amount of silver deposited in the electroplating process is an exact measurement of the number of electrons flowing through the plating solution per second. It has been computed that one ampere of electricity consists of 100,000,000,000,000,000,000 electrons flowing per second.

We find that we are unable to measure conveniently the number of electrons flowing each second in a wire, so we measure the effect of large groups of electrons as amperes of current. We can check the amount of current flowing or amperes flowing either by observing a meter or by measuring the amount of silver that is deposited each second on the metal. A wire carrying a current is somewhat similar to a pipe carrying water. The flow of water per second is measured in gallons. The quantity of electricity flowing per second in the conductor is measured in amperes. When we measure the quantity of water, we do not count the number of water molecules, but instead

we measure the space occupied by an enormous number of water molecules and call this quantity gallons.

**Definition of Milliampere.** *Milliampere* is a term used to indicate the output of B batteries and B eliminators where the current delivered is very small. *Milli* means *one-thousandth*, so the word *milliampere* means *one-thousandth of an ampere*.

**Electrical Circuits Compared to Water Pipes.** The electrical circuits can be compared to water pipes in other ways. Suppose we have five 1 inch water pipes 3 feet long.
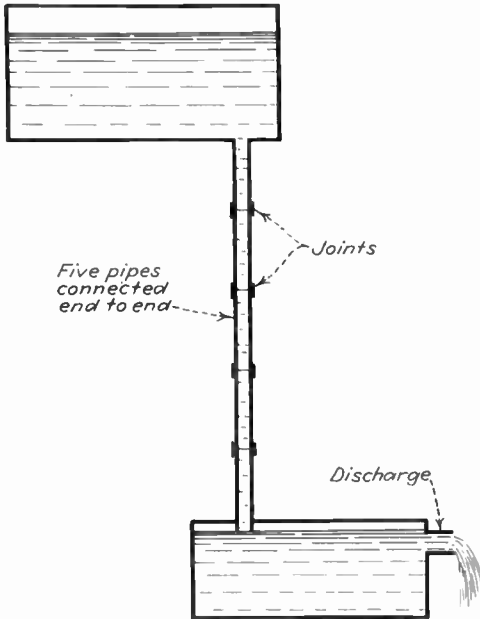


Fig. 57. Water pipes in series.

To connect them in series, we attach one pipe to the source of water, connect the end of the second pipe to the first, and the other end of the second pipe to the third pipe, until the five pipes are connected to make one 15-foot continuous pipe to carry water. This is shown in Fig. 57.

If we connect them in parallel, we attach one end of
each of these five pipes to the source of our water supply
as in Fig. 58.    These pipes will all discharge into the outlet.

The amount of water that can flow each minute through
the pipes when connected in series will be determined by
the size of the first pipe, and the total amount of water
delivered per minute will be the same as though none of the
other pipes were connected to it.    (If these five pipes are
extremely long, friction in the pipes will reduce the total



*Discharge*
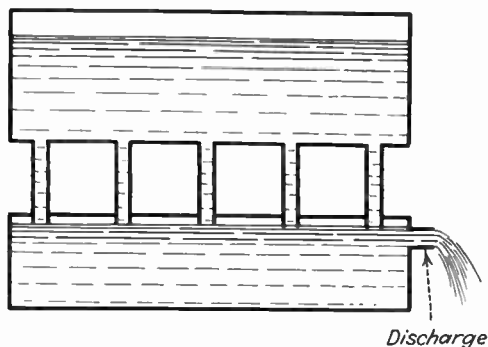
FIG. 58.    Water pipes in parallel.

amount of water flowing through them per minute.)    The
total amount of water per minute flowing through the pipes
when connected to the source in parallel will be five times
as great as the amount flowing through one pipe alone.    A
parallel connection will carry a greater quantity of water,
as measured in gallons, than will a series connection.

**Current Used by Radio Tubes.**    Connect several direct-
current tubes in series with a 6 volt A battery and an
ammeter.    Try the type 01A, and the type 71A tubes to see
how many amperes of current flow through the filaments.

**The Amperes of Current Delivered by Various Power
Sources.**    The current output of a storage battery is very
great.    A 100-ampere-hour storage battery will deliver a

current of 1 ampere for 100 hours. Or it will deliver 50 amperes for 2 hours. Dry cells will deliver about 30 amperes at $1\frac{1}{2}$ volts for a short period of time. B eliminators will deliver about 60 milliamperes of current. But if you draw heavy currents from any kind of battery or other source of power, so much heat is generated that the batteries, the wires, or the eliminator burn up.

**Small Wires Cannot Carry as Much Current as Large Wires.** A small pipe will carry less water than a large pipe of the same length. Since water and electricity act somewhat alike, a small wire should carry less current than a large wire.

To test this out, we shall connect several sizes of wire to a 6-volt battery and read the amount of current flowing.

## An Explanation of Voltage

**Voltage Is Pressure.** A volt is the pressure of electricity required to force 1 ampere of current through a resistance of 1 ohm. Voltage in electricity corresponds to pressure in water. The wire carrying the current of electricity corresponds somewhat to the pipe carrying the water. Quantity in water is measured in gallons. The quantity of electricity, or the number of electrons flowing per second, is measured in amperes.

Water pressure, or the pressure exerted by the molecules of water flowing in the pipe, is measured as so many pounds per square inch. In electricity the pressure exerted by electrons flowing through a wire is measured in volts. The number of volts has nothing to do with the number of electrons in the wire. A Tesla coil causes an extremely high pressure on very few electrons. In other words, we have a low-amperage current at a pressure of many volts. A Tesla coil generates an extremely high voltage, but the amount of current flowing is so small that the current is not dangerous if taken through the body.

We may also have very heavy currents flowing in circuits under very low pressure. An example of this is in the step-down transformers used for arc welding. In this kind of circuit, the 110-volt alternating current is stepped down to about 16 volts. The currents, or the amounts of electrons flowing, run over 100 amperes.

**Current through a Resistor Increases as Voltage Increases.** In this experiment we shall show that an increase in voltage will force more current through a fixed resistance. Connect a rheostat across the secondary of a toy transformer in series with an alternating-current 0–10
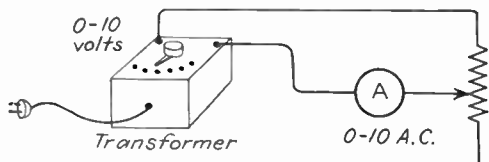


Fig. 59.    Circuit diagram for voltage-current tests.

ammeter (see Fig. 59). Turn the arm of the rheostat so that all the resistance is connected in the circuit. Do not change the resistance in this test.

Read the voltage across the resistor. Connect to the 6-volt tap on the transformer secondary and read the current flowing through the ammeter. Now connect to the 12-volt tap. Read the current flowing through the resistance as indicated on the ammeter. Continue making tests for each voltage tap on the transformer, running up to about 50 volts if possible.

Did you find that the amount of current flowing through the resistance increased when there was more pressure, or voltage?

**Voltage Drop—How the Voltage Drops through a Resistance.** Every wire or conductor has a resistance to current flow. Voltage or pressure is required to force the electrons

through a wire.   Heat is generated as the voltage or pressure
forces the electrons through the resistance of the wire.

Try an experiment with a rheostat having from 30 to 50
ohms resistance.   Make the connections in the way that is
shown in Fig. 59.   Move the contact arm to vary the volt-
age drop across the resistor.   Now, take the rheostat apart
and stretch the wire out to see how many feet of wire you
had in this resistance element.   This is a way to get some
idea of the number of volts used up for each foot of wire.
The rheostat is just a handy arrangement for sliding the
contact along the wire and thus lengthening the amount of
wire in the circuit.
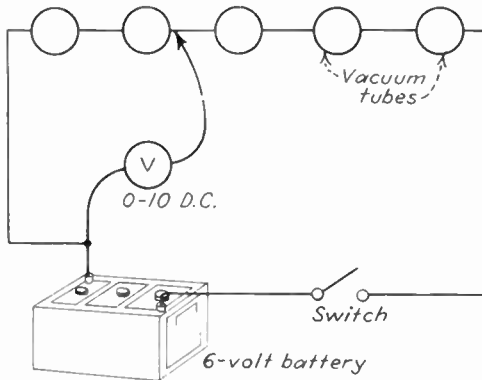


Fig. 60.   Voltage drop through tube filaments.

**Voltage Needed to Light Tubes in Series.**   Connect the
filaments of five 01A tubes in series.   Connect the tubes,
voltmeter, and battery as shown in Fig. 60 to see what
voltage has been used (the voltage drop) after the elec-
tricity has flowed through one or more tubes.   Will one
6-volt battery be large enough to supply the voltage needed
to light several tubes connected in series?

Connect the negative side of the voltmeter to the negative
battery post.   Connect a test point to the other side of the

meter. Touch the test point to the positive side of each tube so as to measure the voltage drop up to that point. Note the voltage. Touch it to the $F$ positive post on the second tube. Note the voltage. Touch it beyond the third tube, and read the voltage. Continue until you have taken the reading for all of the tubes. This experiment shows that several tubes cannot be connected in series when using only a 6-volt battery. Many more volts of pressure are needed to force the flow of electrons through several tubes connected in series than through one tube. This would require a battery of higher voltage. This is not practical, so the parallel circuit is used. If one tube in a series circuit burns out, all go out.

The current in a series circuit is the current needed by one tube.

### 7. VOLTMETERS AND AMMETERS

**The Field of Force around a Coil.** Make two holes with a pencil through a piece of cardboard about 4 inches by 6 inches in size. Space the holes about $2\frac{1}{2}$ inches apart. Thread 50 to 75 turns of enameled or cotton-covered wire, about size 22, through these holes to form a round coil (see Fig. 61). Sprinkle iron filings on the card around and inside the coil.



6-volt battery
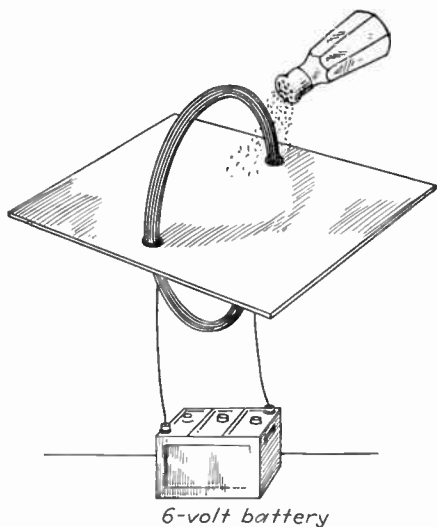
FIG. 61. Coil to study field of force.

Attach the ends of the wire from the coil to a 6-volt battery. Tap the edge of the card with a pencil. The iron filings will form parallel lines showing the path of the

magnetic lines of force through and around the coil.
The lines of force are strongest inside the coil, and they
gradually weaken near the ends of the coil.

You can see from the appearance of the lines of force on
the cardboard around the coil that the strength of the
magnetism is increased by coiling the wire up so that many
turns of wire are close together.

**Turning Effect of a Coil in a Magnetic Field.**    We know
that a wire carrying a current will move when placed in
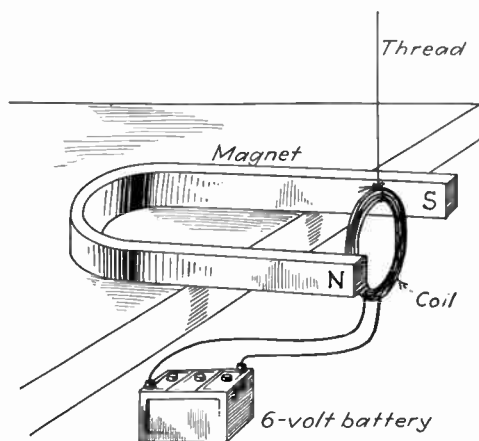


Fig. 62.   The coil turns.

the field of a permanent magnet.   Let us see what will
happen when we wrap the wire into a coil having many
turns and pass the same amount of current through the coil.

We know that like magnetic poles repel each other when
we are using bar magnets and horseshoe magnets.   Let us
see if this same thing will occur with an electromagnet.
We shall test this by hanging the coil between the poles of
a magnet as in Fig. 62.   Suspend the coil by a long thread
so that it may turn easily.   Have the connecting wires
arranged so that they will not hinder the motion of the coil.

Touch the ends of the wire leading to the coil to a 6-volt battery and notice the direction in which the coil turns. Now reverse the connections to the battery and notice what happens to the coil.

It is apparent that if the lines of force created by the current flowing in one direction cause the coil to turn one way, then when the current flows in the other direction through the coil, the magnetic force changes its direction and causes the coil to turn the opposite way.

Connect the ends of the wires leading from the coil to test points and try the same experiment on 2 volts, 4 volts, and 6 volts. Notice that the more current used, the stronger and more rapid the motion of the coil. Now, we can use this device as a means of testing the strength of different currents. This combination of a coil and magnet we have worked out is a simple form of meter for measuring the strength of electricity flowing in a coil.

## Construction and Operation of Direct-current Voltmeters

**Types of Meters.** Almost all meters consist of a combination of some form of coil and a magnet. The magnet sometimes is a permanent magnet and sometimes is an electromagnet. The coil is suspended in various ways. A pointer, connected to the coil, moves over a card on which is a scale indicating the amount of current flowing through the coil. The motion of the coil is usually opposed by some form of a spring. In the more expensive meters the coil is suspended on jeweled bearings. The meter is covered by a protecting case with a glass cover, which keeps out dust and dirt and keeps drafts from influencing the extremely light moving parts of the meter.

The simple meter that we constructed is called a galvanometer, and measures the electricity flowing through the coil. For our purpose we shall want a meter which

measures the pressure of the electrons moving in the wire. This kind of meter is called a voltmeter. Later, we shall describe a meter which measures the amount or quantity of electrons flowing in the wire. This is called an ammeter.

**Direct-current Voltmeter.** The direct-current voltmeter is a sensitive galvanometer; that is, a coil suspended between the poles of a permanent magnet. See Fig. 63 for the arrangement of the coil and the different parts of the meter. Notice that the ends of the pole pieces are curved. The magnetic force will remain the same between the two poles as the coil turns, since the coil is always the same distance from the pole pieces. The coil is wound on a form

around a soft iron core. The purpose of this core is to furnish a more even magnetic path between the pole pieces. This means that the meter is more sensitive and will measure weaker currents accurately. The electricity flows into the meter and through the coil. From the coil the electricity flows to a high resistance made of resistance wire which
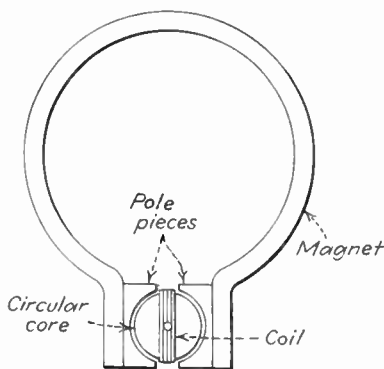


Fig. 63.   Direct-current voltmeter.

prevents all but a few electrons from flowing through the very fine wires of the moving coil. If too much current flows through the meter, the meter coil will be burned out.

This arrangement gives us a means of measuring the pressure of electrons without allowing many of them to flow through the coil. Voltage in electricity, as we know, is the pressure forcing the electrons along the wire.

**Experiments with the Voltmeter.** *Test Voltage of Various Batteries.* Connect test points to the voltmeter and touch

the points to the terminals of several kinds of batteries to test their voltage. Test a dry cell, an air cell, a storage battery, a flashlight cell, a new battery, and an old battery to see what voltage each shows on the meter. It is important to see that the positive terminal of a direct-current voltmeter is connected to the positive terminal of the cell. If this is not done, the current flowing through the coils of the meter causes the needle to swing backwards. The best way to test the meter for correct polarity is to tap the test points on the terminals of the battery while watching the meter hand to see in which direction it moves. This is better than making a permanent connection, which could probably cause the meter to burn out before the connection could be changed.

*Voltage Drop across Rheostat.* Take measurements of voltage across several kinds of resistors or rheostats that



are used in receiving sets. Connect a rheostat across the battery. Tap the test points of the meter to the two terminals of the rheostat. The voltmeter will measure the voltage drop, or the pressure used up in forcing the current through this high-resistance wire.

Connect a radio tube to a battery to make the tube light and test the drop of voltage
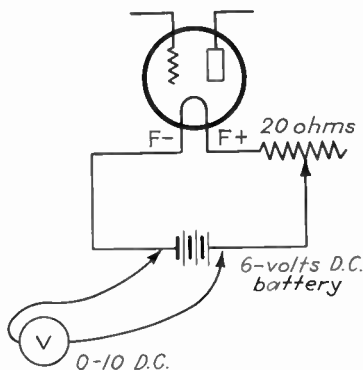
Fig. 64.  Circuit diagram for testing rheostat voltage control.

across the filament terminals.

*Rheostat Controls Voltage.* Connect the type 01A tube to a 20-ohm rheostat and a 6-volt storage battery, as shown in Fig. 64. Clip the test points to the voltmeter. Touch the points to the battery terminals. The meter should read 6 volts.

Touch the points to the tube *F* positive and *F* negative binding posts.    The voltage now should be less than 6 volts.

Touch the points to the opposite ends of the rheostat. The voltage drop in the rheostat should be about 1 volt.

Move the rheostat control while the points are connected to the rheostat ends.    The voltmeter measures the loss of electrical pressure in the tube and in the rheostat.    This loss of electrical pressure is called voltage drop.

Vary the setting of the rheostat to see what the change in the voltage drop in the rheostat will be.    When the length of the resistance wire in the rheostat is increased by moving the contact arm, the resistance becomes greater and either less current can flow through the wire or more pressure is required to force the current through, and thus more pressure is used up.    Another way of saying this is that the voltage drop increases as the length of resistance wire is increased.

## Construction of the Direct-current Ammeter

The construction of the direct-current ammeter is the same as that of the di-rect-current voltmeter (see Fig. 65). A delicate suspend-ing staff carries a coil of fine



Fig. 65.    Direct-current ammeter.

wire.    A spring is used to return the pointer to zero.    The better type of meter has a permanent magnet and a core inside the coil.    A high resistance in series with the winding prevents too much current from flowing through the fine wire.    Now, the direct-current ammeter is connected so that
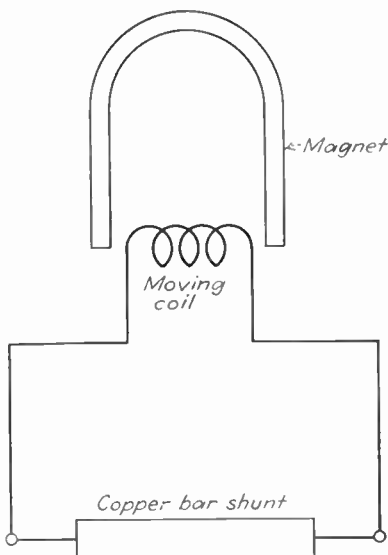
any current flowing in the circuit flows through the meter.
We know that the fine wire used in winding the coil will not
carry heavy currents which we may wish to measure, so a
strip of copper is connected in shunt across the meter
terminals, as is shown in Fig. 65. The bar is called a
shunt.  The size of this bar is accurately measured.  Since
we know the current-carrying capacity of copper, we can
work out the amount of cur-
rent this length of bar will
carry.  From this we can
work out the drop in voltage
across the bar.  This deter-
mines the size of the shunt
needed for a meter scale
which will read from 0 to 5
amperes or from 0 to 50
amperes, and so on.  The
range of the meter may be
changed by attaching differ-
ent shunts and by using
different scale cards in the
meter.  Many meters have
several scales drawn on the
card.
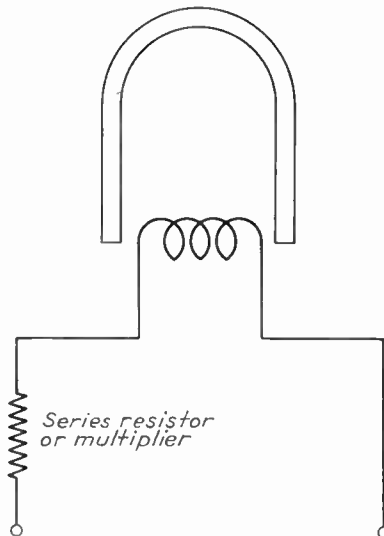


Series resistor
or multiplier

Fig. 66.   Voltmeter.

**The Milliammeter.**  An ordinary ammeter can be
arranged so that it measures very small values of current.
An ammeter which measures currents of a few thousandths
of an ampere is called a milliammeter.  A milliampere is
a thousandth of an ampere.  The milliammeter is used to
measure the current flowing in the plate circuits of receiving
sets, for laboratory measuring purposes, and for measuring
the plate-supply current in transmitting sets.  The milliam-
meter is easier to damage than the ammeters of ordinary
range.

**Milliammeter as a Voltmeter.** The milliammeter may be converted into a voltmeter by the addition of a high resistance in series with the moving coil (see Fig. 66). A direct-current milliam- meter of 0–1 range is used. An accurate meter will have 1000 ohms in the series resistance to every volt on the scale. This type of meter, with a special scale, can be used to measure resistance in ohms and is then called an ohmmeter.
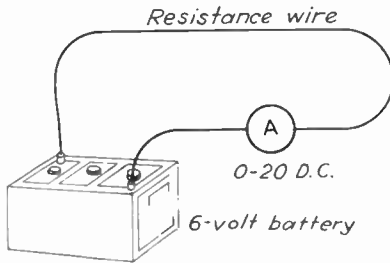


FIG. 67.   Wire size and current flow.

**Milliammeter Measures Plate Current.** Connect a milliammeter in the plate circuit of several standard tubes to test the plate current of each type of tube. Check these plate currents with the rated current shown on a standard tube chart. Compare the plate current in different detector and amplifier cir- cuits when different B volt- ages are used in each circuit.
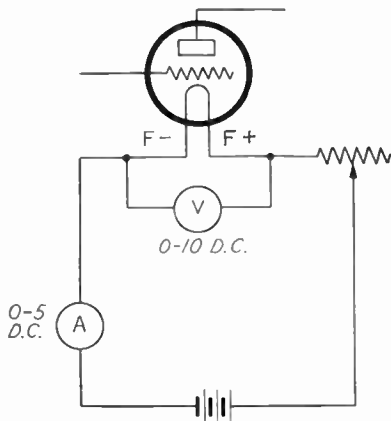


FIG. 68.   Current flow in a tube.

**Experiments with the Ammeter.** *Amperes Carried by Different Kinds of Wire.* Connect 5 feet of wire taken from a 30-ohm rheostat in series with an ammeter and a 6-volt storage battery as in Fig. 67. (Check the polarity of the meter connections.) See how much current flows through this wire. Measure the size of the wire with the gauge. Now, connect in the same size copper wire. Make a tap connection to the

meter to prevent damage if too much current flows.    Tap
the connection to the meter and see whether the same size
copper wire carries as much or more current than the
resistance wire.

*Current Used by Common Tubes.*    Connect an ammeter,
tube socket, rheostat, and battery with a voltmeter across
the *F* positive and *F* negative socket posts, as in Fig. 68.

Place a type 01A tube in the socket.    Adjust the rheostat
for 5 volts, and read the ammeter.    Make the same test
with the type 12A and the type 71A tube.

The proper battery voltage can be found from any stand-
ard tube table.    Can you see why certain kinds of tubes
were used when battery charging was found to be expensive?

## Alternating-current Meters

Three types of alternating-current meters are discussed
in the next few pages.    Each meter can be made into an
ammeter by adding a shunt or into a voltmeter by adding
a resistor, as is shown later in the text.

**The Moving-vane Alternating-current Meter.**    The prin-
ciple of magnetic repulsion is used in the construction of a
moving-vane meter for alternating currents.    A fixed coil is
used in this meter.    A curved iron core is fixed permanently
inside of the coil (see Fig. 69).    The moving pointer is
attached to a small curved iron vane, or moving core, about
the same size as the fixed core in the coil.    Both the moving
core and the fixed core are curved.    These two pieces are
machined so they can be placed very close together.    The
alternating current flowing in the coil magnetizes the core
pieces.    The corresponding ends of the cores have the same
polarity and are forced apart.    As the strength of the
current increases, the strength of the magnetism of the cores
increases, and they are forced farther apart by the magnetic
repulsion.    The strength of the current flowing through the

coil may be measured by the motion of the pointer con-
nected to the moving core. When a known current flows
through the coil it produces a certain amount of motion
of the arm. This point is marked on the meter card.
Enough points are marked so that the meter will read in
amperes or volts, or parts of amperes or of volts.
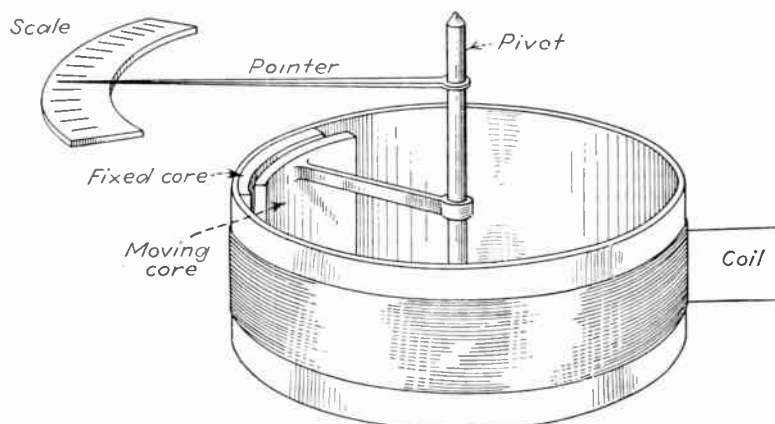


Fig. 69. Moving-vane alternating-current meter.

**The Solenoid Gravity Alternating-current Meter.** The
form upon which the coil of this type of meter is wound,
we notice, is bent in the arc of a circle (see Fig. 70). The
moving core of the meter is a piece of soft iron hung from
a knife edge placed above the coil. The magnetism caused
when a current flows through the coil pulls the soft iron
core into the coil, or solenoid. A small weight counter-
balances and opposes the motion of the core and returns it
to zero when no current is flowing. The magnetism created
in the coil pulls the core against the action of gravity on
the small counterweight. This type of meter can only be
used in a vertical position. The markings of the scale are
crowded at either end.

**Construction of the Inclined-coil Meter.** The coil in this meter is set at an angle to the shaft, as shown in Fig. 71. The moving magnetic vane, or core, is set on the shaft
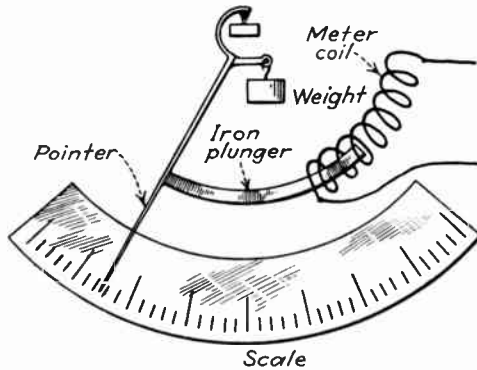


FIG. 70. Solenoid gravity alternating-current meter.
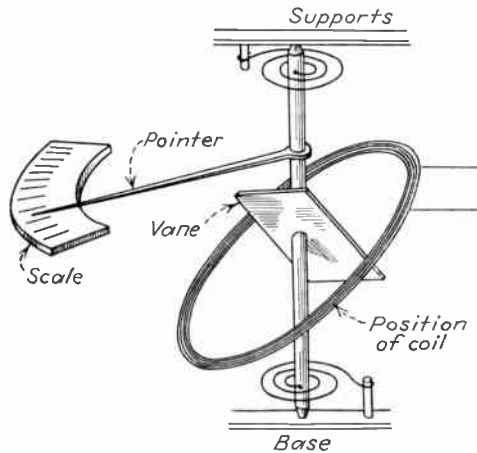


FIG. 71. Inclined-coil meter.

at an angle to the coil. Hair springs are connected at each end of the shaft to oppose and control the motion of the vane and to return the pointer to zero reading. The oper-

ation of this type of instrument depends on the fact that when a current flows through the coil it magnetizes the

vane. The vane, which is set at an angle to the coil, tends to turn and line up with the magnetic lines of force produced by the coil. The motion of the vane depends upon the strength of the current flowing in the coil. The stronger the current, the greater is the turning force on the vane.
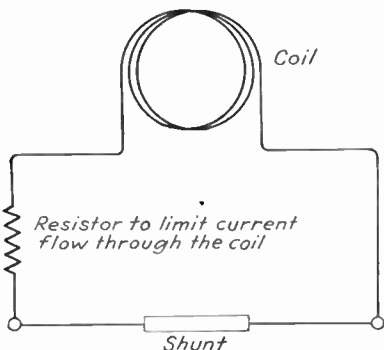


Fig. 72. Alternating-current ammeter.

**Construction of an Alternating-current Ammeter.** We can make an alternating-current ammeter by connecting a shunt across one of our alternating-current meters (see Fig. 72). The resistance which is connected in series with the coil of the alternating-current ammeter is of different value from that used for the alternating-current voltmeter.
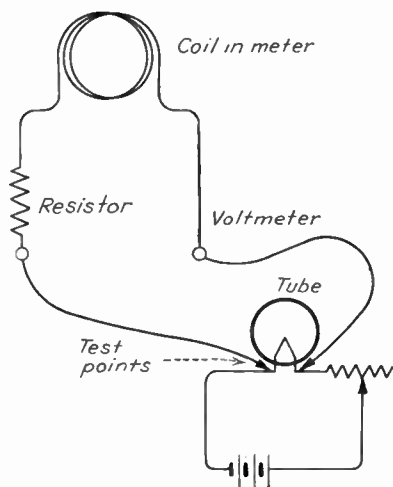


Fig. 73. Measuring voltage at tube filament.

**How to Connect the Alternating-current Voltmeter.** The connections of the alternating-current voltmeter and the direct-current voltmeter are the same (see Fig. 73). A voltmeter is always shunted across the piece of apparatus whose loss in voltage is to be measured. Try out the meter

we have just constructed by measuring the voltage drop across tube filaments, rheostats, and B batteries. Measure the voltages of the secondary of a bell transformer, of storage batteries, or of dry cells. Test the voltage of a B eliminator.

## Care of Meters

Meters must be handled with care. They will not stand rough handling, jars, or being dropped, since their construction is similar to that of a good watch. Care should be taken to see that voltages and currents larger than those for which the scale reads are never allowed to flow through the coil. Either the coil or the shunt will be burned out. Damaged meters of average or good quality can be repaired either at the factory or through your nearest dealer. Often the expense of such repairs is as great or greater than the price of a new meter. It pays to take care of a good meter.

No meter should be connected to a power source with a voltage greater than the highest reading in the meter scale. For example, no meter with a scale for 0–10 volts is used when the voltage to be measured is over 10. If a meter which is designed to handle 10 volts is used on a 50-volt supply, the resistance will be burned out, and also the coil in the meter may be burned out. It is possible, however, to use the same meter for several voltage ranges, such as 0–10 volts, 0–50 volts, 0–150 volts, by having different resistors called multipliers connected as shown in Fig. 66. These resistors change the range of the meter. Meters may be protected by placing a coil or a fuse in the circuit which will burn out before the current is great enough to damage the meter. The meter will also be damaged if it is connected so the current flows in the wrong direction through the coil.

Heavy jars will damage the jeweled bearings or the parts which carry the moving coil. Some meters are designed so that they must be used in either a flat position or an upright position.

**Alternating- and Direct-current Meters Compared.** The alternating-current meter will read on direct current, but the reading is not accurate. A direct current will cause the hand to move. When a direct-current meter is connected to an alternating current, we see no reading and the meter may be damaged.

### 8. RESISTANCE

**Resistance and Current Flow.** The resistance of a metal to the flow of electrons that make up an electric current is due to the arrangement of the electrons in the atoms of metal of which the wire is made. An atom, we know, has central protons or positive electric charges, around which are several levels of electron energy or motion. These levels were originally thought of as rings in which electrons moved. When few electrons are in the outer level or ring of the metal, then the metal is generally a good conductor and has a low resistance; but when many electrons are in the outer ring or level of the atom, the material is a poor conductor of electricity.

Apparently when there are many electrons in the outer ring of atoms, the electrons in the atom are not easily disturbed and offer more resistance to that flow of electrons from atom to atom which we call an electric current. The best scientific thought does not agree on exactly what a flow or current of electricity is. The only satisfactory explanation of electron current flow is by means of differential equations, a branch of higher mathematics. An explanation using mathematics is much too complicated to be of interest to a student of elementary electricity.

**Electron Explanation of Resistance.** When electrons flow through a wire, they collide with electrons in the outer levels of the atoms of the wire and their passage is interfered with. This interference, or obstruction, is called resistance. The atoms in a copper wire offer very little obstruction to the electrons flowing through them, but in metals like iron the atoms offer great resistance to the flow of electrons. The atoms in molecules of some substances like bakelite, isolantite, glass, and wood offer so much obstruction or interference that the flow of electrons is almost completely stopped. Electrons can flow through them only when thousands of volts pressure is used to drive the electrons.

**Resistance Increases with Length of Wire.** Resistance is measured in ohms. A resistance of 1 ohm requires a pressure of 1 volt to force 1 ampere of current through it.

A No. 14 copper wire 1 foot long has .0025 ohms resistance. A No. 24 copper wire 1 foot long has .0262 ohms resistance. The bigger the wire the less resistance it has. Copper-wire tables show the resistance per thousand feet of the standard sizes of wire.

A rheostat is a coil of resistance wire on which a contact arm slides. As the arm is moved to put more wire in the circuit, the resistance is increased.

**Resistance Causes Heat.** Resistance may be caused by several things. A wire or metal that is a poor conductor has high resistance. Electrons cannot flow through this metal easily. The wire may be small; even copper or silver wire, both with good electron-carrying ability, have much resistance to large currents if the wire is small.

This is easy to understand if we compare a wire carrying a current to a pipe carrying water. For example, if a large pipe delivers a gallon of water in 10 seconds, a smaller pipe will deliver a smaller quantity of water in the same time provided the pressure is the same. In order to force a

gallon of water through the smaller pipe in 10 seconds, more pressure must be applied to the water in the small pipe.

Similarly, large wire can carry a current with little or no heating, but if we try to force the same amount of current through a small wire of the same kind of metal, there is more resistance to the flow of current. Heat is generated by this resistance of the atoms in the wire to the electrons forcing their way through the metal.

**Resistance of Wires of Different Composition.** It has been found that different metals have different resistance. In other words, one metal will allow currents of electricity to flow through it quite easily. We say that this metal has a low resistance. Silver has probably the least resistance of any metal, but it is too expensive for use in wires and in other parts. Copper, which has a resistance a little higher than that of silver, is cheap enough to find general use. Aluminum has a low enough resistance to find some use in radio, but it is not as widely used as copper. Iron and steel have too high resistance for use in radio circuits. Carbon and other high-resistance materials are used for grid leaks and as fixed bias resistors. Among the high resistance metals are nickel, chromium, and manganese alloys. Nichrome is a trade name of an alloy used quite extensively for resistance wires in rheostats, voltage dividers, and many of the small resistors used in modern sets.

### 9. SERIES AND PARALLEL

In part 5 we have already had an explanation of the terms *series* and *parallel*, by comparing electric circuits with water pipes. Now we shall study the behavior of various electric appliances when connected in series and in parallel.

**How to Connect in Series.** Batteries, phones, tubes, resistors and other apparatus may be connected in series

or in parallel.     In the series connection, a wire is connected between each piece of apparatus, linking each piece together
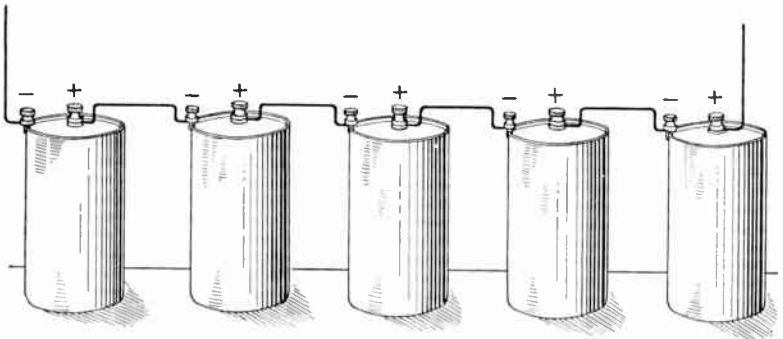


Fig. 74.    Cells wired in series.



*Tubes*

6-volt battery
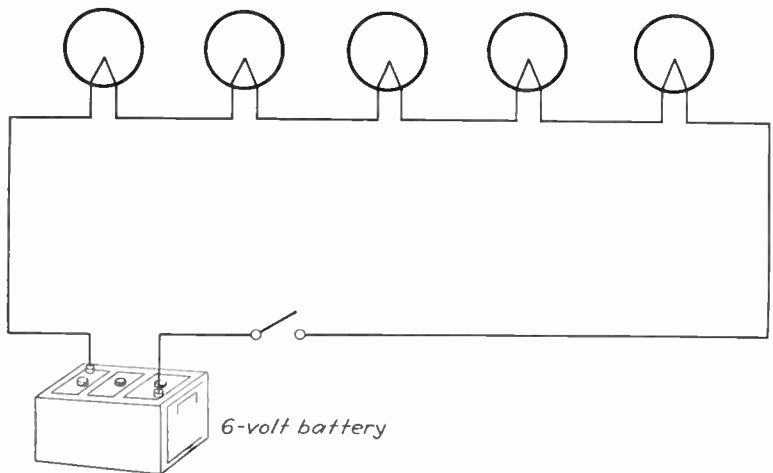
Fig. 75.    Tubes wired in series.

as in a chain, with one linked to the other to form the circuit.

In the sketch in Fig. 74 five cells are connected in series. A wire runs from the negative post of the first cell to the

positive post of the second; from the negative of the second cell to the positive post of the third, and so on.

Tube filaments are connected in series in the same way (see Fig. 75). A wire runs from the positive binding post
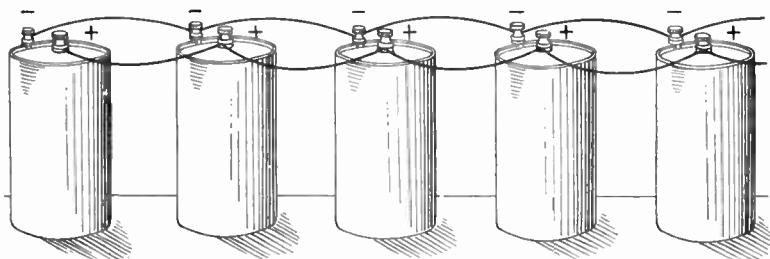


FIG. 76. Cells wired in parallel.

of the first tube to the negative binding post of the second tube, to the positive binding post of the third tube, and so on.
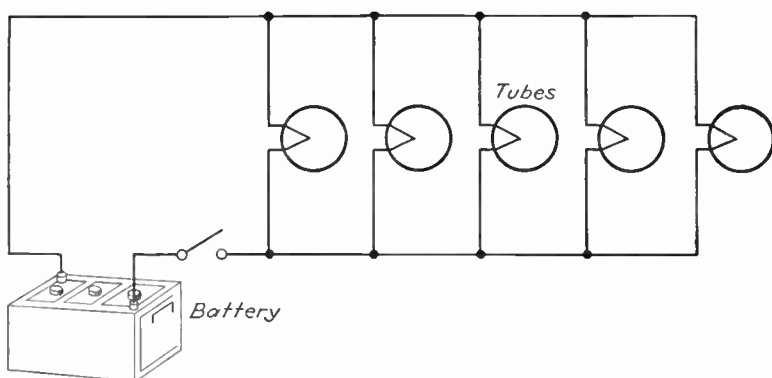


FIG. 77. Tubes wired in parallel.

**How to Connect in Parallel.** To connect five cells in parallel, attach the positive terminals of all of the cells to one wire, and the negative terminals of all the cells to another wire (see Fig. 76).

When tubes are connected in parallel, the leads from the
battery supply may come in at either end of the combina-
tion (see Fig. 77).

**Voltage Delivered by Batteries in Series.**    A dry cell has
a pressure of $1\frac{1}{2}$ volts and a current of 28 amperes when
new.    Measure the voltage of five cells connected in series
to find the effect a series connection will have on the total
battery voltage.    Measure the voltage with a direct-current
0–10 voltmeter.    The first cell exerts a pressure of $1\frac{1}{2}$ volts
on the second cell.    The second adds $1\frac{1}{2}$ volts, making the
total pressure of the two cells 3 volts.    This pressure is
exerted on the third cell which also has a pressure of $1\frac{1}{2}$
volts, making a total of $4\frac{1}{2}$ volts.

The total voltage of cells in series is equal to the sum of
the volts pressure of each cell.    In this battery of five cells
it is five times $1\frac{1}{2}$ volts, or $7\frac{1}{2}$ volts.    Check the voltage
after each cell to prove the accuracy of these facts.

Each cell is like a bucket full of electrons.    When the
five buckets are connected in series, it is like piling the
buckets on each other to make a tank that is five buckets
high.    When electrons are drawn out of the bottom of the
tank, the pressure is equal to the pressure of each bucket
added on top of the first.    The deeper the tank the greater
the pressure.

**Current Delivered by Batteries in Series.**    Now let us
see what happens to the total amperage, or number of
electrons, when cells are connected in series.    The first cell
can deliver enough electrons to make a quantity of 28
amperes.    This amount of current flows to the next cell,
but since it can let through only 28 amperes, the total
amperage from the second cell is 28.    The same is true
with each added cell.    The result is that five cells connected
in series will deliver the same amperage that one cell alone
will deliver.

**Voltage and Amperage of Cells Connected in Parallel.**
Connect five dry cells in parallel. What will happen to
the voltage? Each cell can deliver a pressure of $1\frac{1}{2}$ volts.
Now think of these cells as pipes of the same size carrying
water from a tank (see Fig. 58).

We have a water reservoir, and there are five 1-inch
pipes coming out of it on the same levels. Each pipe
can deliver a pressure of $1\frac{1}{2}$ pounds. Now the pressure
on the lower tank will be $1\frac{1}{2}$ pounds regardless of how
many pipes you put through, but the quantity of water
flowing will be the sum of the water flowing out of each
pipe.

Prove this by testing cells connected in parallel with a
voltmeter, 0–10 volts range. Check the voltage of the first
cell, that of the second cell, then check the total voltage
across the terminals of both cells. Add a third cell in
parallel, check the voltage, and so on until five cells have
been connected in parallel. The total pressure or voltage
across the five cells connected in parallel remains $1\frac{1}{2}$ volts,
the same as the voltage of one cell alone.

Now test the amperage of these cells when connected in
parallel. The first cell can deliver 28 amperes. The
amperage measures the number of electrons per second
flowing to the terminals. The next cell when connected in
parallel adds 28 amperes, or an equal number of electrons,
to these terminals, and the total number of electrons, or
the total amperage, is double the amperage of the one cell.
Each cell adds to the total of electrons delivered so the
amperage of the combination of five in parallel is equal to
the sum of the amperages of each cell.

**Tubes in Parallel and Series.** Should five type 01A
radio tubes used in a battery set be connected in series or
in parallel? We have a 6-volt storage battery capable of
delivering from 100 to 150 amperes. This is far more than

we need.    Each type 01A tube requires $\frac{1}{4}$ ampere of current
at 5 volts pressure to heat the filament.

Now, if we connect these tubes in series as in Fig. 75,
the battery exerts a pressure of 6 volts on the first one.    It
takes about 5 volts to push the electrons through that tube.
There is only about 1 volt left to force the electrons through
the second tube filament.
However, it takes 5 volts to
heat a 01A filament to the
operating    temperature.
The result is that while some
current will flow through the
whole series of filaments,
there is not enough current
to light the filaments to
working heat.    You can tell
this by the brilliance of the
tube filaments.    You will
need a 25-volt battery if the
tubes are to be operated in
series  ($5 \times 5$  volts $= 25$
volts).    Five batteries are
too expensive and impracti-
cal, so let us see what can
be done with a parallel circuit.



2000 ohms          2000 ohms

Total- 4000 ohms
Fig. 78.    Phones in series.

The 6-volt battery can force $\frac{1}{4}$ ampere of electrons to the
first tube filament and have enough amperage left to oper-
ate many other tubes.    In the parallel circuit of Fig. 77 the
battery can also deliver 6 volts to the second tube and to
all other tubes in the circuit.    In other words, in a parallel
circuit the voltage between the wires coming from the
battery is the same at each tube.    When a 6-volt battery
is connected in parallel to five tubes, it can deliver 6 volts
to each of the five tubes.    This connection is more satis-

factory than the series circuit.    Each tube requires only 5 volts of pressure.    A rheostat is connected in one lead of the circuit to drop the pressure 1 volt.

**Phones in Series and Parallel.**    When phones are connected in series, the total resistance is increased.    Two 2000-ohm headphones connected in series have a total resistance of 4000 ohms (see Fig. 78).    It is possible in this way to increase the resistance so much that the receiving set will not work satisfactorily.    The increased resistance uses up the energy in the signal and weakens it.    If you wish to connect several phones to the receiver to hear faint signals and yet receive the program fairly loud, connect these phones in parallel (see Fig. 79).    From three to five phones in series will begin to weaken the signal.
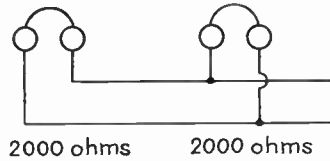
When phones are connected in parallel, the resistance is decreased.    When you connect two phones in parallel, the resistance is one-half of the total resistance or the sum of the reciprocals.    Suppose the resistance of each phone is 2000 ohms:
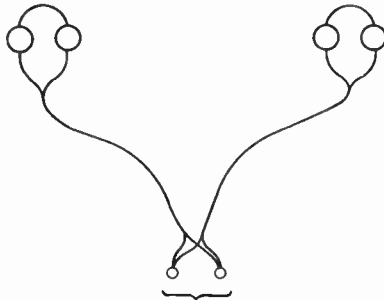
2000 ohms         2000 ohms

Total- 1000 ohms

Fig. 79.    Phones in parallel.

$$\frac{\text{single resistance, ohms}}{\text{number of resistors}} = \frac{2000}{2} = 1000 \text{ ohms}$$

Try connecting three or four phones on your radio set in series and in parallel to see the difference in the strength

of the signal.    From three to five pairs of phones in parallel
have little effect on the signal.

**Resistors in Series.**    Resistors connected in series or in
parallel will give exactly the same result as when we connect
Christmas-tree lights in series or in parallel.    The filament
of a Christmas-tree lamp is a small resistance wire, enclosed
in the glass vacuum bulb to prevent it from burning out.
The small lamp filament has a resistance of about 15 ohms.
When connected across the 110-volt line, this low resistance
will allow so many electrons to flow that the lamp will burn
out.

But by connecting several lamps in series, the resistance
of each is added to that of the others until only a safe
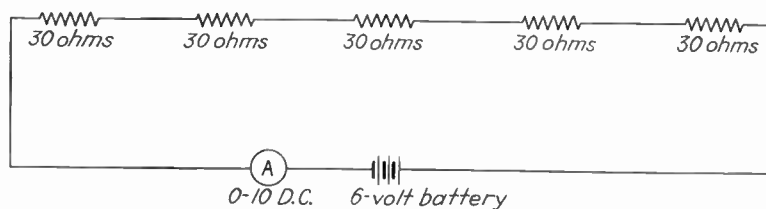


FIG. 80.    Resistors in series.

amount of current can flow.    The lamps now light brightly
but do not burn out.    If one lamp is removed and the
socket shorted out, too much current will flow, and the
lamp having the lowest resistance will burn out.

If we connect five 30-ohm rheostats in series with a
storage battery or with dry cells, the effect would be the
same as if we used five 30-ohm light-bulb resistors in series.

Think of electricity as electron flow.    Suppose we con-
nect resistors in series as in Fig. 80.    The first resistor will
let through only a given number of electrons when a given
pressure is applied.    The second resistor gets its supply of
electrons from the first, and since the second also has great
resistance, it will not even let through as many electrons

as the first supplied it. The third resistor stops more
electrons. The result is that the total amount of electrons
that get through the resistors connected in series is much
less than the amount that could flow through a single
resistor. (The electrons are not lost in going through each
resistor, but each resistor holds back some. Some electron
effect is lost in each resistor and appears as heat.) The
total resistance of five 30-ohm resistors connected in series
is the sum of the separate resistances.

Tube filaments are connected in series in the same way.
If we have a set using a type 24 and a type 27 and a type
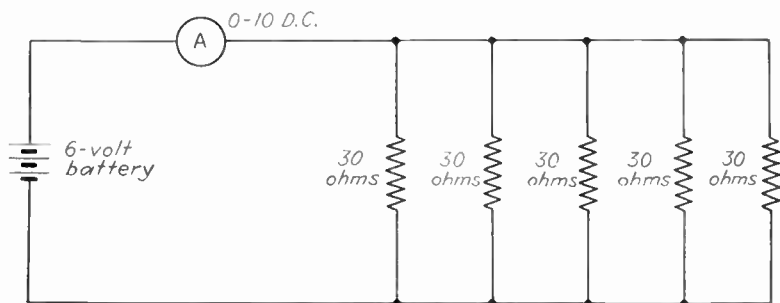


Fig. 81. Resistors in parallel.

80 rectifier tube, (5-volt filament), we can use a 10-volt
transformer by connecting the tubes in series.

**Resistors in Parallel.** Now, suppose we connect these
five 30-ohm resistors in parallel as in Fig. 81. The first
resistor allows a given number of electrons to flow from one
wire to the other. The second resistor also allows the same
number of electrons to pass through.

More electrons flow through the two resistors than flow
through one resistor. The resistance of two resistors in
parallel is less than the resistance of one alone, and the
resistance of five resistors is less than that of two and also
less than that of one.

The total resistance can be figured out by the following method: Divide the size of a single resistance by the number of resistors connected in parallel.

$$\frac{30 \text{ ohms}}{5} = 6 \text{ ohms.}$$

**Fuses.** Certain metals have low melting points. They will get hot enough to melt when small currents flow through them. We can use a metal which has a resistance higher than that of copper and which melts at a lower temperature than copper to act as a fuse for the purpose of



Carries much current

Carries much current

Carries little current

Carries little current
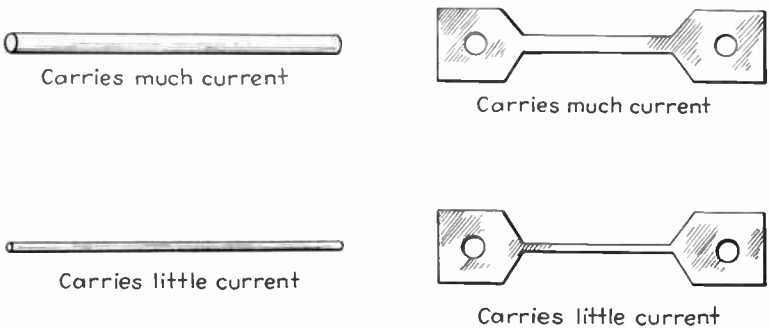
Fig. 82. Fuses.

protecting apparatus and circuits from danger of overload of current. The fuse melts and opens the circuit when more than a certain desired amount of current flows in that circuit.

The fuse is either a strip of metal or a small wire (see Fig. 82). The current-carrying capacity of this metal is known quite accurately, and a sheet or strip of measured thickness can be put to definite widths so that it will carry a specified amount of current.

When electrons flow through these wires or metal strips, they find it difficult to force their way from atom to atom,

and in doing so create heat which melts the wire. The fuse has a melting point about the same as that of wax. The fuse melts when the heat is far below that required to ignite clothes or paper, so there is little danger of fire from a melting fuse. The fuse wire is mounted in a guard which prevents even this slight danger from occurring.

The fuse is connected in series with the tubes or meters and other apparatus so that the metal strip will melt when more than a specified number of amperes of current flows through it. If a tube will carry 1 ampere of current safely with a 50% overload, a $1\frac{1}{2}$-ampere fuse is put in the circuit. Any surges of current of more than $1\frac{1}{2}$ amperes will melt the fuse wire and so will protect the tube.

### Technical Terms

**A battery**—Either dry cells or a storage battery used to heat the filament.

**ammeter**—An instrument which measures the amount of current flowing through a circuit.

**amperage**—The current, either alternating or direct, flowing through a wire.

**ampere**—A word used to describe the amount of flow of electricity.

**amplify**—To make stronger. A weak voltage on the grid of a vacuum tube makes changes in the plate current that are much stronger than the changes of the grid voltage.

**audio amplifier**—A tube circuit used to amplify the audio-frequency output of the detector circuit.

**bakelite**—An insulating material.

**bar magnet**—A bar of steel that has been magnetized.

**base prongs**—Small brass tubes set in the tube base. The prongs are arranged so they will fit into the tube socket only in the correct way. Wires from the tube elements pass through the prongs and are soldered to the tips of the prongs.

**B battery**—A high-voltage battery used in the plate circuit to make the plate positive.

**B eliminator**—A unit which is attached to the alternating-current supply and which furnishes a direct-current output; used to replace or to eliminate the use of a B battery. The unit has a transformer,

a rectifier, and a filter to change the alternating current to a pure direct current.

**conductor**—A wire, metal, or a solution through which a current of electricity will flow.

**dielectric**—The material, generally some form of insulator, placed between the plates of condensers.

**electromagnet**—A coil of wire through which a current flows becomes an electromagnet.

**galvanometer**—A sensitive instrument that indicates a flow of current.

**gassy tubes**—A tube in which some gas has been left during manufacture.   Gassy tubes are very uneven and critical in action.

**getter**—A small metal cup filled with magnesium and welded to the plate support, used after the air is exhausted from the tube to get or absorb all remaining air or gas driven out of the glass and metal by heating.

**glass stem**—The part of the glass in a vacuum tube that supports the tube elements.

**grid**—A coil of fine wire supported between the filament and the plate of the tube.   The grid controls the flow of electrons through the tube.

**grid circuit**—The grid of the tube, the tuning circuit, and the grid return wire attached to one filament lead.   The input circuit of the tube.

**milliammeter**—A sensitive ammeter which measures thousandths of an ampere.   Used to measure the current flowing in the plate circuits of tubes.

**milliampere**—A current of a thousandth of an ampere.

**nichrome**—A high resistance wire made of alloy metal.   "Nichrome" is a trade name.

**ohm**—A word used to describe the unit of resistance.   A resistance through which 1 volt can force 1 ampere of current.

**parallel**—A connection in which all negatives are connected together and all positives are connected together.

**plate circuit**—The output circuit of the tube, which consists of the plate, the phones, speaker or amplifying transformer, the B battery, and the plate return wire connected to the tube filament.

**plate current**—The current, generally a few milliamperes, flowing in the plate circuit.

**plate return**—The wire connecting the plate circuit to the tube filament.

resistance—The opposition of a wire or a conductor to the flow of an electron surge.

rheostat—A variable resistor of from 10 to 30 ohms to control the heat of the filament by controlling the current flowing through it.

series—A connection in which the negative of one cell or appliance is connected to the positive of the next cell or appliance, and so on.

shunt—To connect in parallel. Also, the bar that carries the current in an ammeter.

solenoid—A hollow coil of wire which forms an electromagnet. A soft iron plunger moves inside the coil.

step-down transformer—A transformer used to reduce or step down the voltage of a source of current. Bell transformers and toy-train transformers are used for reducing house lighting circuits to from 1 to 50 volts.

thoriated filament—Filaments of tungsten to which traces of thorium have been added during manufacture.

thorium—A metal used in filaments to produce a more plentiful supply of electrons.

tip seal—The point on the older glass tubes where the air was removed from the tube. This seal broke easily and was replaced by the base seal.

tungsten—A hard metal of high resistance used in tube filaments.

vacuum—The absence of gas. As much gas as possible has been removed from vacuum tubes.

volt—The unit of electrical pressure.

voltage—The pressure exerted on electrons.

voltage drop—The loss in voltage, or the voltage used in forcing a current of electrons through a resistance.

voltmeter—An instrument used to measure the pressure on the electrons in a circuit.

watt—The unit of power. Watts of power are found by multiplying the amperes of current by the voltage.

# CHAPTER IV

## TUNING

When an aerial and ground system is connected to a receiving set, many radio waves are brought to the set. Each wave sets up a set of electron surges in the circuits of the receiver. Each set of surges is at a different frequency. If all of these different currents were to operate the phones, all we could hear would be a jumble of sounds.

But it is possible to select one set of surges and to concentrate the operation of our set on this one frequency. We shall learn how it is done in this chapter on tuning.

Parts 8 through 11 are concerned with electrical principles and with methods of work. These parts may be studied before or at the same time with the other parts of the chapter.

### Contents of This Chapter

### 1. NEW SYMBOLS USED IN THIS CHAPTER

These symbols are illustrated in Fig. 83 (pages 132–133).

**aerial or antenna**—A wire used to pick up radio waves. This wire is generally suspended as high as possible on poles, towers, from trees or buildings, etc.

**ground or ground connection**—The place where a connection is made to permanently moist earth. This may be either a clamp connected to a water pipe, a rod driven in the ground, or buried metal.

**coil**—Wire wound on a cardboard or bakelite tube.

**receiving transformer**—In a radio-frequency receiving transformer, the two coils are wound on a bakelite form.

**variable condenser**—A receiving-type condenser. Two sets of metal plates are mounted so one set can be turned between the other set. All of the plates in each set are connected together, but the sets are insulated from each other. The set that turns is called the rotor ($R$). The stationary set is called the stator ($S$).

**fixed condenser**—Two sets of tinfoil sheets separated by thin sheets of mica all enclosed in molded bakelite insulation. Sometimes made of tinfoil and paper rolled into a small cartridge with connecting wires extending from each end.

**lamp**—An ordinary electric lamp.

**choke coil**—A coil used in the filter system of a power supply.

**electron flow**—Arrows show direction of flow of electrons in a wire.

### 2. THE AERIAL AND GROUND NEEDED FOR THE FIRST EXPERIMENTS

**Metal Picks Up Radio Waves.** Radio waves act constantly upon any wire fence, metal roof, or other body of metal. All you have to do is to hook the proper instruments between the fence and the ground, and you will be able to transform the millions of invisible radio waves into music.

The sky is filled with myriads of invisible radio waves which are moving about in all directions. It is not known

PICTURE    SYMBOL

Aerial

Ground

Coil

Primary

Secondary

Receiving
transformer

FIG. 83.    New symbols used in Chapter IV.

| PICTURE | | SYMBOL |
|---------|---|--------|

Rotor plates

Stator plates

Variable condensers

Stator (S)
Rotor (R)

Molded bakelite, mica dielectric

Fixed condensers

CAP .00025 mf.

Paper dielectric

Lamp

Choke coil

Electron flow
(arrows show direction)
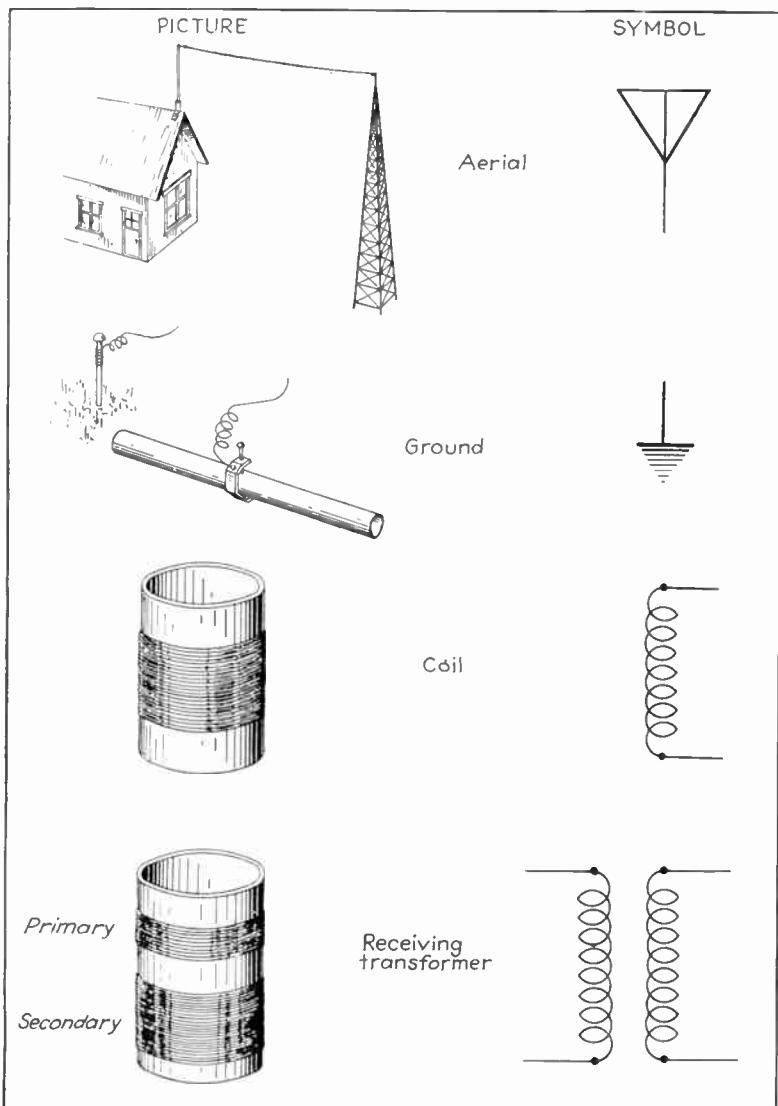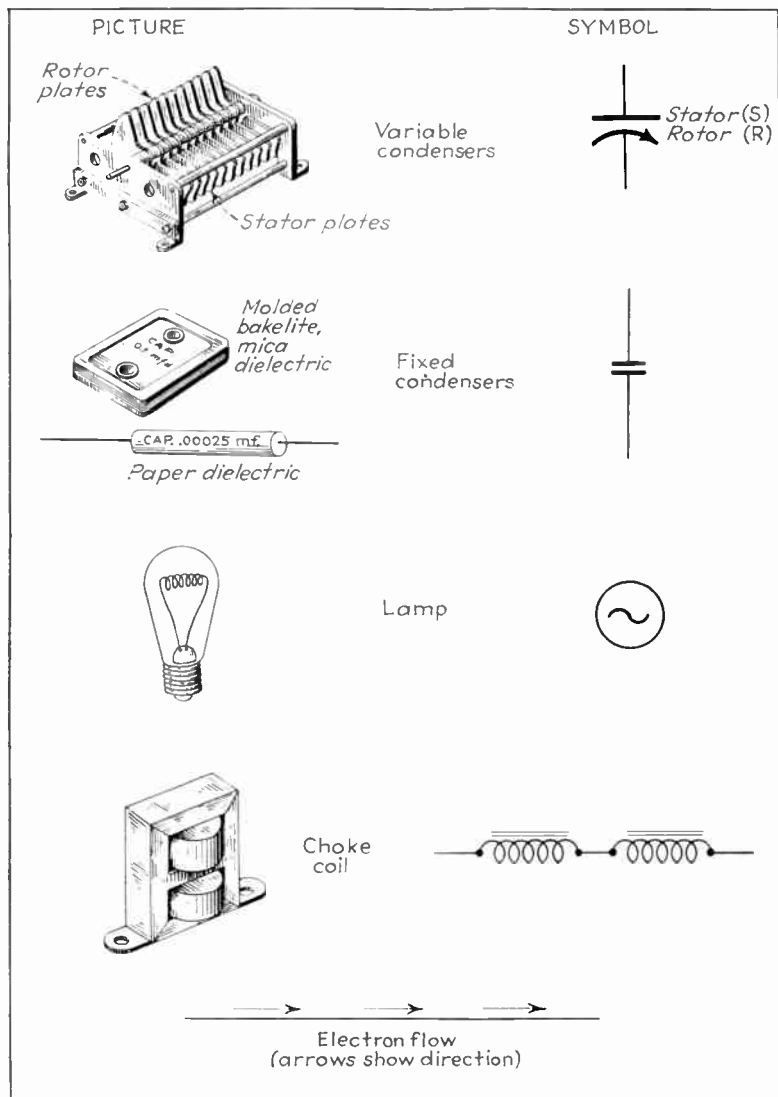
FIG. 83 (*continued*). New symbols used in Chapter IV.

exactly what these waves are or what they are made of,
but it is known that they are present in untold numbers.

**How to Build the Aerial.**    For the first sets only a simple
form of aerial and ground will be needed.    The aerial may
be made of bare wire, enameled wire, or of cotton- or silk-
covered wire.    The aerial may be in one piece or may be
twisted together from several pieces of wire.    It should be
from 50 to 100 feet long.    A suitable aerial is shown in
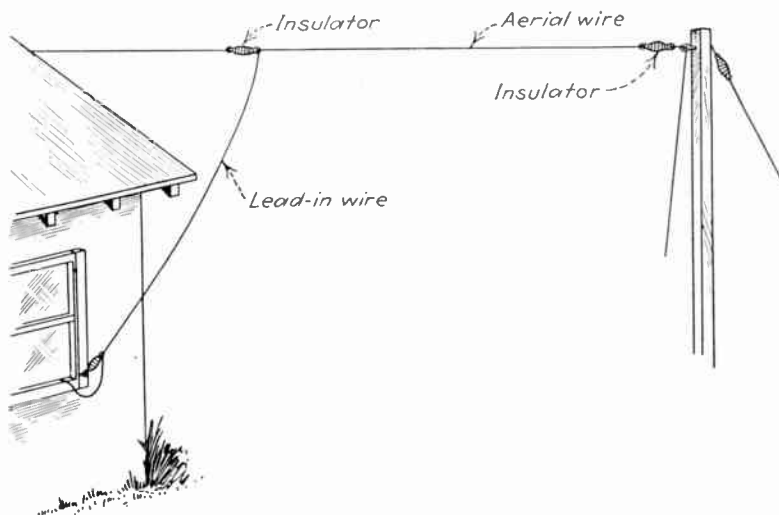


FIG. 84.    Aerial and lead-in.

Fig. 84.    If the wire has been twisted together, the joints
must be scraped with a knife until all the insulation is
removed and the copper is bright and clean.

Most of the current from the radio waves can be lost in
loose or dirty wire joints.    Make several tight twists for
each joint as shown in Fig. 85.    Good workmanship in the
installation of apparatus and care in making joints as well
as possible are repaid by better results in the operation of
the set.

**How to Hang the Aerial.** Hang the aerial as high above the ground as possible. A vertical wire is best, but it is hard to put up clear of buildings and trees. For the first set, the aerial may be thrown over any kind of support with no special insulation in dry weather. The wire from the aerial to the set is called the lead-in. The programs will be stronger and clearer if the aerial is high and well insulated. The construction of aerials is covered fully in the Chapter XII.

The aerial and ground wires may be unwound from a burned out transformer or from any coil taken from an old set. The larger sizes of wire work better, but radio waves can be received on nearly any size of wire.



Fig. 85. Good splicing.

**The Radio Ground Connections.** The ground connection is made in several ways. You can wrap a bare wire around a water pipe, or you can bury a piece of metal about a foot or more square, or you can drive a metal rod or pipe 4 or 5 feet long far enough into the earth to reach permanently moist soil. You can attach the ground wire to a water pipe by using a ground clamp. The ground wire needs no insulation. If a pipe ground is used, the pipe should be scraped clean where the wire is attached.

**Insulators and Aerial Insulation.** Glass, mica, bakelite, hard rubber are all good insulators. An insulator is a substance that offers a very high resistance, or opposition, to a flow of electricity.

No insulation is necessary in dry weather, but for wet weather the aerial must be well insulated, or the electric currents in the wire will flow to the ground through the water on the buildings or on the wood support. Place insulators as shown in Fig. 84. Use the cheap insulators

that can be purchased for a few cents, or any of the above insulating materials which are handy in your shop.

## Questions

1. Are radio waves visible?

2. What substances will intercept radio waves?

3. Will insulation on a wire prevent the wire from being acted upon by radio waves?

4. If the aerial is made of several short pieces of wire loosely twisted together, can the radio currents flow easily from one wire connection to another? Why?

5. Try twisting two wires together in the approved manner for a splice.

6. Would this connection be improved by covering it with solder? Why?

7. What effect does the height of the aerial have on the received radio waves?

8. Suggest some simple cheap insulators for your first aerial.

9. What are satisfactory ground connections?

10. If your only chance for a ground connection is to drive a short rod into dry soil, would you have a better ground if you poured several buckets of water over the rod?

11. If you pass the ground wire out of the window, is it necessary to insulate the wire from the window ledge?

## Wave Pictures of Current Flow in Aerial-ground Circuit

**Radio Waves Produce Aerial-ground Current.** When an aerial wire is connected to the ground, as shown in Fig. 86, radio waves will be intercepted by the aerial and will cause a very weak current of electricity to flow between the aerial and the ground. This current is so weak that it cannot be measured by the ordinary millivoltmeter or milliammeter. This alternating current changes direction, in the case of a 300-meter wave length at the rate of about 1,000,000 cycles per second.

**What Is an Alternating Current?** An alternating current is one which is constantly changing its direction of flow.

Batteries deliver a direct current which flows steadily in the same direction through the wires. Certain types of generators deliver alternating currents which change the direction of flow rapidly. Most of the current delivered for lighting the home is an alternating current (abbreviated A.C.). The house lighting system uses what is known as a 60-cycle alternating-current, which means that the current changes direction 120 times a second. The cycle is made up of two alternations. When the current flow builds up in one direction and dies out, it is called an alternation. Alternating currents have been explained in greater detail in Chapter II of this book.



Aerial

Ground

F I G . 8 6 .
Radio's basic
circuit.

**Radio Frequency and Audio Frequency.** Currents that change direction of flow at a frequency of less that 20,000 cycles a second are called audio-frequency currents. (Audio means hearable.) Frequencies of over 20,000 cycles per second are called radio frequencies. This current varies in strength or intensity.

We have no workshop method to indicate that this radio frequency current is flowing in the aerial-ground hookup shown in Fig. 86. A method of hearing this radio-frequency current will be given in a later discussion.

**The Wave-form Picture of the Aerial Current.** In showing the wave form of the current flowing in the aerial-ground circuit, you will notice that the amplitude of the waves changes constantly and seems to increase or decrease, according to some regular form. We shall explain in Chapter XI how the transmitting station generates a radio-frequency carrier wave which is modulated or changed by the voice wave. The modulated carrier waves are radiated or sent out from the transmitting station and picked up by our receiving aerial.

**Aerial Current Has Same Wave-form Pictures as Radio
Wave.** The radio wave that was sent out from the trans-
mitting station strikes our aerial and sets up the weak
currents shown in Fig. 87. The wave form of the current
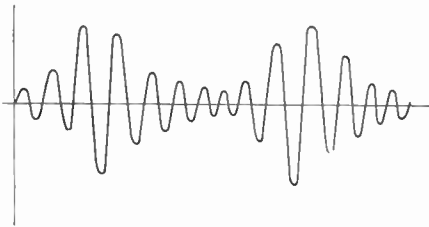


flowing in our aerial-
ground circuit, therefore,
is exactly the same as the
wave form flowing in the
aerial-ground circuit of
the transmitting station.
Notice that the modu-
lated wave is made up of

FIG. 87.   Aerial current.

groups of radio-frequency waves.

In a transmitter, electrons moving in the aerial send out
radio waves, while in a receiver the process is reversed.
Radio waves strike the aerial and cause electrons to move
in the aerial wire. This sets up the radio-
frequency currents flowing or oscillating to
the ground from the aerial.

**Will Earphones Produce Sound from
Aerial Currents?** Telephone receivers or
earphones are sensitive indicators of ex-
tremely weak currents. But when we con-
nect phones to the aerial-ground circuit, as in
Fig. 88, we hear no signals as the radio-fre-
quency alternating current flows through the
phones. Why is this true?

An alternation of high-frequency current
will cause two sets of opposing magnetism in
the phones, which cancel each other so that
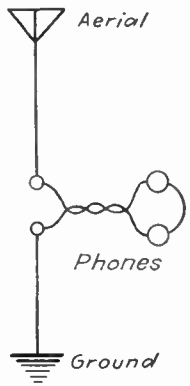


FIG. 88.   Can
you hear sound
in this hookup?

no sound is heard when a radio-frequency current passes
through the phones. Low- or audio-frequency alternating
currents flow through the windings of the receivers easily
and will produce sound.

**The Picture of the Phone Current.** Only the amplitude and the time lines are shown in Fig. 89 to represent the current flow through the coils of the receivers. No diagram of the current can be drawn, since none flows. The resistance of the coils in the receivers is so great that alternating currents of high frequency are choked out. The reason for this is that the magnetism of the coils and core cannot be reversed so rapidly.
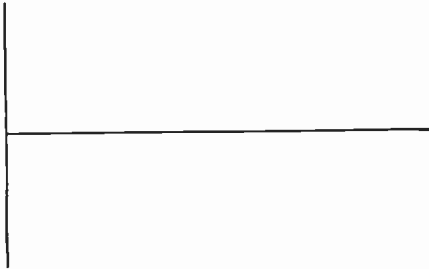
FIG. 89. No current is flowing.

Much of the radio-frequency alternating current is by-passed to the ground by the condenser action of the phone cord and thus never reaches the phones.

No current can flow in the phones so no sound is heard.

**Surges Can Flow through a Condenser.** When a condenser is connected in the circuit, as in Fig. 90, electron surges can still travel through the aerial-ground circuit. (Read part 9 of this chapter for an explanation of the principles on which condensers operate.)

FIG. 90. Aerial, condenser, and ground in series.

When the surge from the aerial reaches the condenser, it fills one set of plates and forces electrons from the other plates so the surge continues. This process repeats as the surge returns to the aerial.

In the next hookup we shall learn how this current can be made to produce sound.

### Questions

**1.** Are high-frequency currents continually flowing in every wire fence or metallic object which happens to be connected to the ground?

**2.** Are these radio-produced electric currents strong enough to give you a shock if you touch a wire fence and an iron rod which is struck in the ground?

**3.** If you connect a voltmeter between a fence and the ground, will you get a reading on the meter?

**4.** If no sound can be heard in the hookup (Fig. 88), would you expect to get signals from a regular set if the aerial and ground should accidently get shorted together?

**5.** What is meant by the term *radio frequency?*

**6.** What is meant by the term *audio frequency?*

## 3. TUNING BY CHANGING THE LENGTH OF THE AERIAL

### How to Build and Wire the Set

**The Set Board.**    This is shown in Fig. 91.    It is the tube-test board, but notice the changes that have been made in the board to adapt it to use as a simple receiving set.

**The Meter.**    Remove the meter.    In this experiment the meter, which produced the seeable effect in the motion of the hand across the dial, is replaced by a pair of phones which will produce a hearable effect.    You can leave the meter in the circuit if you wish, but the sounds will be weaker if you do.

Connect a grid leak of 2 to 10 megohms between the filament and grid, as shown in Fig. 92.

**The Phones.**    Connect the phones in place of the meter, as in Fig. 92.    Use a pair of 2000-ohm phones.    There are no other changes in this set board.

**How to Make the Aerial Reel.**    Make the mast of a piece of pine about 6 feet long by 1 inch by 2 inches.    To this attach a reel made of three pieces of wood nailed or screwed together; the reel needs a deep groove (see Fig. 93).

Attach a handle to the reel so that you can turn it as you
reel the wire in or out.

At the top of the mast attach a wooden block through
which a hole has been drilled.    Round the upper end of
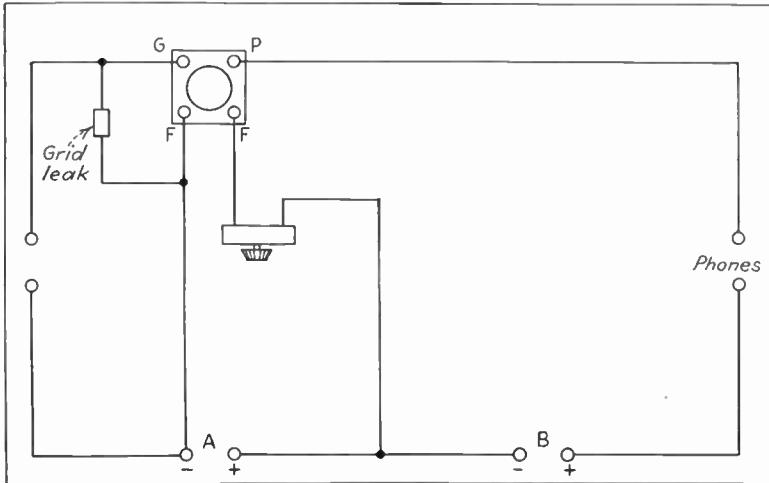


FIG. 91.    Board layout for a simple radio receiver.
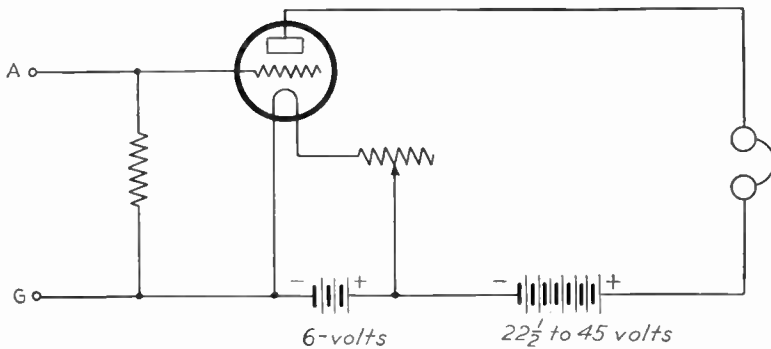


FIG. 92.    Circuit diagram for a simple radio receiver.

the hole so the wire will run smoothly through it.    Attach
the reel to the mast with a stove bolt, about 18 inches
from the lower end.
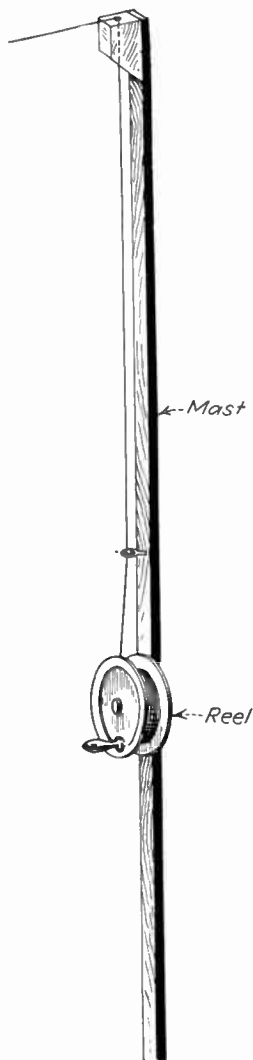
## How to Operate the First Hookup

**How to Wire the Set.** Connect up the tube board as shown in the hookup (see Fig. 94 and Fig. 95). Attach the aerial reel of bare copper wire to the grid binding post. Connect the ground wire to the A negative post.

**How to Operate the Set.** Two persons should work together on this test. One unreels the aerial and the other operates the set. The one operating the set should put on the earphones and listen for stations.

This set tunes very broadly. It will pick up much hum and will be very noisy. You will find the correct size of grid leak by experiment. This will improve the operation of the set somewhat.

The grid leak must be used, because the grid will collect electrons on each positive surge until it becomes so negative that the tube will no longer operate.

Turn the rheostat to heat the filament. Then turn on the B power.

The reel carrier should slowly unwind the aerial as he walks away from the building, holding the wire so that it will not touch the ground. When a station is heard, the listener should write down the number of steps the reel carrier has taken from the set.

FIG. 93. Aerial reel.
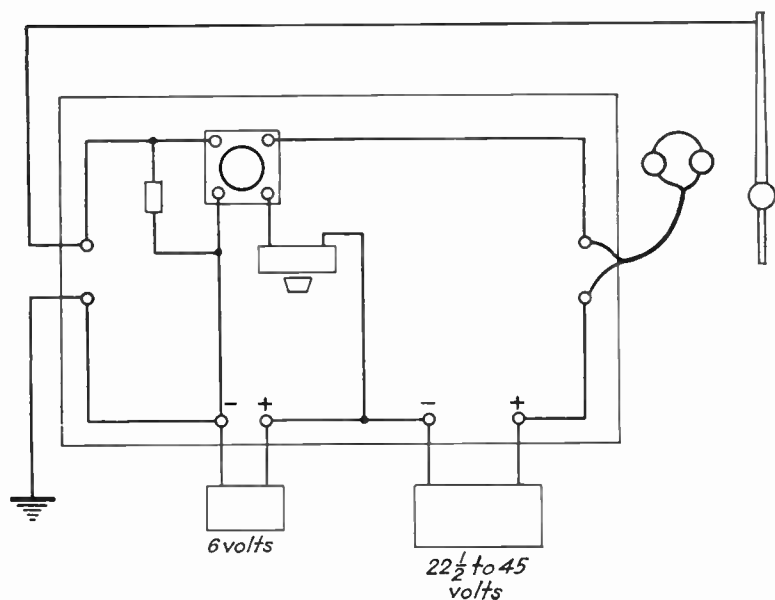
FIG. 94. Board layout showing aerial, phones, and ground connected to the simple radio receiver.
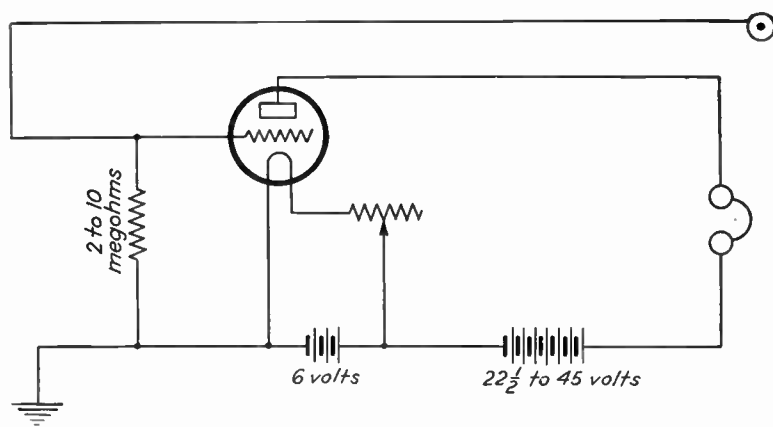


FIG. 95. Circuit diagram showing aerial, phones, and ground connected to the simple radio receiver.

The reel carrier now goes farther away. When the first station fades, the set operator should again call out to find the number of steps. Keep a record of the lengths of aerial needed to tune in several nearby stations.

Check the person's steps as the aerial is wound in to see if the various stations reappear on the same lengths of wire where they were first heard. This set is too inefficient to separate different stations completely, but it shows nicely a very simple method of tuning. It will pick up considerable hum if it is near power wires or lighting circuits, but the signals will be heard through the hum.

### Questions

**1.** Why must the aerial be prevented from touching the ground?

**2.** How far from the set was the person unwinding the aerial when the first station was heard?

**3.** Did the station increase in volume for a while as the aerial was unwound?

**4.** How many steps long was the aerial when this station faded out?

**5.** Could any other stations be heard at the same time that the first one was heard?

**6.** Record the lengths of aerial for each station when it comes in and when it fades out. Graph these figures on a straight line on a piece of paper in order that you may see just how much the stations overlap.

## Why It Works—the Theory of Tuning Explained

**Length of Aerial Affects Tuning.** When one part of a radio wave strikes the aerial, it causes a current to surge from the aerial to the ground (see Fig. 96). There is enough capacity between the tube elements to allow the passage of these surges. The aerial and ground wire must be of exactly the right length for the electrons to return to the end of the aerial before the next wave arrives. When the next wave arrives, it gives the electrons a push and starts another surge down the aerial. This aerial-

Aerial Length Correct
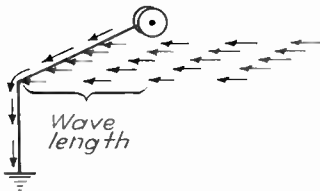
A wave crest starts a radio-fre-
quency current flowing in the aerial
toward the ground.

Aerial Too Long
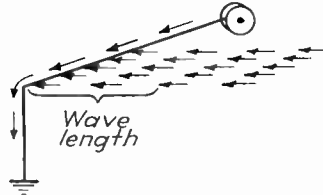
The wave crest starts a radio-fre-
quency current flowing, but it has
farther to travel and has not
reached the ground.
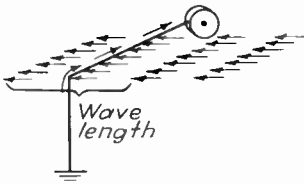
The first wave's current returns to
the reel end of the aerial when the
second wave arrives.
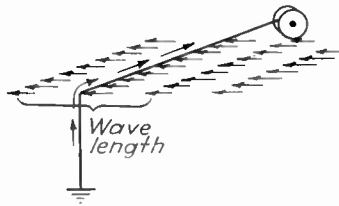
The first wave's current is only
part way back toward the reel when
the second wave arrives.
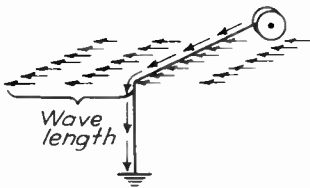
A second wave arrives and starts
a second current toward the ground
just as the first wave's current starts
toward the ground a second time.
The strengths of the two currents
reinforce each other and build up
greater strength.
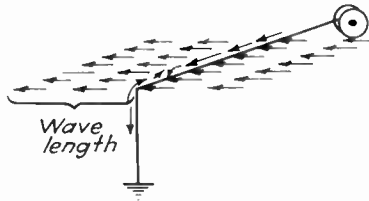
The second wave's current going
toward the ground is opposed by the
returning current from the first
wave. These currents oppose each
other and reduce the strength of the
total current flowing in the circuit.

FIG. 96.   How the length of the aerial affects tuning.

ground wire will pick up the strongest current possible from each passing wave.

**Effect of Too Long or Too Short an Aerial.** When the aerial is too long, as in Fig. 96, the electrons do not have time to surge to the ground and return to the end of the aerial before the next radio wave arrives. This wave again starts electrons down the aerial. The two surges meet and their motion is killed. The result is that weak signals or no signals are heard. Also, if the aerial is too short, the incoming wave and the aerial current will likewise be out of step and the current will be reduced.

**An Aerial Length for Each Transmitter.** Each broadcasting station transmits on a definite wave length or frequency; that is, it sends out a number of pulsations, or waves, per second. This number of waves is different for each station. So it is possible to tune roughly to some particular broadcast station by changing the length of the aerial to fit the timing or frequency of the waves it sends out.

When you do this, you are adjusting your aerial to the same electrical length as the length of the broadcasting station's aerial.

### Questions

1. If the first radio wave or impulse which strikes the aerial happens to cause the current to flow from the ground to the aerial, in what direction will the next impulse cause the current to flow?

2. Suppose the aerial is too long. If the current flows from the aerial to the ground and has time to get just halfway back when the next corresponding radio wave arrives and sends another current down the aerial, will the currents oppose each other, or will they add and produce a greater volume of signals?

3. Suppose the aerial is too short. If the current flows from the aerial to the ground and has time to get back to the end of the aerial long before the next corresponding radio wave strikes, will you get maximum efficiency and loud signals?

**4.** Suppose the aerial is of such a length that the current which flows from the aerial to the ground has time to get back just to the end of the aerial when the next wave strikes. Will there be any interference among the following radio-frequency currents? How will the volume of the signals compare with that in questions 2 and 3?

**5.** A transmitting station is heard loudest when the receiving aerial is 200 feet long. Draw a diagram to show the positions of the radio waves and the radio-frequency currents for this station when you are using a receiving aerial 50 feet in length.

#### 4. TUNING BY A LOADING COIL IN THE AERIAL CIRCUIT

In this hookup we use the same electrical principle in tuning, but we make the mechanical tuning operation much
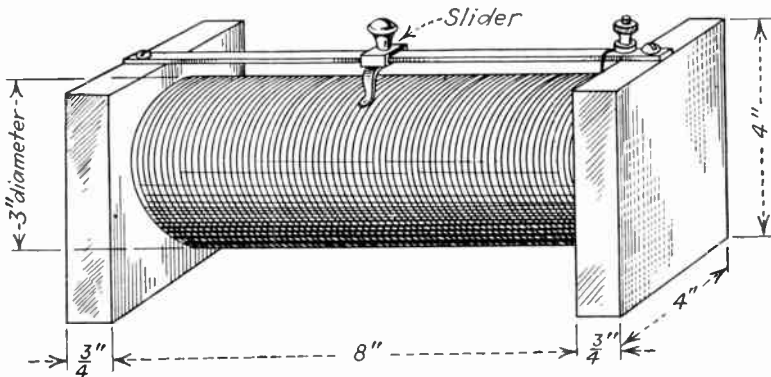


FIG. 97. Aerial loading coil.

simpler. Here we wind part of the long aerial on a tube along which runs a contact. We can change the length of aerial wire in the circuit by moving the contact instead of by reeling and unreeling the aerial.

Tuning is further simplified by using an aerial of fixed length built permanently in place.

### How to Build the Loading Coil

**The Coil Form.** The coil form is a cardboard or bakelite tube about 3 inches in diameter and about 8 inches long

(see Fig. 97). Square wooden ends support the tube and carry the slider rod. The slider runs on a $\frac{1}{4}$-inch-square brass rod and makes contact with the bared wire by means of a spring or ball bearing.

If you use cardboard, boil it in paraffin for 20 minutes. This fills the pores with paraffin and keeps the form from swelling and shrinking with weather changes. If the tube shrinks, the wire loosens. Shellac painted on the form will also prevent moisture from affecting the cardboard. Cover the inside, outside, and the ends thoroughly. If you use a bakelite tube, no shrinkage will occur.

**The Winding.** Use 265 turns of enameled wire, size 22, for winding the coil. Fasten the wire in place with shellac or clear lacquer.

**Other Wire and Tube Sizes.** If a smaller tube is used, wind on more wire. If a larger tube is used, less wire will be needed. Again, small wire requires fewer turns and large wire more turns on account of the spacing. The tube may be a cleanser can or an ice-cream carton, but a heavier piece of tubing is to be preferred. The wire may be unwound from a burned-out transformer formerly used in a radio set. The wire may be spliced if necessary, provided that the splice is soldered. If no slider can be had easily, a bare wire held in the hand and moved over the coil will act as a slider.

### Questions

**1.** Describe a handy means of tuning the coil while you are winding on the wire.

**2.** Would this be a satisfactory method of winding the coil: Give the wire one wrap around your leg to hold it tight, then turn the coil slowly by hand?

**3.** What are the advantages of tight winding?

**4.** What are the advantages of using an insulated wire for the coil?

**5.** If a fine insulated wire is used, what is a handy method for making contact with the slider?

## How to Operate the Set

**Hook Up the Set.** Attach the coil in series with the aerial as shown in Fig. 98. Connect the aerial to the slider and connect the end of the coil to the aerial post on the tube board.

**Operate the Set.** Start with the slider near point *O*, Fig. 99, moving it until you hear a station. At this point
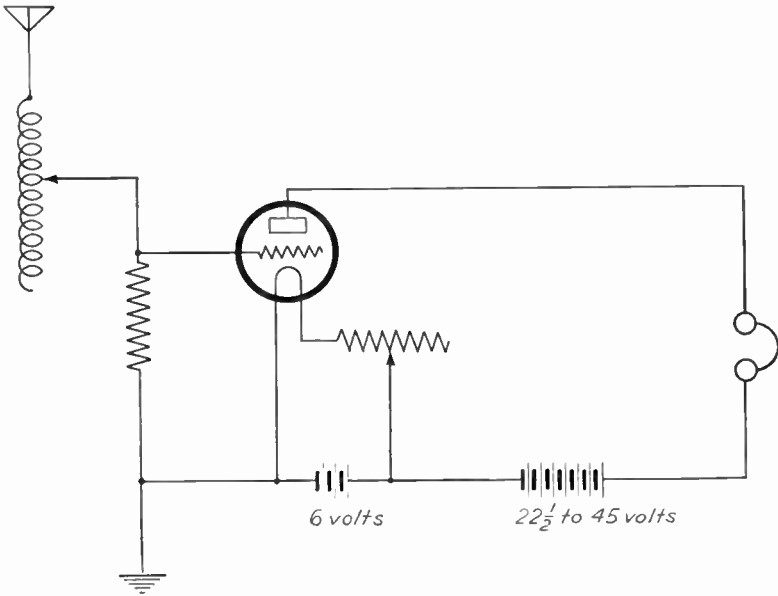


Fig. 98. Circuit diagram for loading-coil tuning.

little wire in the coil is in the circuit, and the effect is similar to using a short aerial.

Now, set the slider near point *M*, and adjust as before until a station is heard. Here the effect is the same as when using a longer aerial.

**Wave Lengths of Different Stations.** The wave lengths of the different stations in your locality can be determined

from the radio programs published in your local newspaper
or from lists of stations that can be obtained from your
radio dealer.    Station wave lengths are listed also in radio
magazines and call books.    When frequencies are given, the
high frequencies are for the short wave lengths and the low
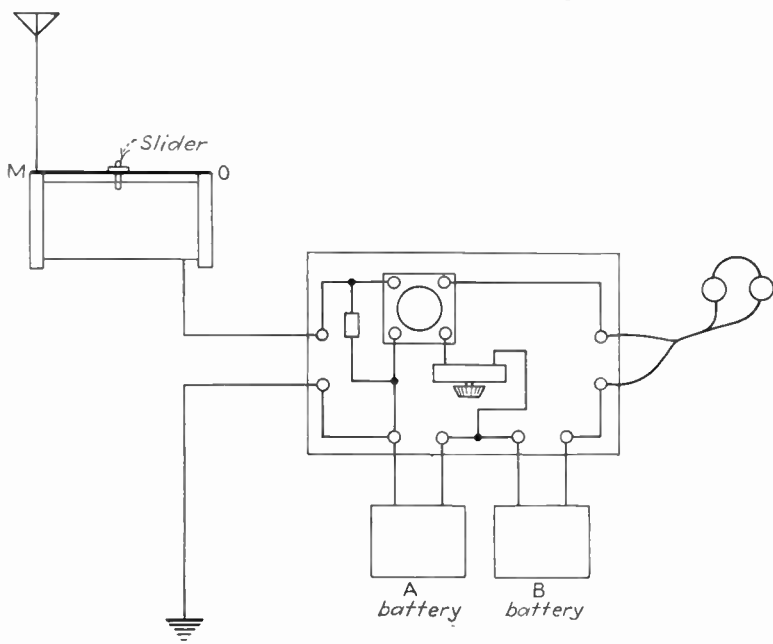


Fig. 99.    Board layout for loading-coil tuning.

frequencies are for the long wave lengths.    That is, the
short aerial tunes to a high frequency and a long aerial to
a low frequency.

Conclusion.    It can be seen from this experiment that
the coil may be used as a simple way to change the effective
length of the aerial and so to simplify tuning.    It has not
been necessary to go outside and work with the aerial at
all; but it has been possible to make any adjustment for
tuning right on the set itself.

### Questions

**1.** Does the coil tune sharply? That is, does a small motion of the slider bring the station to greatest volume and then a small motion farther tune out this station entirely?

**2.** Is it possible entirely to separate one station from another?

**3.** Compare the sharpness of tuning by means of a coil with the sharpness of tuning in the preceding set, which you tuned by unrolling the aerial.

**4.** Does a long aerial tune in stations with long or short wave lengths? with high or low frequencies?

**5.** What stations are heard when the slider is set to use only a little of the wire on the coil? Is the wave length long or short?

**6.** What stations are heard with much of the coil in use? Is the wave length long or short?

### 5. TUNING BY THE USE OF A TRANSFORMER

In this hookup we no longer tune the aerial itself. We shall try a new method for tuning, in which we use two coils in the form of an air-core radio-frequency transformer for tuning. One coil of wire is connected in series with the aerial and ground. We shall call this the *primary* coil. A second coil, called the *secondary*, is wound on the same tube but spaced about $\frac{1}{4}$ inch from the primary. *The two coils are not connected together.* These coils form a tuning transformer, which operates on the same principle as transformers used for doorbells, toy transformers, and power transformers. (See part 11 of this chapter for principles of transformers.) The primary is connected to the aerial, and the secondary is connected in what is called the grid circuit. The secondary, or grid, circuit consists of the secondary coil, a slider for adjusting the coil's length, and the detector tube.

The use of the transformer produces much better signals and much better selectivity, allowing stations to be separated much easier than with the loading coil.

## Construction of a Tuning Transformer

**How to Build the Coil.** Wind two coils on a 3-inch bakelite tube taken out of an old broadcast set (see Fig. 100). The cardboard carton of a cleanser can with the metal ends cut off will do. The metal must be removed, since it would absorb energy from the coils of a transformer. The wire may be of any size from No. 20 to No. 28, cotton-covered, silk-covered, or enameled. If cardboard is used,
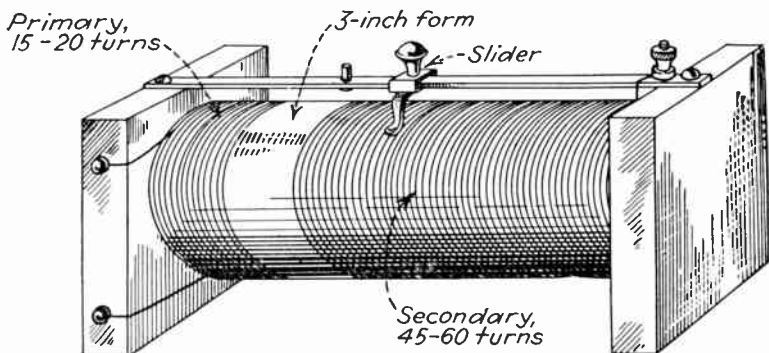


FIG. 100. Tuning transformer.

either boil the tube in paraffin or shellac it thoroughly to keep out moisture.

Drill or punch two $\frac{1}{16}$-inch or smaller holes about $\frac{1}{4}$ inch apart through the tube for the ends of both coils. Loop the wire at the ends of the winding through these holes tightly to prevent the coil from unwinding. Wind 15 to 20 turns for the *primary* and 45 to 60 turns of wire of the same size for the *secondary*. Space the coils $\frac{1}{4}$ inch apart.

Tune the secondary by a slider on a $\frac{1}{4}$-inch square brass rod, as in Fig. 97, which makes contact with the wire under the bar where the insulation has been scraped off. If no slider is handy, the wire may be scraped, and the end of a loose wire may be moved over the coil by hand. Any

other handy scheme may be used. If cotton- or silk-covered wire is used for the winding, it will be necessary to substitute a switch for the slider.

### Questions

**1.** If a pasteboard cleanser carton is used for the tube, why is it necessary to remove the metal ends?

**2.** Should the slider run on the primary or secondary coil?

**3.** Show one outstanding difference between this transformer and, for example, a toy-train transformer.

**4.** Why use insulated wire on the coil?

**How to Hook Up the Set.** Connect a wire from one end of the primary coil to the aerial post, and a wire from the other end of the coil to the ground post (see Fig. 101). Connect a wire from one end of the secondary to the *F* positive post, and a wire from the slider to the grid post on the tube socket. Check your wiring with the hookup shown in the circuit diagram (see Fig. 102).

Use no grid leak, since the wire from the secondary connected to the positive A filament wire sets the bias on the grid. Try moving this wire to the negative filament wire. You may find the signals stronger.

## How to Operate the Set

Connect the A and B batteries and turn the filament rheostat. Connect $22\frac{1}{2}$ volts to the B positive terminal. Start at one end of the coil and move the slider across the secondary coil slowly to tune from station to station. Several stations probably will be heard.

Perhaps you will find that two stations come in at one point on the coil. By moving the slider in one direction you gradually tune out one station and bring in the other more strongly.

Notice how far the slider must be moved before it cuts out either station. Several turns of the coil may be

occupied by two overlapping stations. Sometimes the
station is heard best by setting the slider so that it touches
two wires at a time.
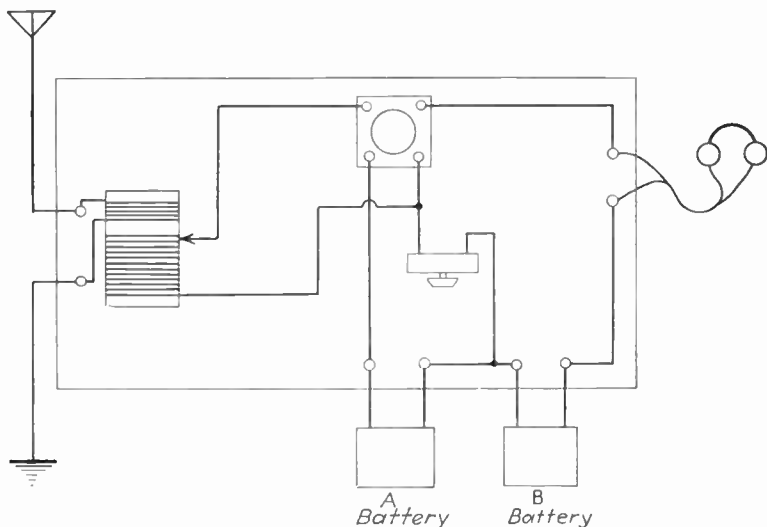


Fig. 101.   Board layout with tuning transformer.

### Questions

**1.** Does it make any difference which end of the primary is con-
nected to the ground post and which to the aerial?

**2.** Is it necessary to use soldered joints in all of the above connections?

**3.** Make a list of the stations you can hear on this set.

**4.** Compare the sharpness of tuning of this set with the loading-coil
set, and with the variable-length aerial used in the first hookup.

## Why It Works

**How the Set Is Tuned by the Slider on the Secondary.**
We find that we tune the set when the slider is moved
across the secondary of the transformer. Tuning the
secondary seems as satisfactory as tuning the primary or
aerial in the earlier experiments. This test shows that

secondary tuning has the same effect as primary and aerial circuit tuning.

Tuning the secondary now also tunes the aerial circuit. Let us see why this is possible.

**A Radio-frequency Alternating Current Flows through the Primary Coil.** The primary coil is part of the aerial circuit. The aerial circuit now consists of the aerial, the
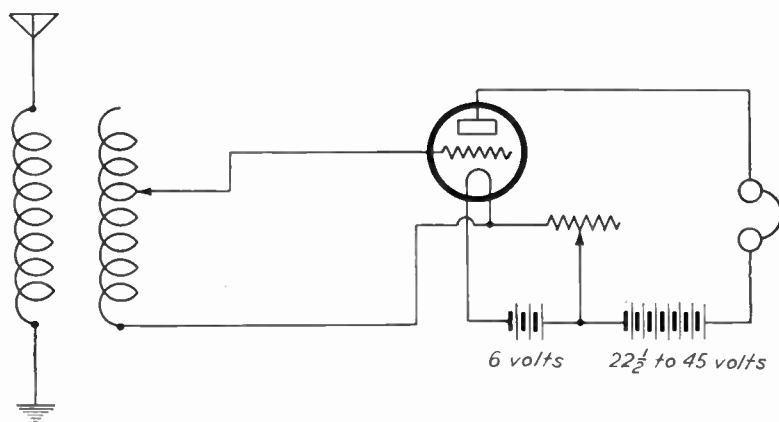


Fig. 102.   Circuit diagram showing tuning transformer.

lead-in, the primary coil, and the ground lead.   The radio-frequency currents flowing in the aerial flow through the primary coil.

**The Radio-frequency Current Builds Up a Magnetic Field around the Primary Coil.** The radio-frequency currents flowing in the aerial circuit flow through the primary of the tuning transformer and build up a magnetic field through and around the coil. The magnetic field changes polarity as the radio-frequency current changes direction.

**Part of the Magnetic Field Energy Is Used to Induce a Current in the Secondary.** The primary magnetic field surrounds the secondary coil and induces a current in it.

The induced current flowing in the secondary creates a magnetic field around the secondary coil.

**More Power Is Drawn from the Primary Radio-frequency Current to Maintain the Magnetic Field.** The primary coil furnishes the power which builds the magnetic field in the secondary, and anything affecting the secondary will, therefore, affect the primary, since the secondary draws its power from the primary.
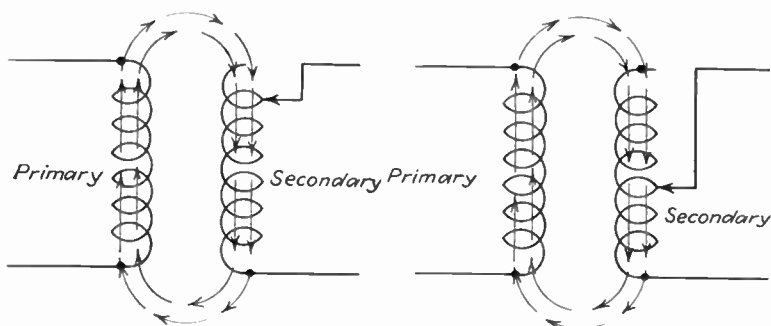


FIG. 103. Power from a transformer secondary. Many turns draw much power from the magnetic field.

FIG. 104. Power from a transformer secondary. Few turns draw little power from the magnetic field.

**More Secondary Turns Take More Power from the Primary and So from the Radio-frequency Current.** It is more difficult to change the directions of the lines of force of the magnetic field in the long coil of Fig. 103 than it is to change this field for the short coil of Fig. 104. So we see that a change in the length of the secondary has the same effect indirectly as a change in the length of the aerial.

Since more energy is drawn from the primary by more turns in the secondary, it will take longer for the primary to build up to full strength. Therefore, a change in the length of the secondary will tune the primary coil.

### Questions

**1.** Is the current induced in the secondary coil of the same frequency as the radio-frequency current in the primary?

**2.** Does changing the length of the secondary have the same effect on tuning as changing the length of the primary coil?

**3.** Is it more difficult for an alternating current to flow through a transformer when the secondary has many turns or few turns of wire?

**4.** What would be the effect on the signals if the secondary were moved farther away from the primary?

### 6. TUNING BY A VARIABLE CONDENSER ACROSS THE SECONDARY

Tuning the secondary of the transformer by means of a slider, as in part 5, is inconvenient and is a source of noise in the operation of the set. This method is inefficient electrically also, since the turns short easily and do not permit close tuning. A most efficient and simple scheme for tuning the one-tube set is by means of a variable condenser shunted across the secondary coil. Much sharper and more convenient tuning is possible by means of condensers.

### How to Wire the Set

**Make the Baseboard.** Make the baseboard of $\frac{1}{2}$-inch pine, $9\frac{1}{2}$ inches wide and 20 inches long. Screw two $\frac{3}{4}$-inch by 9-inch cleats 1 inch from the ends on the under side of the board. Paint or lacquer the board. This will prevent the board from soiling and will show up the wiring better.

**Use Some Definite System When Wiring.** Some system must be used when wiring a set, or wires will be left out of the circuit and the set will not work. It is easy to burn out tubes and to ruin parts by incorrect connections. Here is a simple system of wiring that you can follow on all of your sets. Wire each part of the circuit separately, completing it before you start another part. This will be

easy to do, since each part has been placed on the set
board in the position shown in the circuit diagram.

**Wire the Aerial-ground Circuit.** Connect a wire from
the aerial binding post to one end of the primary coil (see
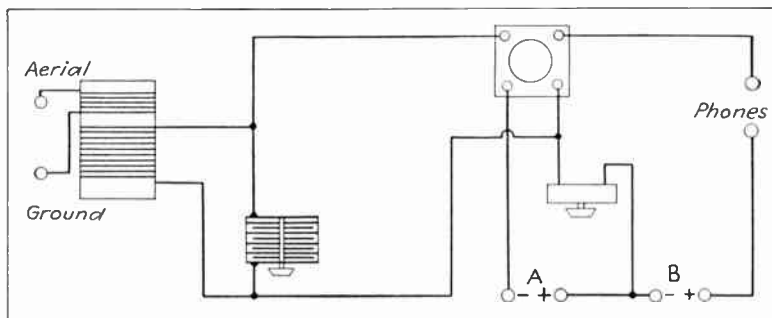


FIG. 105.    Condenser across the secondary.
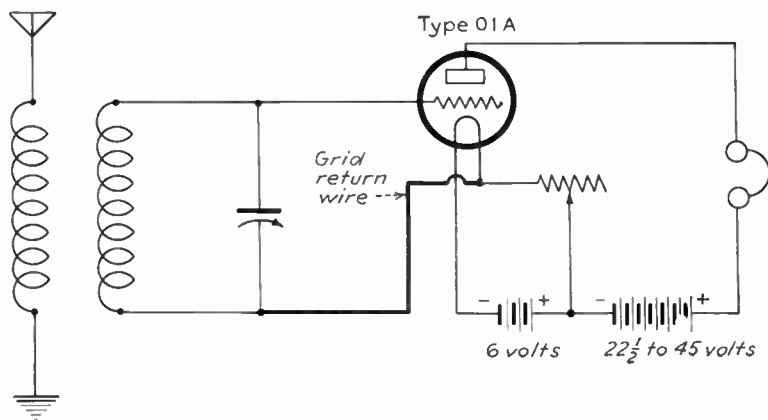


FIG. 106.    Condenser across the secondary.

Fig. 105).    Connect a wire from the other end of the pri-
mary to the ground post.

Solder the wire in place.    Bend the wires to form corners
as shown in the circuit diagram in Fig. 106.

**Wire the Secondary-grid Circuit.** Run a wire from the secondary to the *G* post on the tube socket.

Connect a wire from the other end of the secondary to the A positive binding post. This wire is called the grid return and is connected to the *F* positive side of the filament when the type 01A tube is used.

Now connect a wire from the stator, or fixed plates of the condenser, to the grid end of the secondary.

Connect a wire from the rotor, or movable plates of the condenser, to the grid-return wire. Connect the condenser this way to cut down squealing when the hand comes near the knob in tuning. Squealing is more noticeable in the sets described later in Chapter V.

**Wire the Filament Circuit.** Connect a wire from the A negative binding post to the *F* terminal on the tube socket.

Connect a wire from the A positive post to one connection of the rheostat.

Connect a wire from the other rheostat connection to the other *F* post of the socket.

**Wire the Plate Circuit.** Connect a wire from the *P* post of the socket to one of the phone binding posts.

Run a wire from the other phone post to the B positive post.

Connect a wire from the B negative post to the A positive post.

**Wiring Hints.** *Soldering.* Solder every joint. If a joint cannot be soldered conveniently, it should be scraped clean and screwed down tight under a binding post. Most noisy set operation is caused by loose joints.

*Kind of Wire.* Use size 18 tinned wire for the experimental sets. It is much easier to handle than insulated wire.

*Neat Wiring Methods or "Haywire."* The sets in this chapter should be neatly wired, since we want to become familiar with the circuits and to avoid mistakes in wiring.

Fasten the wires to the baseboard with small staples.

## How to Operate the Set

*Step* 1. Connect the aerial and ground lead-in wires to the aerial and ground posts on the set. The aerial lead-in must be insulated.

*Step* 2. Connect the A battery. (*a*) First, turn the rheostat to the *off* position. (*b*) Put a type 01A tube in the socket. (*c*) Connect two insulated A-battery wires to the connectors on the set. (Do this before you attach them to the battery. This is to prevent the wire ends from touching and shorting the A battery.) (*d*) Connect the A-battery wires to a 6-volt storage battery. Be sure that the connections are correctly made. This makes a difference in the operation of the set. (The large post is the positive on a storage battery. It is generally marked in red. The inner or carbon post of a dry cell is positive.) (*e*) Turn up the filament rheostat to light the tube. If the tube does not light, check the wiring of the filament circuit or try another tube.

*Step* 3. Connect the B battery and the phones. (*a*) Connect two insulated wires to the B positive and B negative posts on the set. Connect these wires to the set first to avoid shorting the B battery. (*b*) Connect the wires to a 45-volt B battery. Check to see that the positive and negative connections are correct. The set will not work if these connections are reversed. (*c*) Put the headphones on. Connect one tip of the phone cord to the phone connection on the set. A loud noise will be heard in the phones when the other tip is touched to the connection. The filament must be heated, or no sound will be heard.

*Operating Hints.* The B battery will burn out the tube filament if it is connected across the A connections. This mistake will not happen if the A battery is connected first.

Hissing, frying, and popping sounds heard in the phones
are caused by the chemical action of the B battery or by
the internal action of the tube.

Loose connections are noisy since the resistances of the
connections change as the set
or table is jarred. Small
changes of resistance may be
heard in the phones as a
noise.

Tube sets are quiet either
when all connections are
soldered or when the wires



FIG. 107. Condenser has full capacity
when plates are meshed.

are scraped clean and bright, then twisted tightly together
for several turns.

### How the Setting of the Condenser Affects Tuning

We found in the last experiment, where a slider was used
to tune the secondary of the transformer, that it was hard



FIG. 108. Condenser has very small capac-
ity when plates are separated.

to tune out stations that
were close together. It
seemed that if we could
only tune "between the
turns" in some way, or
could tune "part of a
turn," our tuning would
be much sharper and
more satisfactory. We
could then separate sta-

tions more easily and reach the hard-to-get weak ones.

The variable condenser does just this. It allows us to
tune "between the turns," and the tuning is much sharper.
It is possible to tune out stations that were too close
together to be tuned out with only a slider.

When the rotor (the movable plates) of the variable con-
denser is turned so as to mesh with the fixed plates of the

stator, the capacity is increased (see Fig. 107). When the rotor is turned so the plates move out from the plates of the stator, the capacity is reduced (see Fig. 108).

When the condenser is shunted across the coil, an increase in the capacity of the condenser increases the wave length (decreases the frequency) to which a set will tune; when the plates are turned out or the capacity decreased, the set will tune to stations having shorter wave lengths (higher frequencies).

### Questions

1. Count the number of stations you can hear on the new set as you slowly turn the rotor of the condenser.

2. Compare the sharpness of tuning with that in the previous sets.

3. Compare the loudness of the signals.

4. Give a reason why it was not as simple or easy to tune with the coil as sharply as it is with the condenser.

5. As you move the plates of the rotor in between the fixed plates, do you increase or decrease the capacity of the condenser?

6. Do you then increase or decrease the wave length to which the set will tune?

7. Can the set be operated or tuned if a proper-sized condenser is shunted around a primary instead of around the secondary? Try this.

## Why It Works

**Tuning Is Timing.** Tuning, as we learned before, is entirely a matter of controlling the time required for a radio-frequency current to surge from one end of the circuit to the other and back. The longer the circuit is, the longer the time required to complete one cycle, or one complete round trip through the circuit. The shorter the circuit is, the shorter the time required to complete the round trip. Each round trip is called one *oscillation*.

**Frequency.** If a surge takes a long time to make one round trip, few trips will occur in a second. If each round trip occurs quickly, there are more round trips each second.

The number of round trips occurring each second is called
the *frequency* of oscillation. High frequency means many
trips a second; low frequency means fewer trips in a second.

**What a Condenser Is.** A condenser is made of two sets
of metal plates set close together but separated by some
kind of an insulator. (See part 9 of this chapter for expla-
nation of condenser action.) A condenser can be thought
of as a large "electrical dishpan" or reservoir which will

hold a great many elec-
trons. A large number of
electrons flows into one set
of condenser plates and
shoves an equal number of
electrons off the other set of
plates. A condenser then
is a convenient device for
temporarily storing large
quantities of electrons.
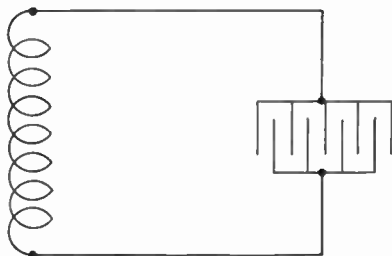
Fig. 109. Condenser with large area
has great capacity.

The bigger the plates, the more they can hold.

**How a Condenser Affects Frequency.** A condenser in a
circuit has the effect of increasing the electrical length of

the circuit, since it takes
time for the electrons flow-
ing in that part of the cir-
cuit to fill the condenser
plates. Condenser plates
of large area connected in
the circuit will fill slowly,
and the frequency of oscilla-
tion will be slower (see Fig.
109). This will make the
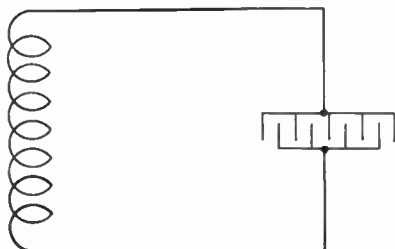
Fig. 110. Condenser with small area
has little capacity.

coil and large condenser tune to a lower-frequency station.

A condenser of small area will fill more rapidly (see Fig.
110). The round trips of electrons will be more rapid (the

frequency will be higher), and the circuit will tune to a
higher-frequency station.

· A condenser shunted across a coil adds to its wave length
and decreases the frequency. Another way of explaining
this would be to say that a small condenser tends to add
but little to the effective length of the coil, and a large
condenser tends to add much to the effective length of the
coil.

**Vernier Condensers—Fine Adjustment.** The condenser
can be adjusted quite easily and tuned accurately to any
wave length possible with this coil. The condenser gives
an easy way to tune "between the turns" on a coil. It
acts much as if the slider could roll around the coil, making
contact with the wire all the way around each turn instead
of jumping a complete turn at a time. The tuning is
smoother and more even. When a condenser is used for
tuning, no loose contacts are in the circuit.

If the tuning needs to be still finer, a gear or friction drive
is used which slows the motion of the dial and of the moving
plates. Later we shall take up other methods of fine tuning.

### Questions

**1.** Does a large condenser increase or decrease the effective length of a
coil?

**2.** Explain why a small condenser will cause the set to tune in stations
operating on a high frequency.

**3.** What is a vernier? Can you describe two or more types used on
sets?

**4.** Assume that the electrons at a given instant are flowing from the
ground to the aerial in the primary circuit. Tell how the electrons
flow through the secondary and condenser of the set.

**Coupling Affects Tuning.** In many older receiving sets
transformers were built so the coils could be moved apart,
twisted, or turned at an angle. Early in radio experi-
menting it was learned that this change of position, or

coupling, affected tuning. Many ingenious schemes were used to control coupling. Soon it was found that few of these controls were used regularly, so a "best" position for the coil was built in the set and a few dials were made to do the work of many.

**What Is Coupling?** Any change in the spacing between coils affects the amount of electrical energy that can be transferred from one coil to the other. This degree of the transfer of energy between coils by induction is called coupling. When the wires are closely coupled, much energy is transferred from one coil to the other. When the coils are spaced apart or turned so that little energy is transferred, the coupling is said to be loose.

**Close Coupling.** More current is induced in the secondary when it is closely coupled to the primary. A stronger signal is heard in the phones. But the tuning is so broad on account of the closeness of the coupling that it is hard to tune to any one station. The aerial currents are strong enough to overcome the tuning effect of the secondary circuit.

When the coils are close together, much energy is transferred to the secondary, and all frequencies picked up by the aerial get through, strong and weak alike.

**Loose Coupling.** When the coils are loosely coupled, all of the currents of different frequencies picked up by the aerial are weaker in the secondary circuit. Loose coupling results in sharper tuning but weaker signals. But the strength of the signal frequency that you want to hear is built up by tuning the coil and condenser to resonance with it. At resonance, the impedance to that frequency is practically zero; hence that frequency surges easily in the secondary circuit.

With all of the signal energy of one station concentrated by sharp tuning, you can hear the station and understand

it even if it is weak.    You can get a stronger signal by
closer coupling, but this causes broad tuning with inter-
ference from other stations.

Close coupling gives a big transfer of energy to the sec-
ondary, and all stations come in loudly.    Loose coupling
gives smaller transfer of energy, and all stations come in
weakly.

**Tuning by Changing Impedance.**    When you tune a set,
you adjust it to select one frequency.    Theoretically, every
station on earth that happens to be transmitting sets up a
signal current in the aerial of your receiver.    Actually, only
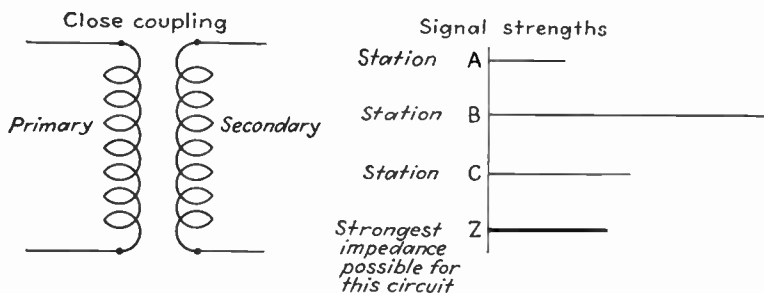


Fig. 111.    Close coupling produces strong signals with poor tuning.

a few of the station frequencies are strong enough to be
heard.    We shall find this is true as we build the more
sensitive sets later in the book.    These sets will pick up
many more stations than will the set you are now using.

**A Current Picture to Illustrate Tuning.**    The diagrams
in Figures 111 and 112 show lines whose length indicates
the strength of the signal from three different station fre-
quencies transferred to the secondary when coupling is
close.    The line Z is the amount of impedance in ohms
that the tuning circuit, condenser, and coil can build up to
stop or tune out any frequency in the tuning range of the
coil and condenser.    This circuit can set up only a certain
amount of impedance to the flow of any of these frequencies.

When the coupling is close, as shown in Fig. 111, you can tune out station $A$ but not station $B$ or $C$. You can reduce the strength of $A$ and $B$ by tuning, but you can still hear both of them. You cannot cut them out. This is known as broad tuning.

Now loosen the coupling so the transfer of energy to the secondary is somewhat less (see Fig. 112). This will not change the impedance of the secondary, but the strength
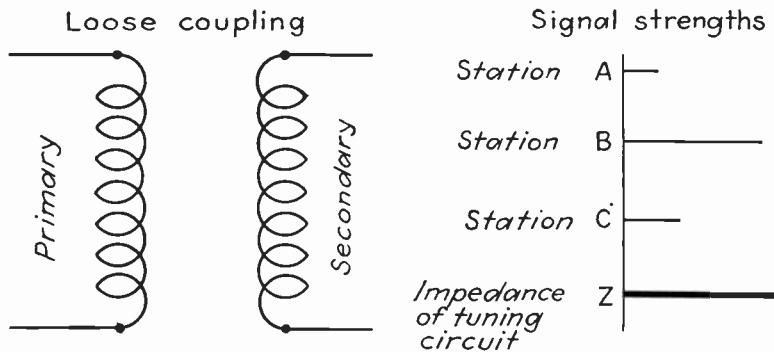


Fig. 112. Loose coupling produces weaker signals, but the tuning is better.

of any of the signals is less than the possible impedance. Now you can tune out any of the stations and allow only the station you want to get through.

Set the secondary tuning condenser so the impedance for the station frequency you want to hear is very low. Now, the impedance for the other frequencies is so great that both frequencies are killed. Only the signal current of the desired frequency flows in the secondary circuit and is heard in the phones.

### Questions

1. What is coupling?
2. What is the difference between loose coupling and close coupling?
3. What bad effect does close coupling have upon tuning?
4. What is meant by broad tuning?

## 7. RESONANCE—THE ELECTRICAL EXPLANATION OF TUNING

Let us compare the action of the electrical tuning circuit to some common thing with which we are familiar. Let us compare tuning to a person in a swing. It is easy to show that a weak push repeated at the proper instants will cause a heavy person to swing gradually higher and higher, while if the push is given at the wrong instant a person swinging very high will soon be stopped.

Now, we shall take an example that is more like the radio circuit in its action. Suppose you have a heavy ball rolling on an ideal billiard table, one which is perfectly level, built so it is practically frictionless to the rolling ball. At the ends of the table are rubber cushions. When the ball is shot across the table with considerable force, it will rebound many times before stopping. Now, if we arrange a device in each cushion to give the ball a push at the instant it bounces away from the cushion at the end of each trip, the ball will continue rolling back and forth across the table. Perfect timing is necessary, or the push will kill the motion of the ball instead of building up the motion enough to overcome the slight rolling friction. If the distance between the end cushions is changed, the push must be retimed to fit the new distance. Or if the timing of the push is changed, the distance between cushions will have to be changed to fit the new time between pushes.

This arrangement is quite similar to the radio tuning circuit. The push on the electrons traveling back and forth in the circuit is timed by the oscillator tubes in the transmitter. In the receiving circuit the push comes from the currents set up in the aerial by the radio waves. The condenser acts as the cushion which stores up energy as the electrons fill one set of plates, and the rebound comes when the electrons rush back through the coil to the other set of condenser plates.

The size of the condenser plates and the number of turns in the coil determine the length of the path the electrons must travel through the circuit during each round trip. When the size of the condenser or of the coil is made larger, the electrons need more time for each round trip, or oscillation. If the coil or the condenser is made smaller, the electron round trips need less time and more oscillations occur each second. The frequency is higher.

You can change the length of the aerial-ground system by moving the slider on the loading coil, or by adjusting the condenser setting which, in each circuit, adjusts the length of the circuit to meet the tiny push given by the radio waves striking the aerial. The strongest current will build up from the radio waves and will flow when the circuit is just the right length. This circuit is then in tune or in *resonance* with the transmitting circuit and with the incoming wave.

Now if the aerial is too short or too long, or if the tuned circuit is too short or too long, this push from one radio wave will generate a current which will oppose the current from the preceding wave. The circuit is now out of resonance with the transmitter, and little or no current flows in the circuit and no sound is heard in the phone.

So the process of tuning is one of adjusting the length of the path over which the ball rolls, or of adjusting the electrical length of the receiving circuit to resonance by adjusting the tuning coil or the condenser so the current may built up to its greatest strength. We know when the current is strongest by the volume of the sound in the receiver.

It is plain at this point to see that good connections in the joints in the wire of the aerial or of the set wiring must be tight and clean. These wires should be large and short so that the flow of electrons through the circuit is not

impeded or hindered. Poor connections slow up the flow of current on account of the resistance and make tuning less accurate and sharp. The electrons cannot get through the circuit in time.

In the one-tube circuits you will notice the difference in signal volume resulting from good or poor connections because you are supplied with so little current by the aerial. But in the sets with several tubes (which you will study later), you can amplify the current, and this loss is not noticed as much in volume as it is in the sharpness of the tuning.

### Questions

**1.** What is the source of energy which keeps the oscillation going in the tuning circuit?

**2.** What determines the length of the path the electrons must travel in a tuning circuit?

**3.** When the condenser and coil are made larger, what effect does this have upon the frequency at which the set tunes?

**4.** What is meant by the term *resonance?*

### 8. THE USE OF TOOLS

## How to Tin a Soldering Iron

A soldering "iron" is not made of iron at the point or tip; this is made of copper, since it conducts heat very well and is convenient to handle. The tip is filed to one of the shapes shown in Fig. 113. As the "iron" heats, the hot copper surface at the end of the "iron" oxidizes, and solder will not stick to it. To prevent this oxide from forming, it is customary to file the "iron" clean while it is hot and to tin it. A coating of tin is melted onto the surface of the clean, hot copper so it will readily conduct heat. This process is called tinning the "iron."

*Step* 1. Heat the iron to the proper soldering temperature. With an electric iron, all that needs to be done is to

turn it on, and it will reach the proper heat in about two minutes.

*Step* 2. File the tip until the bright copper shows over the entire surface. This should require just a few strokes of a clean file. The heated copper will rapidly discolor again, but this discoloration will be cleaned off by the flux.

*Step* 3. Either dip the hot tip of the soldering iron into some form of flux or touch rosin-core solder to the hot tip
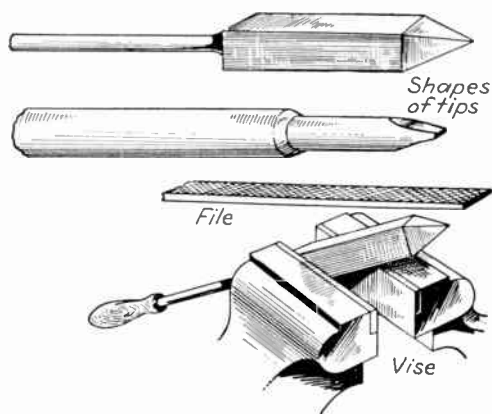


Fig. 113. How to file a soldering iron.

of the soldering iron. The flux will clean off this oxide and permit the solder to flow onto the copper and cover it. If rosin-core solder is used, do not dip your iron in flux. The purpose of the flux is to combine with the impurities and to clean them off.

### How to Splice Wires

*Step* 1. Cut the insulation off the wire for about 2 inches. Scrape till clean and bright. Slice off the insulation as shown in Fig. 114, moving the knife along the wire so as not to cut the wire. Copper breaks easily where it is scratched or marked with a knife or pliers. In making an

aerial this is very important, since the aerial wire will break at such a cut and will fall after it has been in the air a short time. Make a light cut on a piece of scrap wire and then bend the wire to see how quickly a very small
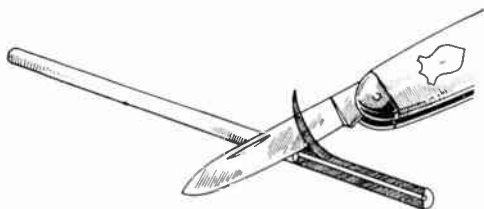


FIG. 114.   Stripping a wire.

mark on the wire will make it break. Now try the same experiment where the wire has not been marked.

*Step* 2. Hold the wires together as shown in Fig. 115.

*Step* 3. Twist one wire around the other for several twists; then start with the second wire and twist it around
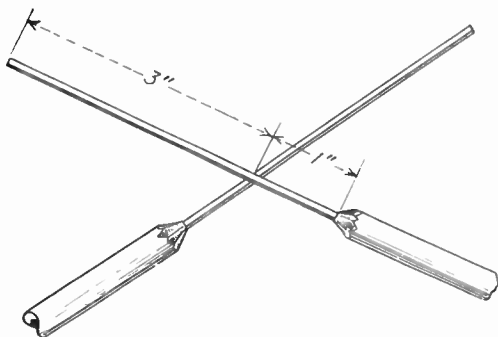


FIG. 115.   Wires ready for splicing.

the first. Keep the first few twists very tight. Make at least four twists with each wire, bending it almost at right angles to the other wire (see Fig. 116). Do not wrap the turns of the joint too closely together as this will prevent

the solder from flowing into and around all parts of the joint. This splice will be sufficiently strong to join parts of an aerial together where there is considerable strain.

*Step* 4. The wire, which was scraped clean before the joint was made, is now soldered. The solder helps make the joint more solid and also keeps out any corrosion from the air or the sun.



Fig. 116. Splice ready for soldering.

## Soldering Fluxes

There are several kinds of soldering fluxes on the market, almost any of which may be used satisfactorily for soldering by the amateur on his set. Select a soldering flux that will not corrode the metal after the joint has been made. Any electrician can tell you a number of good commercial fluxes to use. The local radio man can give you this information.

Many fluxes are good conductors of electricity at high frequencies. Amateurs who have made a set carefully and well often wonder why the set does not operate better. Often the answer is that the soldering flux has flowed not only on the joint but over the bakelite or other insulation in such a way as to furnish a path through which the high-frequency currents flow to parts of the circuit where they do not belong. This cuts down the efficiency of the set.

Many amateurs prefer to use rosin-core solder, since rosin is not a conductor of electricity. Rosin is a good flux for clean new copper or brass. But the rosin sometimes flows into a joint and hardens between the turns of the joint. Such a joint will not carry electricity, since the rosin prevents the two metals from making contact. Take such a joint apart, scrape it clean and bright, then resolder.

Acid-core solder and acid soldering flux, which is called cut acid (hydrochloric acid and zinc), are not suitable for radio soldering, since this acid corrodes copper badly.

### How to Solder a Wire Splice or Wire Joint

Soldering may be done easily if three rules are followed
. *Rule* 1. The joint first must be clean.

This means that all surfaces of the two pieces of metal that are to be held together by the solder must be scraped
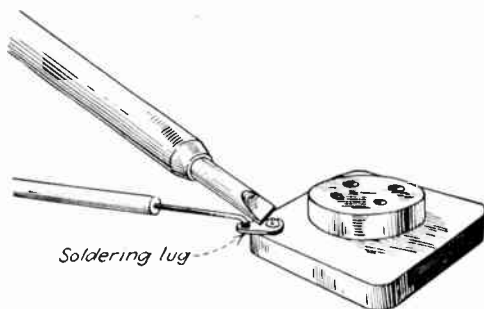


FIG. 117. Soldering to a binding post.

clean or must be cleaned with some chemical. In radio work we scrape wires with a knife, being careful to see that all parts of the joint are clean and bright.

*Rule* 2. The iron must be clean, hot, and well tinned.

An iron that has been overheated or left on for a long time gradually burns. The hot solder combines with the oxygen in the air to form a hard oxide surface which will not conduct the heat from the iron to the joint to be soldered. If this has happened, the iron must be filed and retinned.

*Rule* 3. Have the iron and the joint hot (see Fig. 117).

If the iron feels quite hot when held near the face or hand, it should solder the joint nicely. Use very little flux on the joint. The flux melts and flows through the whole

joint, cleaning the surface of the metal by chemical action. The joint must be scraped clean first unless the wire is new and bright. Special solders and fluxes must be used when soldering aluminum.

When the joint and the iron are thoroughly hot and clean, the solder will flow into the joint quickly and make a smooth joint. If the solder seems to be rough and follows the iron away from the joint and forms a small sharp point, that is a sure indication that the iron or the joint or both are not hot enough.

### 9. CONDENSERS

## Construction and Uses of Condensers

**The Simplest Condenser.** Essentially speaking, the simple condenser consists of two metal plates separated by
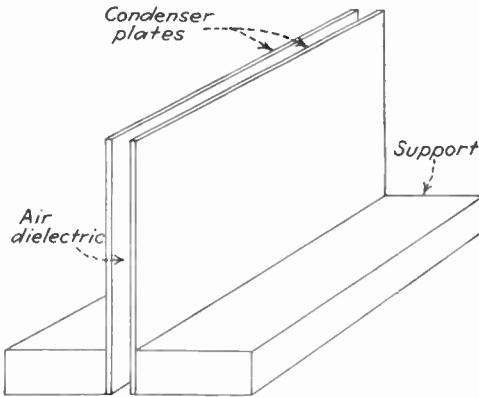


FIG. 118. The simplest condenser.

air or some other insulating material (see Fig. 118). The separating material is called the dielectric. The two condenser plates are not connected to each other.

Condensers are rated as having a certain electronic holding ability or capacity. The terms *capacity* or *capacitance* are used to mean the quantity of electricity that any

condenser can hold.   Capacity is measured in farads or microfarads.   The kind of dielectric used and the thickness of the dielectric as well as the area of the plates of foil or metal determine the capacity of the condenser.

**Dielectrics.**   Glass is a fair dielectric but breaks easily at high voltages.   The dielectric between the plates of a variable condenser is air.   Air is a good insulator and is self-healing.   Cheap condensers have paper dielectrics which often are leaky and affected by moisture.   The better-quality condensers use paper treated to stand higher voltages.   In the better-quality small precision condensers, mica or a high quality of standard glass is used for the dielectric.   Cheap condensers are not entirely accurate.

You may hear the expression *a dielectric constant* and wonder what this means.   Laboratory technicians have carefully tested many materials to see how they compare with air when used for dielectric.   They start with a condenser that has air as the dielectric.   They say the dielectric constant for air is 1.   Then they find a different dielectric material and use it with the same size or area of conductor for plates.   Its thickness must be the same as the spacing between the plates of the air condenser.   If this condenser has twice the capacity of the first, the new dielectric is given the constant number 2.   Its dielectric constant is 2, which means that it gives a condenser the ability to hold twice as many electrons as an air-dielectric condenser will hold.

Some of the common materials used for dielectrics are listed below with their constants.   The values given are approximate.

Air............................... 1.00
Treated paper..................... 2 to 3
Glass............................. 3 to 9
Mica.............................. 4 to 8

## Common Forms of Condensers Now Used

**By-pass Condensers.** Condensers are used in sets today to by-pass radio-frequency currents in the radio amplifier and in the detector circuit, and for by-passing audio-frequency currents in both the detector circuit and in the audio amplifier. Small paper-dielectric condensers are used for this purpose for voltages up to 600; mica-dielectric con-
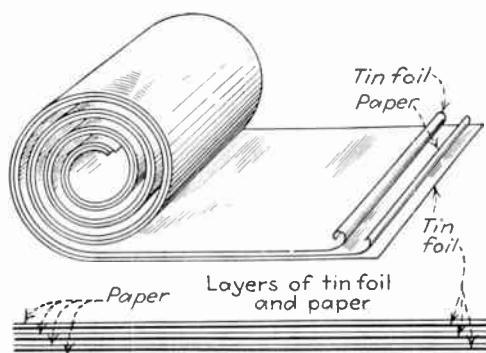


Fig. 119. Paper condenser.

densers are used for the higher voltages. The capacity of radio-frequency by-pass condensers ranges from .1 microfarad to .006 microfarad, depending on the frequency to be by-passed.

The capacity of audio-frequency by-pass condensers is higher, ranging from $\frac{1}{4}$ microfarad to 1 or 2 microfarads. These are generally paper-dielectric condensers.

**Power-supply Condensers.** The capacity of condensers used in power-supply filters is large, ranging from 2 to 8 microfarads. These must have higher voltage ratings than the smaller receiving-type condensers.

These condensers use a high-quality treated paper for the dielectric, with thin sheets of tinfoil for the conductors. The paper condenser is either pressed flat or rolled into

tubular form and sealed with some kind of wax (see Fig. 119).

**Variable Condensers.** These are usually the well-known air condensers used for tuning, regeneration control, neutralizing transmitters, etc.

Transmitter condensers are used for tuning and by-passing in much the same way that they are used in the receiver. They must be better insulated to prevent leakage, and the dielectric must be able to stand high voltages.

**Electrolytic Condensers.** The electrolytic condenser consists of aluminum sheets separated by chemically treated materials. The dielectric is a chemical film that forms on the surface of the plates. The electrolytic condenser has many desirable features. Paper or mica condensers are destroyed and must be replaced when the voltage has become great enough to burn through the dielectric. The electrolytic condenser is self-healing. The dielectric of an electrolytic condenser renews itself after a surge of current has jumped through between plates. The condenser then is as good as new.

Electrolytic condensers must be correctly connected in the circuit. The positive connection is marked.

## The Theory of the Action of the Condenser

**Construction of the Condenser.** For our experiments we shall build a simple condenser of two flat sheets of tin or any other convenient metal, about 4 inches by 6 inches in size. Fasten each of these two sheets to a block of wood large enough to hold them in an upright position. Solder a connecting clip to the condenser plates (see Fig. 120).

Connect one of the two metal plates of the simple condenser to an electroscope (see Fig. 121). An electroscope can be made by hanging a strip of gold leaf or silk or very thin tinfoil across a wire as shown in the diagram. The

electroscope is a sensitive device which will show the presence of a charge of electrons by the action of the gold leaf or tinfoil.
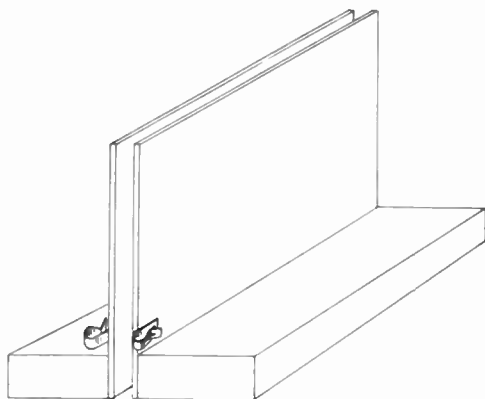


FIG. 120. Condenser made in the laboratory.



Closed fountain pen

Electroscope
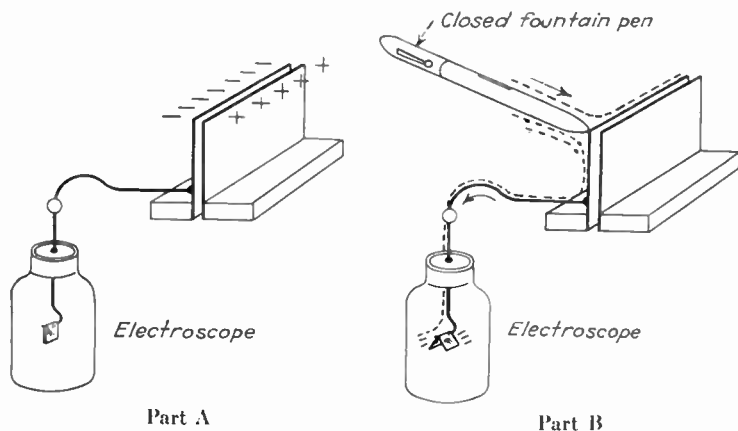
Electroscope

Part A                Part B

FIG. 121. In Part A, at the left, a sensitive electroscope shows the charge on the condenser. In Part B, electrons increase the charge on the condenser and force the electroscope leaves apart.

Then rub a fountain pen on some wool cloth, or rub a glass rod on some sort of fur or on a coat sleeve. This will

charge the rod with static electricity (collect electrons on
the rod). Touch the rod to the condenser plate connected
to the electroscope (see Fig. 121). The surplus electrons
will flow off the rod onto the condenser plate and thus
distribute themselves over the circuit. A lot of them
will flow onto the electroscope leaves, and the leaves will
fly apart. The electrons make both leaves negative, and
the two negative leaves repel each other.

**The Effect of Grounding One Plate.** Now if we ground
the other condenser plate to a water pipe, as shown in Fig.
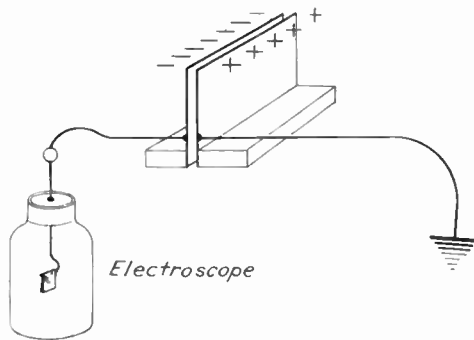


FIG. 122.   Action of a condenser.

122, the leaves of the electroscope will fall together. The
ground acts as a big neutral substance, and the electrons
crowded on the first plate rush over to the surface next to
the grounded plate. They repel the electrons on the other
plate and shove them off the grounded plate into the ground.

The electrons on the first plate try to get across the air
to that second plate and will no longer crowd electrons on
the gold leaves. The electrons that were on the leaves flow
back to the condenser plate, and the leaves fall together.

**The Condenser Is a Reservoir.** The condenser can then
be thought of as a big electrical dishpan or reservoir. Like

a dishpan, it will hold or collect many more electrons than could be placed on a flat piece of metal of the same size.

When the charged rod is touched to a condenser plate, the rod holds a certain number of electrons and it can force only a given number of electrons to the condenser plate. But when the other condenser plate is moved close to the first one, this second plate attracts electrons and makes room so more electrons can flow from the rod onto the first plate. In other words, the greater the pressure is on the electrons, the more you can shove onto the plate. The more electrons you put on, the more pressure will be required to force them on.

It is like pumping up a bicycle tire. The first few strokes of the pump force air into the tire without much effort; as air fills the tire, more pressure is needed to force in more air. Each stroke is harder to shove down than the one before.

This is true of a condenser. A pressure of 10 volts will put only so many electrons on a condenser. After the 10-volt power has put on all it can, 100 volts can add more electrons.

**The Effect of Size on a Condenser.** Now think of two sets of condenser plates the same distance apart. The plates of the first condenser each have an area of 12 square inches. The plates of the second condenser each have 24 square inches. When the voltage on each condenser is the same, the big condenser will hold more electrons.

It would be the same as pumping up a car tire and a bicycle tire. The bicycle tire fills quickly and it takes much pressure to add more air to it, while the big tire has lots of room and not much pressure is needed to put air into it. The automobile tire will hold many times the number of cubic inches of air that the bicycle tire will hold, even when both are under the same pressure. We say that the bigger car tire has more capacity. We say the same thing about

condensers; the one with more capacity or surface will take
more electrons.

Here is a simple way to see that a condenser does store
electrons.    Touch the terminals of a large condenser to the
terminals of a B battery.    Now touch a screw driver across
the terminals of the condenser.    Just before the connection
is made across the condenser a spark will snap across,
showing that the electrons have jumped from one plate to
the other through the screw driver, thus balancing up the
electrons on the two plates.

If we connect a condenser made of two plates of tinfoil
with paper in between to a 20-volt alternating current, the
surge of the electrons flows through the wire and onto one
of the plates.    Since electrons repel other electrons (like
charges repel), the surge repels electrons off the second plate
into the circuit.    The first electrons to reach the first plate
find the plate not crowded at all, and they can go on to
the plate together.    Then as the electrons get closer and
closer together it takes more pressure (voltage) to force on
electrons.    So, in each surge of alternating current, the
first electrons of the surge to reach the plate will flow on
easily, and the later ones will go on with great difficulty.

**Current and Voltage Lead or Lag.**  We say when
charging a condenser that the current leads the voltage;
that is, current leads and voltage lags.    A large number,
or current, of electrons rushes on the plates at first, and
then the voltage has to be high later to force on electrons.

**Summary of Condenser Principles.**  Now let us summa-
rize the operation of a condenser in an alternating-current
circuit.    Electrons surge onto one plate and drive the
electrons off the other plate.    Then, when the current
reverses, the electrons flow back onto the second plate and
drive off the electrons on the first plate.    No electrons
travel through the condenser dielectric.

## Uses of Condensers

Condensers may be used to stop a direct current from flowing in a given circuit and to let an alternating current flow through without interruption. This stops the audio-frequency currents in a given radio circuit and lets the radio-frequency currents get through. This type of condenser has a very low capacity.

If you connect a condenser of certain capacity to a current of 60 cycles frequency, the condenser will hold a given amount of electrons for each alternation. Now, suppose that you connect a radio-frequency current of the same voltage to the condenser instead of a 60-cycle current. The condenser will now hold more electrons per alternation than it would formerly. In other words, a condenser of a given size will increase its capacity as the frequency increases. A condenser which will pass a radio-frequency current will be too small to handle an audio-frequency current. So it is possible by controlling the size of your condenser to permit a given circuit to pass a radio-frequency current and stop an audio-frequency that tries to flow on the same wire.

Small condensers pass radio-frequency currents but stop audio-frequency alternating currents and direct current. Large condensers pass radio-frequency and audio-frequency currents and stop only direct current.

Condensers are used in many places in radio circuits to stop sparking across contacts. This occurs across the key in a transmitting set. Sometimes a condenser is used across a switch. In the old sets a condenser was often connected across the vibrator contacts of the spark coil.

**Condenser and Lamp in Series.** Connect an 8-microfarad condenser in series with a 20-watt lamp. Connect to the 110-volt alternating-current circuit (see Fig. 123).

The light will burn about as brightly as if there were no
condenser in the circuit. There is no flow of electrons
completely through the circuit as in a direct current. The
electrons surge into the plate of the condenser and are
stopped by the dielectric. The electrons are driven off the
other plate through the light. The result is the same as if
the electrons had flowed clear through the original circuit
without having been stopped
in the condenser.
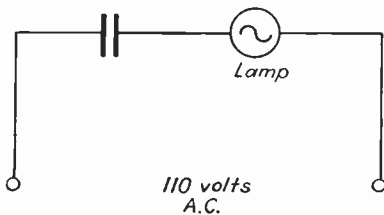


Fig. 123.   Condenser and lamp in
series.

**Tuning Oscillating Circuit
by Means of Condensers.**
An oscillating circuit always
consists of a resistance, a
capacity, and inductance.
The resistance may be the
resistance of the wire of
which the coil is wound, as well as the resistance of the
connecting wires and the wire wound into the coil. The
capacity is concentrated in the condenser, or is distributed
along the length of the wire. Oscillating currents will
flow either in an open circuit consisting of an aerial and
ground in series, or in a closed system where a coil is shunted
by a condenser. Both the open oscillating circuit or the
closed oscillating circuit may be tuned by means of variable
condensers or by changing the size of the coil.

**The Effect of Series or Shunt Condenser.**   When we
tune a coil by shunting a variable condenser across it, the
effect is to increase the wave length of the coil.   If we wish
to decrease the wave length of the coil, we connect the con-
denser in series with the coil.

**Shunt or Series Aerial Condenser.**   When an aerial has
been built and is found to be too long to tune to the stations
which we wish to receive, we connect a condenser in series
with the aerial, coil, and ground to reduce the wave length

of the circuit. The wave length of the circuit can be reduced to only about half the fundamental wave length of the aerial.

The aerial will oscillate at a certain frequency which is called its *fundamental*. But if we find that the aerial is too short to receive stations of certain wave lengths, we shunt a condenser around the coil to increase the wave length.

## The Measurement of Capacity

The unit of capacity is called a farad. A condenser that has a capacity of 1 farad will take up enough electricity at 1 volt pressure to cause a current of 1 ampere to flow for 1 second. A condenser with a capacity of 1 farad would be enormous. In practice the unit of capacity commonly used is a 1-millionth of a farad or 1 microfarad. An air condenser which has 10 square yards of surface has a capacity of about 1 microfarad when the condenser plates are 1 millimeter apart. The area of the plates is not a good way by which to picture the capacity of the condenser, because so many other factors determine capacity—for example, the distance between the plates and the insulation used. It is much better to speak of condensers in terms of microfarads, rather than in terms of the number and area of the plates.

A microfarad equals 1,000,000 micromicrofarads. A variable condenser which is listed in a circuit description as .0005 microfarad is 500 micromicrofarads. Also 350 micromicrofarads is written as .00035 microfarad.

The ordinary 23-plate, 17-plate, and other standard variable condensers range from 250 to 350 micromicrofarads. The midget variable condensers used for tuning in short-wave sets have the following capacities: 23-plate midget, .0001 microfarad; 13-plate, .00005; 9-plate, .000025; and 5 plate, .000015. Condensers made by different manufacturers vary from the capacities given here.

Others that are used are grid condensers, for detector tube, which have a capacity of either .00025 or .0001 microfarad. By-pass condensers have a capacity of $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 microfarads. Condensers used in filter circuits range from $\frac{1}{2}$ to 8 microfarads.

## Electromagnets

**Strength of Electromagnets.** An electromagnet may be made by winding a number of turns of wire into a coil on a spool, a cardboard tube, or on any other convenient form (see Fig. 124). A handy way of making an electromagnet



FIG. 124. Electromagnet.

is to wind about 50 turns of enameled or cotton-covered magnet wire on a small nail. When the ends of the coil are connected to a battery, we find that the coil has become an electromagnet and will lift small pieces of iron or steel, such as tacks or filings.

The strength of a magnet may be increased in three ways: (1) by putting a core such as a nail or a piece of soft iron inside the coil; (2) by wrapping more turns of wire around the coil; (3) by passing more current through the same number of turns of wire.

**Like Poles Repel and Unlike Attract.** Now to show that the lines of force actually represent attraction between the two magnets, let us hang a bar magnet in a horizontal position and bring another magnet near its poles. Hang the magnet so it is free to swing, using a double loop of thread or light string to keep it level.

Hold the south pole of another magnet near the south pole of the hanging bar magnet. The swinging magnet's south pole will swing away from the south pole of the magnet in the hand.

Now, hold the south pole near the north pole of the swinging magnet. The two opposite poles swing together. From these results we can write a rule for magnetic repulsion and attraction: The same or like poles repel each other, and different or unlike poles attract each other.

**Penetration of Magnetic Lines of Force.** Lines of magnetic force penetrate paper, wood, and some metals. We find that the lines of force penetrate metals which the magnet will not pick up, such as copper and brass. We call these metals nonmagnetic, since they are not attracted by a magnet. The lines of force penetrate these metals, but magnetic metals stop the lines of force.

### 10. INDUCTANCE AND REACTANCE

**The Effect of Inductance.** You can see the effect of inductance in a simple experiment. Connect a B battery
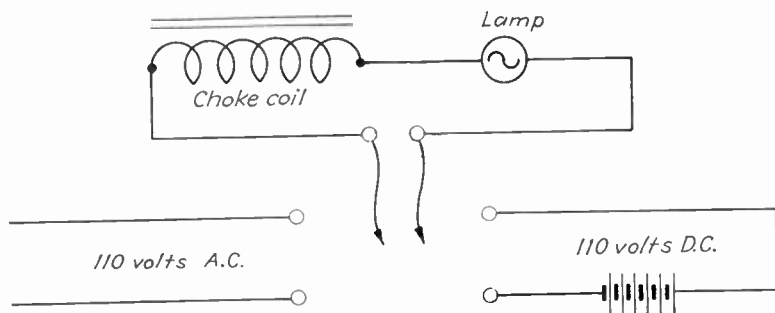


Fig. 125. Inductance of a coil.

of about 110 volts or a B eliminator in series with a choke coil and a 10-watt lamp. (See Fig. 125.) Notice the brilliance of the lamp. Leave the lamp connected to the B battery for only a few seconds, since this is too heavy a load and will quickly ruin a B battery. Then disconnect the B battery and connect the house lighting circuit to it. Notice that the light burns very much dimmer when an alternating-current tries to flow through this choke coil.

The light is dim when the alternating current flows through because of the inductance of the coil.

**What Is Alternating-current Resistance?** The interference with the flow of electrons in an alternating current through a coil is not due only to one property or condition of the coil. Ordinarily one may use the terms *alternating-current resistance* or *alternating-current opposition to current flow*, but technically each particular factor which determines part of that interference must be named. We shall now take this alternating-current resistance which the experiment demonstrated, name the various factors, and show what each does.

**Impedance.** The total alternating-current resistance is called impedance. Impedance is not the sum of all the interferences to the current, but it is the total effect of them all. If electrons flow along a straight wire, there will be a certain amount of interference to the electron flow, called direct-current resistance. But if that wire is rolled up into a coil and an alternating-current is again sent through, it will have a new resistance in addition to the direct-current resistance.

The total effect of this new resistance and the direct-current resistance is called impedance. This new resistance is due to several different factors. Part of it is thought of as inductance or self-inductance.

**Inductance and Self-inductance.** Inductance is the effect of magnetism in opposing the flow of electrons in an alternating-current through a coil. When a current begins to flow through a coil, the magnetic lines of force around each turn of wire will cross the turns next to it. The magnetism makes the electrons in the nearby turns flow in the opposite direction to that of the original current and produces a back voltage in them. This opposition is called self-inductance.

The amount of self-inductance is determined by the number of turns of wire in the coil, the average diameter of the coil, the length of the coil, and the magnetic permeability of the core on which the coil is wound. Some substances are easier to magnetize than others. They



*Courtesy General Radio Co.*

TESTING RADIO EQUIPMENT
A factory technician is checking on the inductance of a group of coils.

magnetize easily and lose their magnetism easily. They have high permeability. Soft iron, such as stovepipe iron and wire, has more permeability than hard steel.

We say when 1 ampere change in current per second in a coil builds up 1 volt in the opposite direction the coil has 1 henry of inductance. If the current changes at the rate

of 2 amperes per second, the opposition voltage would be
2 volts.  The inductance voltage in opposition to flow
depends not only on the actual current that flows but also
on the rate of change of current.  It requires a changing
magnetic field to cause this opposition.

Suppose the coil we used in this experiment has a resist-
ance of 10 ohms when you test it with an ohmmeter using
a direct current.  If you attach a 60-cycle alternating-
current source of the same voltage, the coil will now have
more than 10 ohms of resistance.  Suppose that at this
particular frequency there are 100 ohms of resistance.  This
would be the same as a straight wire with 100 ohms of
resistance.  In other words, this coil gained 90 ohms of
resistance by changing the current from direct to alter-
nating.  The 90 ohms is inductive reactance caused not
only by the direct-current resistance of the wire but also
by the back voltage caused by the inductance of the coil.
The total 100 ohms of resistance to an alternating-current
is the impedance of the coil.

The opposition to the flow of electrons in a condenser is
called capacitive reactance and is measured in ohms, the
same as ordinary resistance in a straight wire.

The alternating-current resistance of a coil is not the sum
of the direct-current resistance plus the reactance.  The
reason for this is that one cause creates a resistance that
tends to oppose or partly kill the effect of another
cause.

The inductance of a coil is a fixed quantity, but the total
interference to the flow of current will change if either the
frequency or rate of change of the current is increased or is
cut down.  Suppose we have a coil which possesses 1 henry
of inductance for a given alternating current.  We can
change the opposition the coil has to the flow of current
by changing only the frequency.  As we increase the fre-

quency, we increase the total resistance until finally little current flows.

Reactance is a term that includes the effect of both the inductance of a given coil and the frequency. The opposition which the coil offers to the flow of current depends upon a given number of henrys of inductance. The greater the number of henrys, the greater is the opposition to a change of direction. If the magnetic field changes more rapidly, the opposing voltage or self-inductance will be greater. Therefore, the greater the frequency, the greater the opposition to a current by the coil. Doubling the inductance of a coil doubles the reactance or doubling the frequency doubles the reactance. Now, if both the inductance and frequency are doubled, the reactance will be four times as great. Reactance is a much more useful term than inductance, because we can measure it in terms of ohms.

**The Henry Unit of Inductance.** This unit of inductance sometimes is written as the letter $l$. The henry can be defined as the inductance of a circuit in which a change of 1 ampere per second produces an induced pressure in the opposite direction of 1 volt. Inductance in a circuit opposes the flow of alternating currents. A microhenry is one millionth of a henry. One one-thousandth of a henry is a millihenry. There are certain conditions of a coil that determine the number of henrys of inductance. For instance, a coil of large diameter will have more henrys of inductance than a smaller coil with the same number of turns or loops. If you have two coils of the same diameter, and they have the same number of turns, but one has the loops very close together and the other has the loops $\frac{1}{2}$ inch apart, the close-looped coil will have more henrys of inductance. Another thing that determines the number of henrys in a coil is its type and use. A coil of many turns of wire has more henrys of inductance than one of few turns.

An iron core in the coil also increases the inductance. A
soft iron core of a given size will cause the coil to have
more henrys of inductance than a steel core of the same
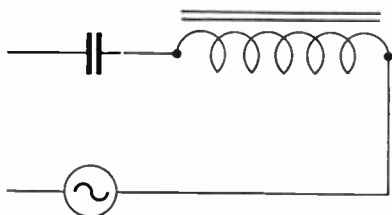


FIG. 126.    Coil and condenser in series.

size. The filter circuit of a
B eliminator generally in-
cludes two 30-henry chokes,
but sometimes a 15-henry
choke is used. The radio-
frequency choke used in the
receiving c i r c u i t has an
inductance of about 85
millihenrys. The impedance-coupled amplifier, which is a
combination condenser and choke coil, uses a choke coil
which has about 700 henrys inductances.

**Coil and Condenser in Series.**    *In a 60-cycle Alternating-
current Circuit.* The coil and condenser
in series, shown in Fig. 126, can be ad-
justed so the lamp will glow brightly.
When an electron surge starts, the coil
retards the surge. But at the start of
the surge, the effect of the condenser is
to speed up the surge. These two
effects cancel when the coil and con-
denser are of the right size and allow
the light to glow brightly.

*In the Radio Circuit.* When we have
the coil in the aerial circuit, as shown
in Fig. 127, it has a certain amount
of interference to the radio-frequency
current flowing and can be tuned to
certain frequencies. Now, when we



FIG.    127.    Condenser
and coil in radio circuit.

connect a condenser in series in the aerial or ground lead,
it will cancel out the effect of the coil the same as in the
electrical experiment. The result is the same as if we cut

off a part of the coil. Now when the coil was in the
circuit alone, it had a certain retarding effect, or slowing-up
effect, on the electrons surging back and forth in the circuit.
But when the condenser at resonance to the certain fre-
quency canceled out other effects of the coil, it was the
same as if the length of the circuit had been cut down.
Thus, the wave length of the signal to which the circuit
would respond was cut down; or to say it in another way,
the wave length was shorter and the frequency could be
higher.

**Condensers in Parallel.** *In a 60-cycle Circuit.* When
a 1-microfarad condenser and a 3-microfarad condenser are
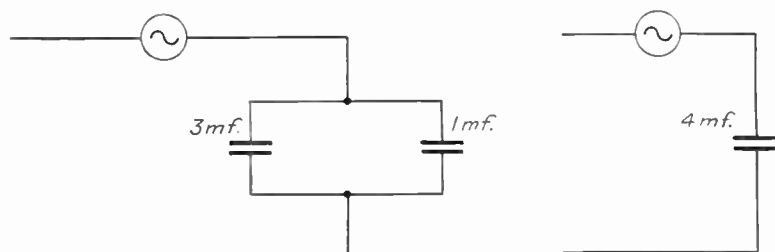


Fig. 128. Condensers in parallel.

connected in parallel, as in Fig. 128, the lamp will burn just
as brightly as when a single 4-microfarad condenser is used
in place of the 1-microfarad and the 3-microfarad condenser
in parallel.

The capacities of condensers add when they are connected
in parallel. If you connect two 1-microfarad condensers in
parallel, there is twice the tin foil surface connected to each
wire for the electrons to fill. Two 1-microfarad condensers
connected in parallel have a capacity equal to one 2-micro-
farad condenser. When you connect a group of condensers
in parallel, you will get the effect of one large condenser with
a capacity equal to the capacities of all the single condensers
added together.

*In a Radio Circuit.* Wire two 23-plate condensers in parallel or in shunt, as shown in Fig. 129. Disconnect one condenser so that it is out of the circuit. Tune condenser 1 until a station is heard with the rotor plates set in about one-third to one-quarter.

Set the position of the rotor plates of condenser 2 at the same position as the plates of condenser 1 and close the switch.

You will have to move the rotors slowly back, reducing the total capacity of the two condensers to hear the same
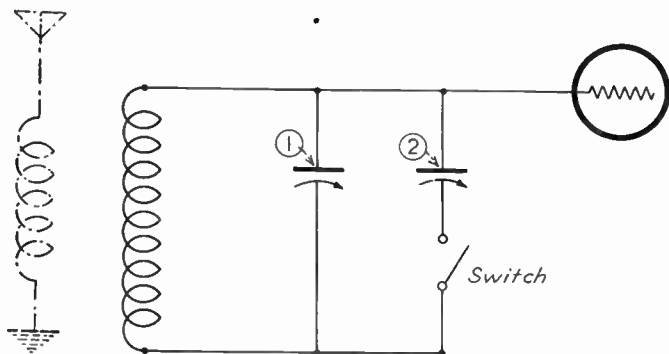


Fig. 129.   Condensers in parallel.

station when both condensers are in the circuit. This must be done since the capacities of two condensers connected in parallel add together. If the capacity of each condenser is .00025 microfarad, the two in parallel will have a capacity of .00050 microfarad. This capacity will make the coil tune to a much longer wave length than when only .00025 microfarad was used.

**Two Coils in Series.** *In a Radio Circuit.* If you connect two coils, each wound with 25 turns on a 3-inch tube, in series, as shown in Fig. 130, and use them for the secondary of the receiving transformer, you will find that they will tune to almost the same frequency as will a secondary

wound on a 3-inch tube but having 50 turns of wire, as shown in Fig. 131.

We find when two coils in series were in the circuit that we have to tune to a certain point with the variable con-
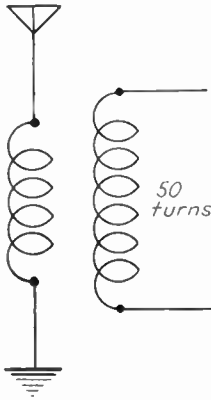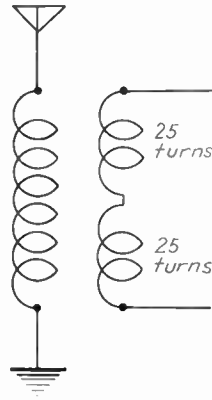


Fig. 130.  Fig. 131.

denser to get any certain station. We find when we substitute another coil of the same number of turns that but slight change is necessary in the setting of the condenser to get the same station.

**Two Condensers in Series.** *In a 60-cycle Circuit.* When one condenser of 8 microfarads is connected in the circuit, the light will glow (see Fig. 132). But when two 8-microfarad condensers are connected in series, the light is very much



Fig. 132. Condensers in series.

dimmer. The capacity of two condensers of the same size connected in series is less than the capacity of one, and less current gets through.

When condensers are connected in series, the effect on the capacity is the same as when the plates are pulled apart. The effect, then, of adding a group of condensers in series, will be to cut down the capacity. The total capacity of a group of condensers in series will be less than that of any one. The capacity of a group of condensers connected in series is found by using the following formula. $C$ stands for the capacity of the group. $C_1$, $C_2$, and $C_3$, each stand for the capacity of a separate condenser.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3},$$

or it can be written

$$C = \frac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}}.$$

*In a Radio Circuit.* Short out one of the two 23-plate variable condensers with a wire, as shown in Fig. 133.
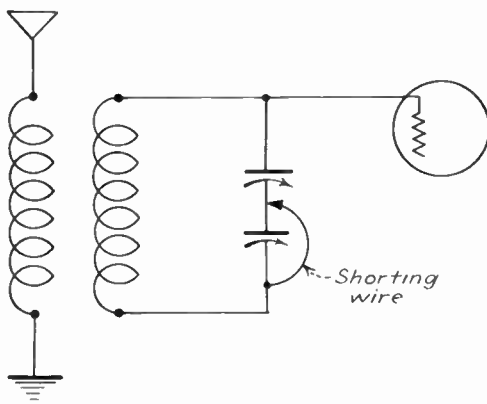


Fig. 133. Condensers in series in a radio circuit.

Tune the condenser left in the circuit until some station is heard clearly. Select a station that can be heard with your rotor plates set in about a quarter to a third. Set

the rotor of the second condenser at the same position as
the rotor of the first condenser.    Remove the shorting wire.
You will find that you must turn the rotors of both con-
densers to add capacity in order to hear the same station
again.

When two condensers are in series, the capacity of both
is less than the capacity of either.    So when you connect
both condensers in the circuit by removing the shorting
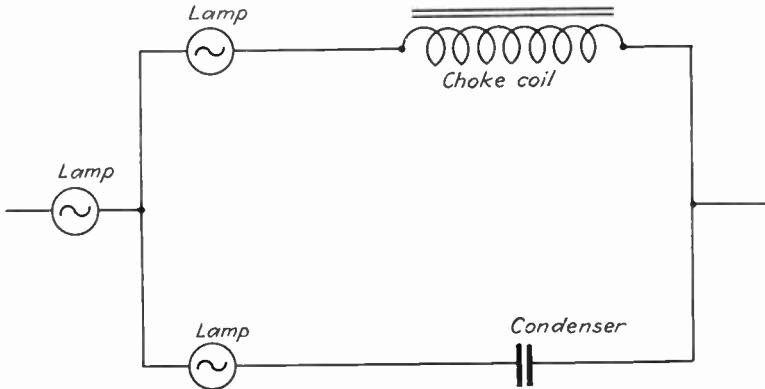


Fig. 134.    Coil and condenser in parallel.

wire, you must turn the plates farther in to increase the
capacity so that you can again tune to the same station.
Two condensers in series cut down the wave length to which
the set will tune.

**Coil and Condenser in Parallel.**    *In the 60-cycle Circuit.*
When the coil and condenser are in resonance, the lamps
in each leg of the circuit light up brightly, but the feeder-
wire lamp is dim (see Fig. 134).    This indicates that at
resonance electrons are surging back and forth in the con-
denser and coil, a closed circuit, and require very little
energy from the feeder circuit to keep the surges going.
The electrons surge back and forth in the closed circuit
much as water surges occur in a tank.    From this we get

the name of the tank circuit. Very high voltages are built
up at the ends of the tank coil.

*The Use of This Principle in the Radio Circuit.* In Fig.
135, the aerial coil is the driving circuit. It furnishes a
very weak radio-frequency current to drive this circuit.
Our purpose in arranging the circuit in this way is to make
this very small amount of current from the aerial control a
much larger current flowing through the tube. So we feed
this very weak current into the receiving tank circuit, which
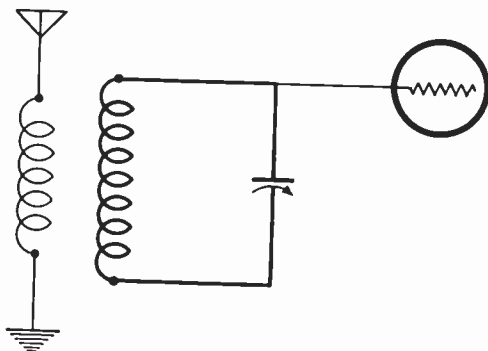


FIG. 135. Tank circuit.

consists of a coil and a condenser in parallel. When we set
the condenser to resonance with the coil for a certain fre-
quency, a much stronger voltage builds up at the ends of
the tank circuit.

When the coil and condenser are in resonance, a very
small amount of current is drawn from the aerial. The
voltage is highest at the ends of the tank circuit. These
voltages are led to the tube grid; or in other words, we
connect the grid of the tube to the point of highest voltage
in the tank circuit. Now, this tube is operated by the
voltage on the grid; or in other words, a very weak voltage
on the grid will control the flow of a very much heavier
current on the plate circuit. If we had hooked the aerial

directly to the grid, the extremely weak current flowing in the aerial circuit would have produced little effect in the phones; but now a larger effect is produced by first passing the weak aerial current through the tank circuit, which builds up a much higher voltage, and the result is to get a very much increased strength of signal in the phones.

## 11. TRANSFORMERS

Probably the simplest transformer that you can make is one formed by winding two coils of wire on a nail (see Fig. 136). Wind 300 turns of size 24 or 26 cotton-covered
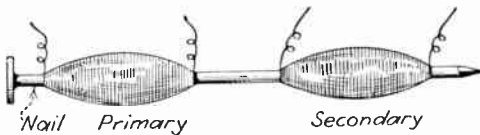


FIG. 136.   Simple iron-core transformer.

magnet wire near one end of an ordinary wire nail. Now wind another coil of about 100 turns at the other end of the nail.

You can use this simple transformer by attaching the larger winding, which is called the primary or the first winding, either to the low-voltage side of a small toy transformer or to some other source from which we can get about 6 volts of alternating current. Now if we attach a voltmeter across the ends of the second winding, or secondary, we will find that there is a current flowing through this coil which will cause the meter hand to move. It is possible to show the current flowing through the secondary by connecting a flashlight bulb to the ends of the winding. This is a crude step-down transformer.

**Names of the Parts of the Transformer.**   The parts of a transformer are: a core, a primary winding, a secondary winding, and any necessary insulation (see Fig. 137).

The core is formed of thin layers of sheet iron insulated from each other by shellac or by insulating paint (see Fig. 138). The core laminations are of Swedish silicon steel (a low-carbon steel) or some kind of soft iron which allows
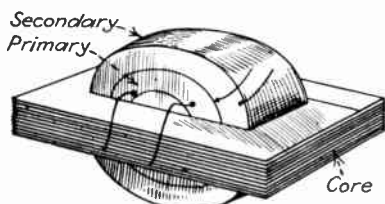


FIG. 137. Laminated iron-core transformer.

the magnetism generated by the current flowing through the coils to change direction rapidly. Currents set up in the iron, which is a conductor, by the changing magnetic field are called eddy currents.

These currents cause the core to heat. The laminations carry the magnetism yet are thin enough so that eddy currents are cut down as low as possible and the power loss is kept small.

The winding through which the incoming or input current flows is called the primary, perhaps because it is the first winding through which current flows. This coil is wound on a cardboard form which slips over the core. This form also serves as insulation between the core and coil.
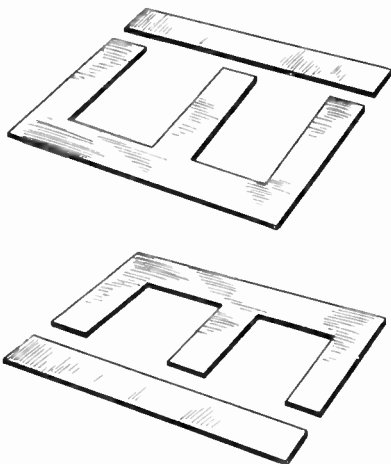


FIG. 138. Core laminations.

The output coil is generally known as the secondary, since this is the second coil. The secondary is wound over the primary. The secondary is insulated from the primary by several layers of treated linen cloth. The

layers of fine secondary wire are separated by treated-paper insulation.

**Size of the Core.** The size of the core is determined by the intensity of the magnetism to be generated by the coil and by the power requirements on the output winding. A core size depends somewhat on the permeability of the iron, whether it allows magnetism to change rapidly or whether it has high reluctance.

**Step-up and Step-down Transformers.** Transformers are known as step-up when the secondary voltage is higher than the primary voltage, as step-down when the voltage of the secondary is lower than the primary voltage. For example, if 100 volts is connected to the primary coil of 10 turns of wire, we would expect to find an output across the 20-turn secondary of 200 volts. You would say that the step-up ratio of this transformer is 1:2, since the voltage was stepped up from 100 to 200 volts. If we had ten times as many turns on the secondary as on the primary, we would expect ten times the voltage in the secondary. Actually, we shall get a little less than 200 volts, for transformers are never perfect.

**Size of Wire on Transformer Winding.** Wire sizes used in winding the coils depend on several factors. Among these are the amount of current the wire must carry. A step-down transformer such as is used for heating filaments has a primary of fine wire which carries the 110 alternating-current line voltage and low current in that coil, and a secondary with few turns of much heavier wire to give the $2\frac{1}{2}$, 5, 7 or 10 volts and the much higher current required for the heaters of several tubes. When there are many tubes in the set, the wire must be heavy enough to carry up to about 10 amperes of current.

The step-up transformer used for the B supply in the power pack has a heavier wire in the primary and many

hundreds of turns of very fine wire for the secondary, which delivers a high-voltage, low-amperage current. Many transformers used on receiving sets today are provided with several secondary windings; one winding for the high B voltages and several windings for the different heater voltages.

**Power from a Transformer.** No machine yet invented will give back more energy than is put into it.

Power is measured in watts. To find the power used by the primary or the power delivered by the secondary, you multiply the current flowing in the coil by the voltage across the coil. Watts of power equals the volts times the amperes.

If 10 volts of pressure forces 5 amperes of current through the transformer primary, we would say that 10 times 5 or 50 watts of power is drawn, or is the input of the transformer. The transformer makes no power. If 50 watts of power go into the primary, we can expect to get 50 watts of power out of the transformer secondary, minus a small loss. A well-designed transformer has very little loss. In our explanation we shall assume that this transformer is 100% efficient which is, of course, not possible.

Now, if we changed the turns ratio so that we have a step-up ratio of 1:2, the output of the transformer should be 20 volts and $2\frac{1}{2}$ amperes. We find that by multiplying 20 by $2\frac{1}{2}$ we shall still receive 50 watts of power output. By the same reasoning, if we make the secondary of the transformer step-up 1:10, we should receive 500 volts and $\frac{1}{10}$ of an ampere, which when multiplied out would produce the same 50 watts of power. Now, if we made the transformer step-down 2:1, we should receive $\frac{1}{2}$ the voltage or 5 volts and 2 times the amperage or 10 amperes. Here again we have 50 watts output.

When a step-up transformer is used, you will get higher voltage but less current. When you use a step-down transformer, you get lower voltage and higher current.

**Transformer Action.** If a bar magnet is passed through a copper ring, the effect of the magnetic field surrounding the bar magnet causes the electrons in the copper to flow around and around like a merry-go-round through the copper ring. In electrical language, a current of electricity is generated in a wire when the wire is in a moving field of magnetic force. When the magnet moves through the copper ring, the magnetic field around the magnet moves and generates or induces a current in a wire. When the magnet is held stationary inside of the copper ring, no current flows; but when the bar magnet is pulled out of the ring, the magnetic field moves and again we find that a current is flowing. When the magnetic field moves in the opposite direction to the original motion, the current in the bar flows in the opposite direction.

When a current flows through the transformer primary, it makes the coil an electromagnet. The magnetic field around the coil is concentrated and is strongest in the iron core. All of the core is magnetized by the current flowing in the primary coil. The space around the core will be surrounded by a magnetic field. Now, as this magnetic field gets stronger or weaker, the effect is the same as if the field were moving. The current induced in the secondary coil flows in the opposite direction from the current in the primary coil.

When the alternating-current flow in the primary coil reverses direction, the magnetic field reverses direction, which induces a current in the secondary coil in the reverse direction. So the change of direction of current flow in the primary coil induces a current in the secondary which

is the same as if a permanent magnet had been thrust into
or pulled out of the coil.

The changing magnetic field strength which induces an
alternating current in the secondary coil may be produced
in several different ways. It may be obtained by passing
a direct current interrupted by a vibrator through the
primary coil, as is the case with the spark coil. A constant
rise and fall of magnetic strength in the core may be pro-
duced by starting, then stopping the current flow in the
primary coil. When the current flow is cut off, the mag-
netic field strength decreases around the core, weakens, and
disappears. The effect is the same as if the core were a
permanent magnet, moved rapidly in and out of the sec-
ondary. It is interesting to note that sensitive meters
show that the current flow created by the dying out of the
magnetic field is stronger than that created when the
magnetic field is building up.

### Technical Terms

**aerial or antenna**—A wire supported above ground, insulated from its
supports and from the ground throughout its entire length. The
aerial is connected to the receiving apparatus by a lead-in wire.

**broad tuning**—Tuning so the set will respond to a group of frequencies.
Close coupling produces broad tuning.

**capacity**—The ability of the condenser to store electrons. Capacity
is measured in microfarads.

**circuit**—A circuit is a pathway from the negative pole of the battery
through which electrons flow back to the positive battery pole.
Various pieces of electrical apparatus may be connected in this
pathway. The pathway must be complete before the electrons
will flow.

**close coupling**—Coils placed closely together so that much energy is
transferred between coils.

**close tuning**—Tuning so only one frequency is heard. Also called
sharp tuning.

**condenser**—Two sets of metal plates separated by air or by an insulator.
The condenser can store a charge of electricity.

**core**—The soft iron center upon which coils of electromagnets are wound. Cores are also used in many other pieces of electrical apparatus.

**coupling**—Two coils so placed together that the field of one coil affects the other coil are said to be coupled together.

**electrolytic condenser**—A condenser that uses a chemical which forms a film of dielectric on metal plates or foil.

**electrons**—The smallest division of matter is known as the atom. The atom is believed to be made up of electric charges, positive and negative. The positive charges are called protons, and the negative charges are called electrons. The different elements familiar to students of chemistry are thought to be different arrangements in the combination of electrons and protons.

**farad**—The unit used in measuring the capacity of condensers.

**generator**—A rotary machine, similar to a motor, that delivers an alternating or direct current.

**ground or ground connection**—Some arrangement, such as a water pipe, buried metal, or a long pipe driven into the ground, by which a radio set makes connection with permanently moist earth.

**headphones**—Two watchcase-type receivers attached to a spring headband so the phones can be worn on the head, leaving the hands free.

**impedance or alternating-current resistance**—The combined effect of resistance and reactance.

**insulation**—Material which does not conduct electricity; glass, bakelite, mica, certain paints or lacquers, asphaltum, etc., are quite common insulators. Silk, cotton, or enamel covering over wire to prevent it from touching other metal in the circuit.

**lead-in**—Insulated wire connecting the aerial to the receiving set.

**loading coil**—A single-layer radio-frequency air-core coil connected in a circuit to add to its electrical length.

**loose coupling**—Coils placed apart so the magnetic transfer is weak.

**microfarad**—A millionth of a farad; the standard unit used for measuring the capacity of condensers.

**millivolt**—A thousandth of a volt.

**oscillating currents**—An alternating current is an oscillating current, one that surges back and forth in a circuit. The current flowing in a tuning coil and condenser oscillate through the circuit.

**reactance**—The resistance of a coil or a condenser to the surging flow of an alternating current.

**receiving transformer**—A radio-frequency transformer wound on a cardboard or bakelite tube. There generally are two or three coils on the transformer.

**resonance**—A setting of capacity and inductance that allows an alternating current of a certain frequency to oscillate with very little resistance.

**secondary**—The output coil of a transformer.

**selectivity**—The ability of a set or circuit to tune to only the frequencies wanted.

**self-inductance**—The back voltage caused by the first rush of current through the turns of a coil.

**signal**—A word used to mean music, speech, code, or other forms of controlled wave coming into the receiving set.

**stator**—The fixed set of plates in a condenser.

**tuning**—The process of adjusting a circuit to the same electrical length with another circuit or to a wave of certain frequency, so a certain signal or program may be heard as loudly and as clearly as possible.

**tuning coil**—A single-layer coil wound on a bakelite or cardboard form. Some tuning coils use switches or sliders to change the number of turns connected in the circuit.

**tuning transformer**—An air-core radio-frequency transformer used in receiving circuits.

**variable condenser**—A condenser designed to permit its capacity to be changed at will. The commonest type is the rotary variable condenser, which consists of two sets of metal plates built so one set can be moved between the other to change or vary the capacity.

**vernier**—A fine adjustment. As used on tuning condensers, a gear or a small shunt condenser furnishes the vernier effect.

# CHAPTER V

## RECEIVING SETS USING DIRECT-CURRENT TUBES

**We Take Up More Efficient Sets.** We found many interesting facts about radio in our study of vacuum tubes. Later, in studying tuning, we learned how to make the receiving set selective. Still, the signals from this set are very poor. We must learn how to blend the facts we have learned about the tube and the facts about tuning into more efficient fundamental receiving circuits.

**Other Possibilities of the Vacuum Tube.** In our study of the vacuum tube, we found that weak currents on the grid of the tube had the ability to control the strength of a much stronger current in the plate circuit. In Chapter IV we used the tube in a circuit to make radio-frequency currents from the aerial-ground circuits produce sound in the headphones. When used for this purpose, the tube is called a detector.

In this chapter on receiving sets, we shall study the applications of the tube in detector circuits, and also the use of the tube as an amplifier. We shall amplify the radio-frequency signals before they reach the tuning system, and we shall also amplify the signals by means of audio amplifiers after it has gone through the detector.

We shall study another interesting application of the amplifying properties of the tube in regenerative circuits, where we make one tube act at one time as a remarkably good amplifier and detector combined in a quite simple circuit.

207

PICTURE        SYMBOL

Audio
transformer

Grid
condenser

Grid leak
resistor

Fixed
resistor
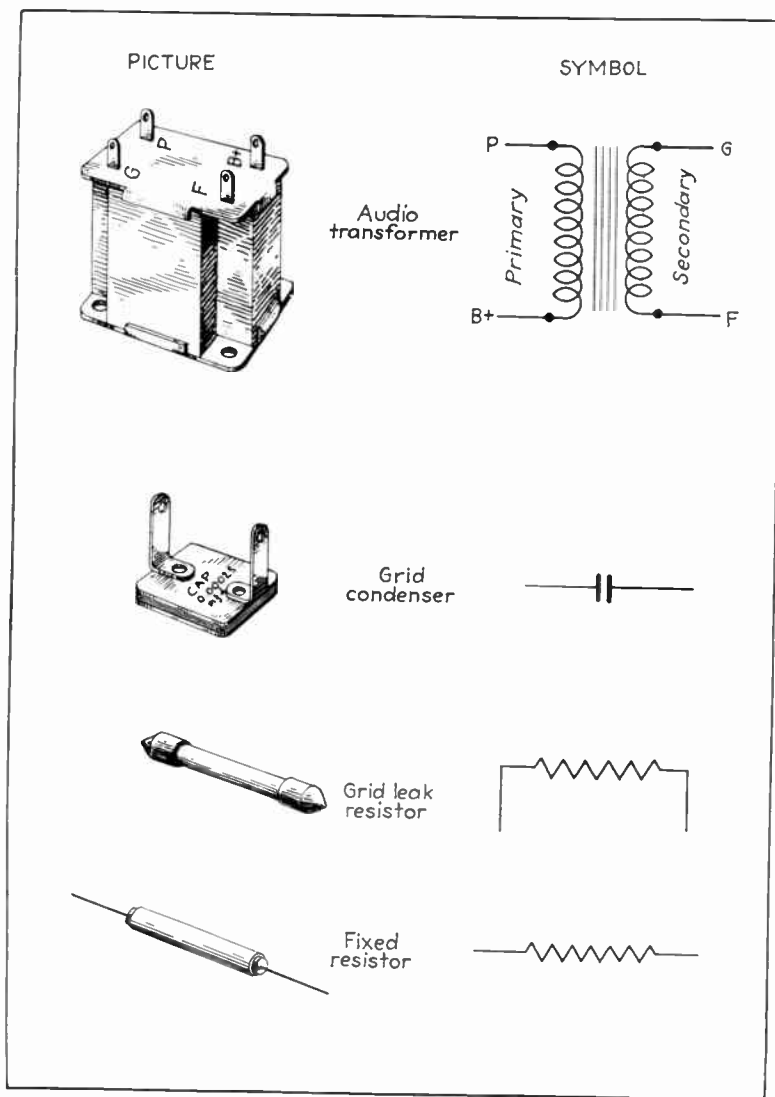
Fig. 139.   New symbols used in Chapter V.

### Contents of This Chapter

### 1. NEW SYMBOLS USED IN THIS CHAPTER

These symbols are shown in Fig. 139.

**audio transformer**—A step-up transformer designed for use in coupling.

**grid condenser**—A small fixed condenser, usually with mica dielectric.

**grid leak**—A small fixed carbon resistor.

**resistor**—Small fixed resistors used for grid leaks or to drop voltage in other parts of the circuit.
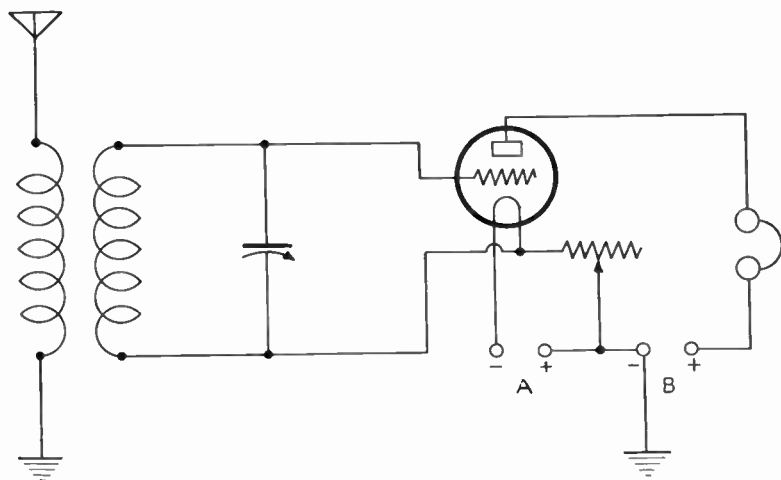


FIG. 140. One-tube detector set. The B negative is generally connected to ground as shown here. For convenience only the B negative symbol will be shown in diagrams, the ground being omitted.

## 2. THE ONE-TUBE DETECTOR SET

### How to Build and Wire the Set

The construction and operation of the set shown in Fig. 140 was described in Chapter IV.

### Why It Works

We tune this set with the variable condenser, as was explained in Chapter IV.

**Radio-frequency Pulsations Cannot Operate the Phones.** The radio-frequency plate-current pulsations cannot flow through the many turns of the phone windings because the coils and iron core act as choke coils. Even if the current could flow through the coils, the minute energy in each current pulsation could not possibly move the diaphragms. Furthermore, we cannot hear vibrations of such a rapid frequency, for our ears will respond to no frequencies higher than about 20,000 cycles a second.
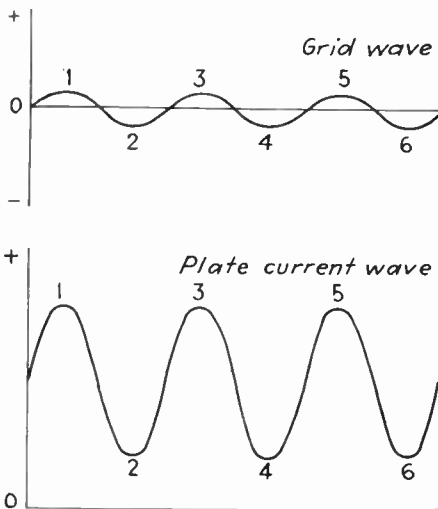
Fig. 141.   Wave forms of current in the plate circuit; no bias is on the grid.

No signals will be heard until something is done to make the radio-frequency pulses operate the phones.   But when we connect a wire from the grid circuit to the positive filament wire, the A-battery pressure pushes electrons on the grid through the wires of the grid circuit.   This steady

electron pressure which keeps the grid slightly negative is
called a negative grid bias. We can now hear signals.

**Plate Current with No Grid Bias.** The shape of the
plate-current wave with no bias in the grid is shown in
Fig. 141. When the grid becomes negative, the plate cur-
rent is weaker (see loop 2). When the grid is positive, the
plate current becomes
stronger (see loop 3).

This process contin-
ues. The plate wave
follows the grid-wave
shape but is stronger.

**Plate Current with
Grid Bias.** When the
grid swings negative,
the bias makes it more
negative. This de-
creases the plate current
more than when no bias
was on the grid (see
loop 2 of Fig. 142).

The positive signal
surge makes the grid



Fig. 142. Wave forms of current in plate
circuit with grid bias.

less negative. Loop 3 shows that the plate current does not
increase as much as it did when no bias was on the grid.

The effect on the plate current is the same as if the top
part of the signal wave had been cut off. The result is a
pulsating direct current of a wave shape that shows most
of the upward swings killed and the downward swings made
stronger.

### Questions

1. Compare the wave shape of the plate current with that of the
aerial current when there is no bias on the grid. Compare the ampli-
tudes of the two currents.

**2.** Compare the wave shape of the plate current with the aerial current when there is a negative bias on the grid.

**The Action of the Pulsating Direct Current on the Phone Diaphragms.** Let us study in detail the action of the phone diaphragms when the pulsating plate current flows through
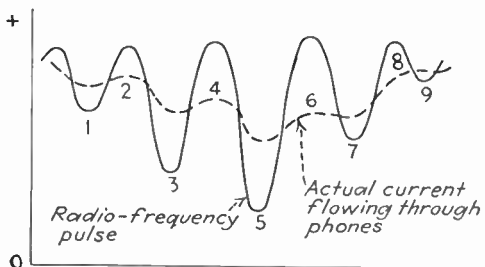


Fig. 143. Pulsating direct current in phones.

the phone coils. The wave-form diagram in Fig. 143 shows several loops of the pulsating plate current. These pulsations flow through the magnets of the phones and set up sound waves.

*Loop 2.* The first radio-frequency pulsation, (2) in Fig. 143, will create a weak magnetism in the phone magnets,



Fig. 144. Motion of diaphragm.

which bends the diaphragms inward slightly. The motion of the diaphragm is shown in Fig. 144.

*Space 3.* In Fig. 143 the space between loops (3) in the wave-form picture shows the time when less current is flowing. Now the magnets begin to lose some of their magnetism, but before the diaphragms have time to bend back, loop 4 arrives.

*Loop 4.* The next radio-frequency pulsation (4), which is stronger than the first pulsation, adds to the pull of the

magnet again.    Since some magnetism remains in the mag-
nets, the second pull will be greater than that created by
the first pulsation that went through the coils.    As a result
the diaphragms bend down still more.

*Space* 5.  Then there is again a space (5) in the wave-form
picture where less current is flowing, and the magnets again
lose some of their magnetism.

*Loop* 6.  The current in loop 6 once more increases the
magnetism, and the diaphragm bends down the greatest
distance possible for this group of waves.

*Space* 7.  During the time (7) between radio-frequency
loops the strength of the magnetism weakens a little.

*Loop* 8.  The next loop (8) is smaller than the preceding
one, and as a result not quite all of the magnetism that
was lost is regained.    The diaphragm begins to move back
toward the rest position.

*Space* 9.  Then during the next break (9) in the wave-
form picture, still more magnetism is lost.    Then, as each
succeeding loop is weaker, the diaphragm gradually falls
back to its original position.

*Summary*.  The average effect from a group of radio-fre-
quency pulsations of the plate current is to exert a single
pull on the diaphragms of the phones.    The drawing in
Fig. 144 shows the effect several groups of pulses will
have on the phone diaphragms.    The radio-frequency
pulses are blended into a motion of the diaphragms that
reproduces the sounds "carried" by the radio-frequency
pulsations.

The heavy dotted line in Fig. 143 shows the wave picture
of an imaginary current which represents the average of the
amplitude of the radio-frequency current loops and the
spaces between loops.

Notice especially that for the whole group of radio-fre-
quency loops there is only one loop of the "average current."

#### Questions

**1.** Which line in the wave-form picture (Fig. 143) represents the current actually flowing through the phones?

**2.** Would the sound be the same in the receivers if, instead of the pulsating direct current, a current represented by the dotted line should flow through the phones?

**3.** How does the frequency of the "average current" represented by the dotted line compare with the number of loops in the pulsating direct current?

**4.** Explain how each succeeding loop, in the group of loops in Fig. 143, adds to the pull of the one just before it.

**A Summary of the Circuit Operation.** The purpose of each section in a radio receiver is shown diagrammatically in Fig. 145.

*Circuit A—the Source of the Radio-frequency Alternating Current.* Radio waves, picked up by the aerial, cause weak radio-frequency alternating currents to flow in the aerial-ground circuits. Many different wave frequencies are picked up by the aerial. These currents flow through the primary of the receiving transformer.

*Circuit B—the Tuning System; One Frequency Is Selected Here.* The radio-frequency flowing through the primary induce radio-frequency currents in the secondary. By adjusting the condenser, one frequency is allowed to flow easily in the tuning circuit formed by the condenser and the secondary coil. The condenser and coil are in resonance with this frequency. At resonance a strong current flow builds up, as we learned in the experiments on reactance and impedance in Chapter IV. The other frequencies picked up by the aerial are tuned out by the high impedance of the condenser and coil for their frequencies.

Tuning is a process of selecting frequencies by setting up high impedance to unwanted station frequencies while at the same time making the impedance to a wanted fre-

| Circuit A | Circuit B | Circuit C | Circuit D | Circuit E |
|-----------|-----------|-----------|-----------|-----------|
| Collects many frequencies | Tunes to one frequency | Controls weak alternating current, controls strong direct-current | Adds power; this is the strong direct-current source | Makes sound from the pulsating direct-current |
| Many radio freqencies are picked up here | Selects one frequency; kills all others | Alternating current on grid makes → | Direct-current added by B battery into a pulsating direct current | Direct-current changes or pulses move the diaphragm and make sound |

Fig. 145. Purpose of each section in a radio receiver.

quency very low.   The unwanted frequencies are killed
and the wanted frequency flows easily.

*Circuit C—the Detector; the Selected Alternating-current
Frequency Controls a Direct Current.*   The alternating-
current flowing in the tuning circuit sends electrons to the
grid during the negative part of the cycle, then takes them
off the grid during the positive part of the cycle.   We say
that one instant the grid is positive, when electrons surge
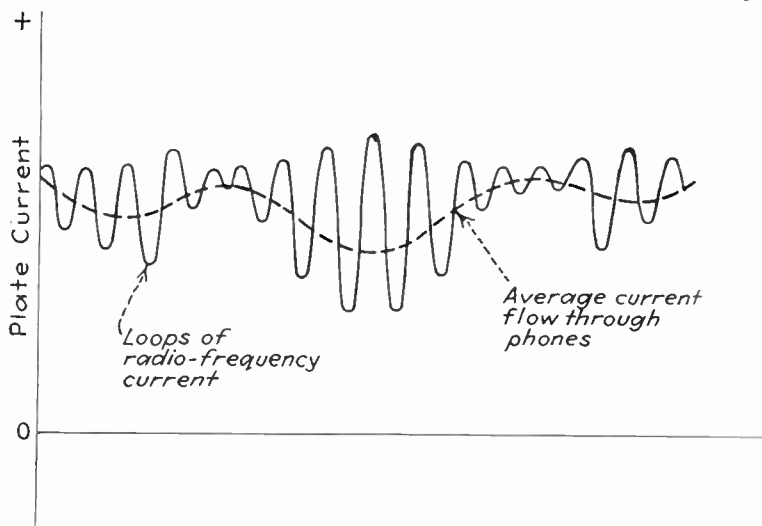


Fig. 146.   Audio and radio frequencies.

off the grid; and the next instant it is negative, when the
electrons surge to it.

When the grid is positive, electrons flow through the
tube, from the filament to the plate.   When the grid is
negative, the electron flow through the tube is greatly
reduced, and the plate current is much weaker.   The plate-
current wave shape is an alternating-current component of
a direct current, or a direct current of increasing and
decreasing strength (see Fig. 146).

*Circuit D—the Tube Power Supply.* All of the power supplied to the tube comes from the B battery, as a steady direct current.

The strength of the steady direct-current "pull" on the plate by the B battery determines how many electrons will be drawn through the tube. Did you notice in the detector
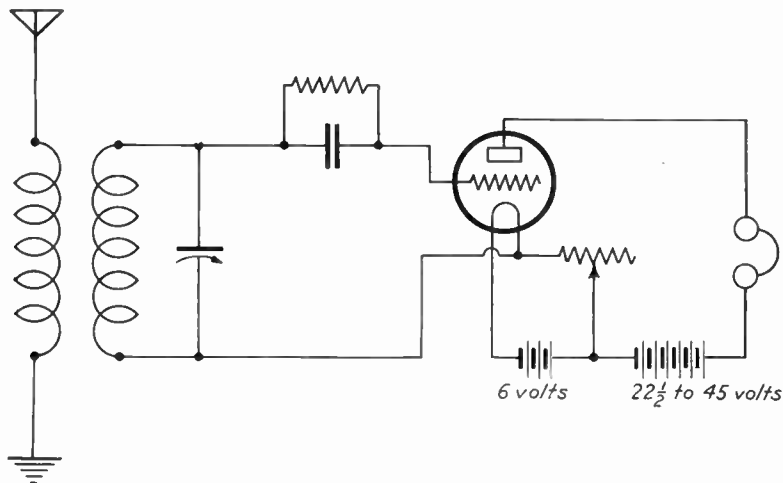


Fig. 147. One-tube detector set with grid condenser and grid leak.

that the grid acted as a faucet or cutoff, turning on and off the electron stream flowing through the tube?

The plate-current wave picture shows a direct current with an alternating-current component of the same wave shape as the radio-frequency alternating current flowing in the aerial, but much stronger. The detector tube amplifies as well as detects.

### Improvements—Add a Grid Condenser and a Grid Leak

**How to Wire the Set.** *The Circuit.* This is the same circuit as used in the one-tube detector set (see Fig. 147).

*The Changes.*    Cut the wire between the secondary and the *G* post of the socket.    Attach a .00025-microfarad fixed grid condenser (see Fig. 148) in series with the secondary and grid of the tube as shown in Fig. 147.    Fit a 2-megohm grid leak into the clips on the grid condenser.

**How to Operate It.**    The set is operated the same as is the one-tube detector set.

**How It Works.**    *Current Changes Produce Sound.*    When a steady direct current flows through the coils in the phones, it causes them to become electromagnets and to add to the pull of the permanent mag-
net cores.    The diaphragm, already under a slight pull, is pulled closer to the cores. The diaphragm will stay in this position as long as the direct current flows through the coils.    We hear a sound when the current flow starts and when it stops.
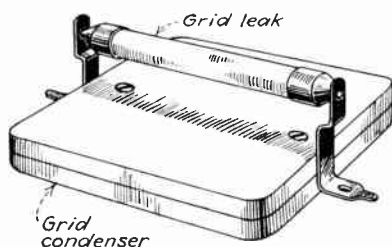


Fig. 148.    Grid leak and condenser, assembled.

Sound is produced when the diaphragm is jerked rapidly back and forth by changes in the strength of the pulsating direct current.    Anything that will change the strength of the current flowing through the phones will produce sound. If we wish the sound to be louder, we must make the changes in current strength quite strong.    In the one-tube detector set the changes in current strength are caused by the changes of voltage in the tuning coil which forces electrons on or off the grid.    We must find a way to increase these changes.

*Effect with No Grid Condenser.*    The electron surges in the tuning circuit are strong enough to produce signals in the phones.    Only a certain number of electrons are available from the tuning circuit; we must find a way to make

them work more efficiently. If we can get more electrons on the grid during each surge, we can get the stronger effect we want. We can use a condenser to store the electrons we collect. Let us see how a condenser can be used in the one-tube circuit.

*How the Grid Condenser Collects Electrons.* The circuit shown in Fig. 149 shows a con-

Grid condenser

Fig. 149. Grid condenser in the detector circuit.

denser connected in the lead from the tuning circuit to the tube grid. When a surge of electrons flows to the grid, it fills side *A* of the grid condenser (see Fig. 150) and forces electrons to flow off side *B* to the grid of the tube (see Fig. 150). The grid, now negative, repels electrons moving toward the plate; and the current to the plate and through the phones is cut down.
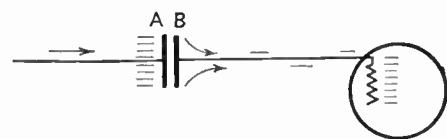
Fig. 150. Electron flow through grid condenser to tube grid.

When the alternating-current surge reverses direction, as in Fig. 151, electrons flow off side *A*, which is now positive. Electrons are attracted to side *B*, which draws the electrons off the grid and makes it positive. The positive grid at-

Fig. 151. Electron flow through grid condenser when flow reverses.

tracts electrons from the space charge around the filament. There are now more electrons on condenser side *B*

than were originally there. When the alternating surge
reverses again and forces electrons on side *A*, it forces
electrons from side *B* to the grid as before. But the grid
wire is cold, and no electrons can leave the grid.

This process continues, and each reversal of current that
makes side *A* positive makes the grid collect a few more
electrons. This process would continue only for a few
surges, until there were enough electrons on side *B* of the
grid condenser and on the grid to build up enough pressure
to cut off entirely the flow of electrons from the filament to
the plate. Then no sound would be heard in the phones
because no current was flowing.

*The Purpose of the Grid Leak—How the Pressure Is Used.*
This whole operation takes place during a few millionths



Fig. 152. Surplus electrons flow through grid leak.

of a second. A perfect
condenser with perfect
insulation would cut off
the flow of current
through the tube almost
instantly. But this is
not wanted. Many
more electrons have
been collected on the
grid by putting the grid condenser in the circuit. The
greater supply of electrons has greatly reduced the flow of
current to the plate. The strength of the current has
changed much more with the grid condenser than before it
was in the circuit.

It is now necessary to remove the electrons on the grid
before cutoff occurs so that the process can continue and
large changes of current strength can occur instead of being
stopped.

We can connect a grid leak across the plates of the grid
condenser, as shown in Fig. 152. Electrons can flow

through this high resistance (1 to 2 million ohms) after enough pressure builds up on the grid and on plate *B* of the grid condenser. The resistor acts as an automatic valve which holds some electrons on the grid. Then, when the first set of surges has passed, the electrons flow or leak through the resistance and past the condenser, so the grid is ready for the next set of surges. A grid condenser and a grid leak of the proper size increase the loudness of the signals. This circuit is good for faint or distant signals. Electrons that the grid collects from the filament flow through the grid leak as a weak direct current.

*The Action of the Plate Current.* If you will examine the tube action, you will notice that the plate current decreases as more electrons are stored on the grid. You may have thought that the plate current should become stronger to produce louder signals. It is the amount of change in plate current which produces signal loudness. Here the current strength drops from the normal strength with no electrons on the grid to a much weaker current when the greatest number of electrons are on the grid. You get the same effect in the phones as if an equal change in strength had occurred in the plate current.

### Questions

1. What is the size of a grid condenser?
2. What is the size of a grid leak?
3. What causes a change of voltage on the grid?
4. Explain how a condenser in the grid circuit can cause electrons to accumulate on the grid?
5. Where do these extra electrons come from?
6. What is the effect on the signals when the condenser causes a large quantity of electrons to collect on the grid?
7. What must be added to the grid circuit in order slowly to remove the excess of electrons from the grid?
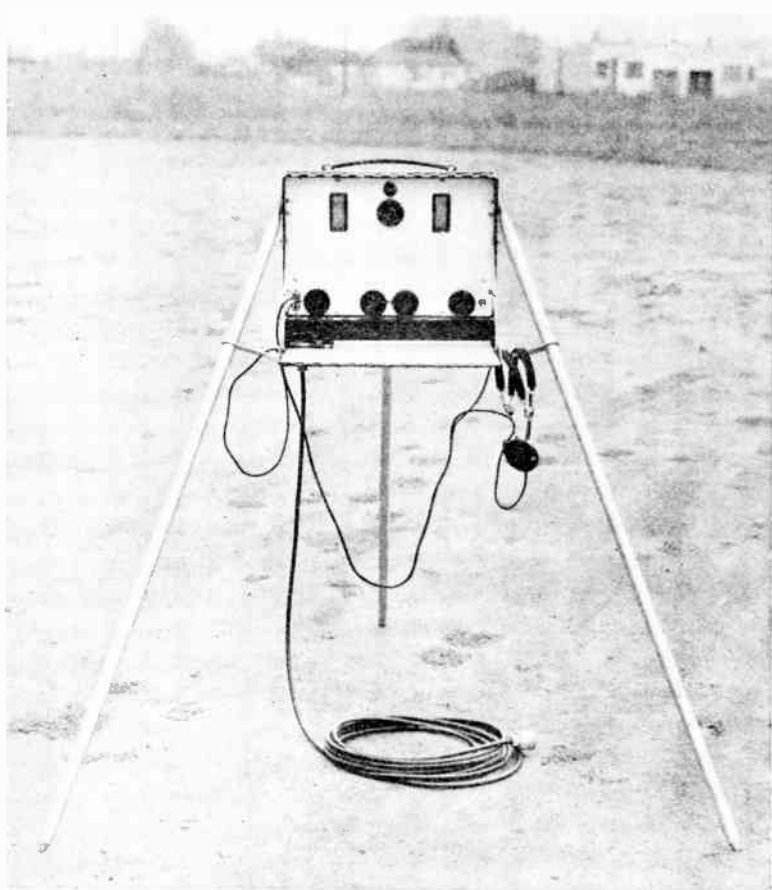
A PORTABLE RECEIVER USED FOR EMERGENCY SERVICE
In times of disaster sets similar to this one are widely used for relief work.

### 3. THE REGENERATIVE DETECTOR SET—CONDENSER CONTROLLED

**The One-tube Set Is Not Sensitive Enough.** As you experiment with this one-tube set, you will hear many stations faintly. You will want to bring in these stations loud enough to get their call letters and to enjoy their programs. Tuning will not bring them in. To reach these stations, you must make the set more sensitive. To make the one-tube set more sensitive and to make the signals in the phones louder, more current must be delivered to the grid.

Power supplied by a B battery may be added to the power of the incoming signals. The circuit which does this is called a regenerative hookup. In this discussion we will study two of the most effective regenerative circuits in common use.

In both circuits, the current flowing in the plate circuit is fed back to the grid circuit by a new coil, called the plate coil, wound near the grid coil.

Regeneration is a form of amplification. When you use the regenerative circuit, your detector set will be as effective as if you had added two stages of radio-frequency amplification, yet you will not have the expense of adding tubes and other apparatus needed in the amplifier.

The most important feature about your new regenerative set is that it will respond to extremely weak signals without the complication of many stages of amplification. You will find regenerative receivers are generally used by amateurs in short-wave work.

**Regeneration-control Methods.** Regeneration is controlled in three-element-tube circuits either by a variable condenser or by a variable resistor in the plate circuit.

The variable condenser tunes very smoothly and quietly. The resistor is somewhat more noisy and affects the setting

of the tuning condenser as it is adjusted. The set will operate better with the condenser control.

## How to Build and Wire It

**Use the One-tube Set Board.** The baseboard of the one-tube receiving set is designed for several receiving circuits. Wind a new coil and add a variable condenser at the right of the board between the rheostat and the phone binding posts for the condenser-control regenerative hookup. See Fig. 153 for the arrangement of the parts. The dotted
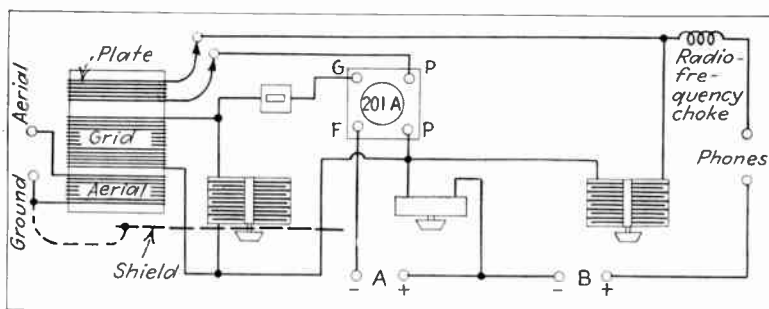


FIG. 153. Regenerative detector set, condenser controlled.

line shows the position of the shield mentioned in How to Operate the Set.

**Wind a New Receiving Coil.** *The Tube.* Use a 3-inch bakelite tube or pasteboard carton.

*The Windings.* Wind three coils on the tube for the regenerative circuit.

*The Wire to Use.* Use wire between size 22 and size 28 for the three coils. The larger size is preferred. The insulation may be cotton, silk, or enamel. More turns will be needed if the wire is larger, and fewer turns if the wire is smaller than size 28.

*The Primary or Aerial Coil.* Fifteen turns of size 22 double cotton-covered wire. Start $\frac{3}{8}$ inch from one end of the tube.

*The Secondary or Grid Coil.*    Forty-five turns of size 22 double cotton-covered wire.    Space this coil $\frac{1}{4}$ inch from the aerial coil.

*The Plate Coil.*    Fifteen to twenty turns of size 22 double cotton-covered wire.    Wind at the end opposite the aerial coil.    Start $\frac{1}{4}$ inch from the end of the grid coil.
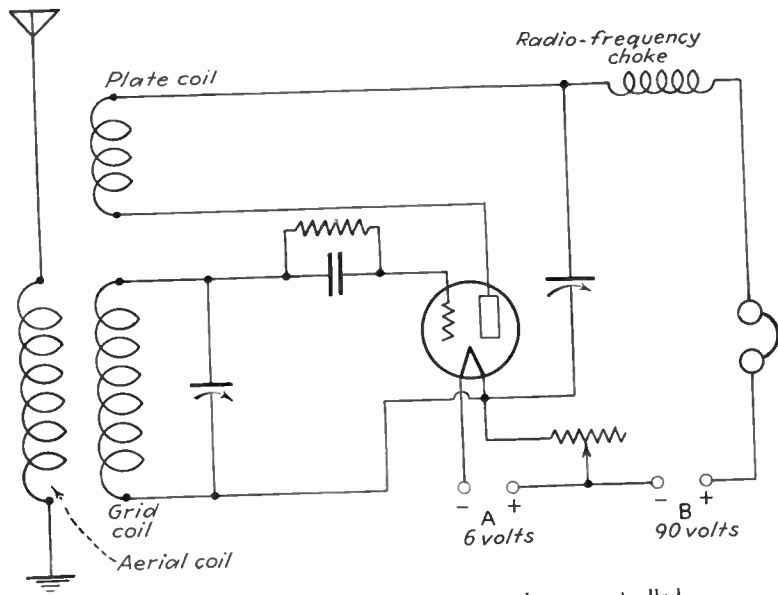


FIG. 154.    Regenerative detector set, condenser controlled.

The correct number of turns in this coil must be found by trial.    Wind too many turns on the coil and cut off turns until the proper number is found.    This will be explained in How to Operate the Set.

*Winding Instructions.*    It is very important in this set that the fields of each coil add together.    If the field of the plate coil opposes the grid-coil field, the set will not oscillate.    By starting at one end of the tube and winding

all coils, turning the tube in the same direction all of the time, the coils will be wound so the fields add.

**Mount the Regeneration-control Condenser.** Screw a 17- or 23-plate condenser in the space between the rheostat and the phone binding posts (see Fig. 153). The regeneration-control condenser should be the same size or a few plates larger than the condenser used for tuning the grid circuit.

**How to Wire the Set.** *The Aerial Circuit.* There is no change in this circuit (see Fig. 154).

*The Grid Circuit.* There is no change in this circuit (see Fig. 154).

*The Plate Circuit.* Run a wire from the $P$ post of the tube socket to the plate coil. From the other end of the plate coil run a wire to the radio-frequency choke. From the other end of the choke run a wire to one of the phone binding posts. From the B negative post a wire connects to the A positive post.

*The Regeneration-control Condenser.* Run a wire from the end of the radio-frequency choke nearest the plate coil to the stator of the condenser. From the rotor a wire connects to the same $F$ post as the grid-return wire.

## How to Operate the Set

*Step* 1. Connect the aerial and ground wires to the set.

*Step* 2. Test the filament circuit. Put an 01A tube in the socket. Connect the A battery. Connect the leads to the set before connecting to the battery, in order to prevent shorts. Set the rheostat to the *off* position. Turn the rheostat knob slowly. If the tube lights up full, the connection is all right. Set the rheostat for 5 volts across the filament.

*Step* 3. Connect the B battery and phones. Connect the B battery to the B positive and B negative posts on the set.

Attach the phone tips to the phone posts on the set. There should be a noise in the phones when the tips are connected when the tube filament is hot, if this circuit is correctly wired.

*Step* 4. Make the set oscillate. Turn the regeneration-control condenser partly in. If the set has been correctly wired and if the B-battery voltage is correct, the set will oscillate at once. When oscillation starts, a "rushing" sound or a soft hiss may be heard in the phones. Test for oscillation by touching the wire between the secondary and the grid condenser. A pop or thud should be heard if the set is oscillating. The same test may be made by touching the plates of the stator of the tuning condenser.

*Step* 5. Tune in a station. Turn the regeneration-control condenser back slowly until the set goes out of oscillation. Stations will be heard with most volume with the condenser set as near the oscillation point as possible yet without having the set oscillate. The set is the most sensitive at this point.

**To Tune in Stations We Use a Different Process.** *Step* 1. We set the regeneration-control condenser so the receiver is oscillating.

*Step* 2. Then we swing the tuning condenser slowly across the dial until a high-pitched whistle is heard. This whistle is caused by the carrier wave of a broadcast or transmitting station mixing with a radio-frequency oscillation built up in the receiving set.

*Step* 3. Now tune slowly until the carrier whistle drops gradually to a low-pitched note and then stops. If the dial is turned still farther, the whistle will start again at a low pitch and rise in pitch until it can no longer be heard.

The station you wish to hear should be found with the tuning condenser set at zero beat just between the two whistles. Tuning by the zero beat method is much more

rapid and more sensitive than by the method we used on the one-tube set. But the signal is mushy and distorted in tone.

*Step* 4. Now turn back the regeneration-control condenser dial until the set just goes out of oscillation. Adjust as close as possible to the oscillation point. You will notice that the sensitiveness of the set increases very rapidly as the oscillation point is approached, and that just below the point where the set goes into oscillation the signals are strongest and clearest. After the set goes into oscillation, the signals are distorted and are not clear.

The tuning of the set is affected somewhat by the changes of the regeneration-control condenser. After a little prac-



Slot for
condenser shaft
Fig. 155.   Condenser shield plate.

tice you will find that by following the motion of the tuning condenser with the regeneration-control condenser you can keep the two nearly together. The motion of the regeneration-control condenser is much less than that of the tuning condenser.

**Hand Capacity and Shielding.** If the set goes out of adjustment and starts to whistle or squeal when you remove your hand from the condenser knobs, the set is being affected by hand capacity.

Set a tin or aluminum shield plate between the tuning-condenser dial and the condenser frame. See sketch, Fig. 155. The shield plate should cut down the capacity effect.

Fasten a wire from the shield plate to the ground. This will completely stop the hand-capacity effect.

## Questions

**1.** How can you recognize by the sound of a regenerative set when it is in oscillation?

**2.** Give a quick way to test a set for oscillation.

**3.** Should the set be in oscillation to receive a station the best?

**4.** What is the cause of the whistling in a regenerative set?

**5.** Explain how to tune by the zero-beat method.

**6.** How do you recognize hand capacity in a set?

**7.** Explain how to stop hand-capacity effects.

## Why It Works

**Current Flow in a Simple Detector Circuit.** We can understand how the variable condenser controls regeneration by first thinking of the set as a simple one-tube receiver with no plate coil.

Electron surges that flow to the grid from the tuning circuit in this set are very weak. If we could get more electrons on the grid from the weak signals picked up by the aerial, we could get a louder signal in the phones.

**Power from the Plate Circuit Helps the Grid.** We can feed the strong current surges in the plate circuit back to the grid through a new coil wound near the grid coil. The power in the plate-current surges induces current surges in the grid coil. The surges reaching the tube grid are now much stronger than when the energy all came from the aerial coil.

**The Set Goes into Oscillation.** The resistance of the wiring in the grid circuit, the alternating-current resistance of the grid coil to the flow of electron surges, and the small alternating-current resistance of the tuning condenser all combine into the alternating-current resistance of the grid circuit that opposes the oscillation or surging of electrons.

Energy must be added continually by the aerial coil to keep up this surging. With no circuit resistance to hinder
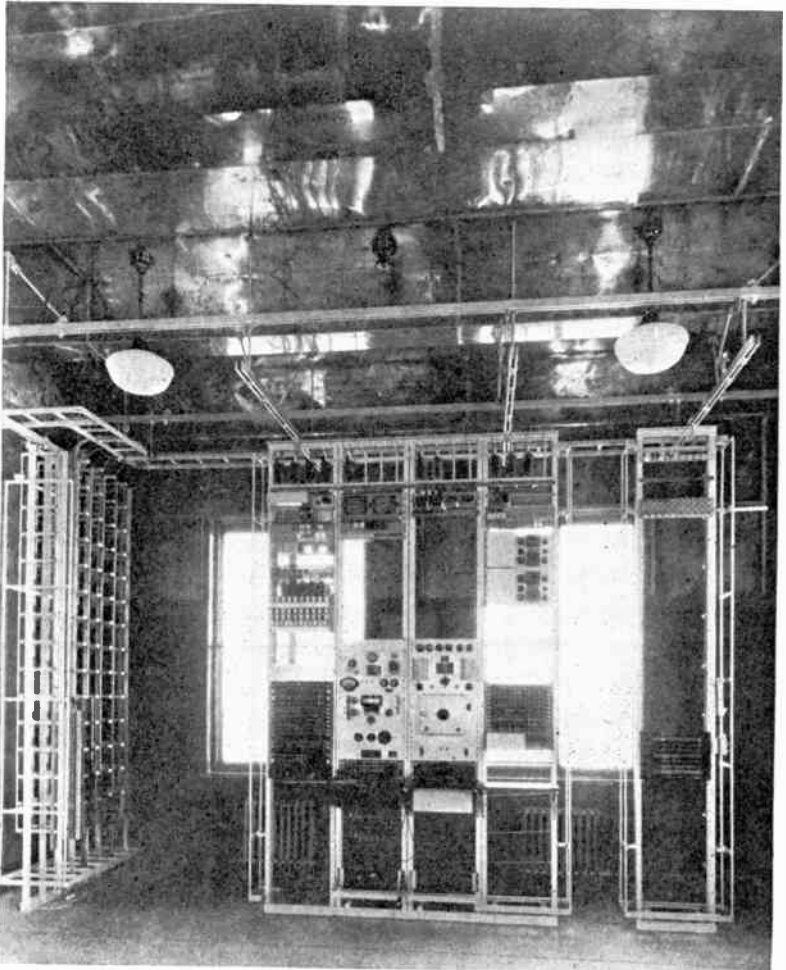
COPPER-SHIELDED TERMINAL ROOM

This room contains the control and monitoring equipment in the transpacific sending station at Dixon, California. Notice the copper-shielded ceiling.

their flow, the surges would be tremendously stronger and the signals would be louder. But since it is impossible to make a circuit of no resistance, we must find another way to get the same result.

We add power from the plate circuit to do this. The grid circuit now receives energy from two circuits, the aerial circuit and the plate circuit. When the energy added by the plate circuit is just equal to the energy used up by the alternating-current resistance of the grid circuit, then a steady surging or oscillation begins in the grid circuit, and we say the set is in oscillation.

During oscillation the electrons surge back and forth through the grid coil, first into one set of condenser plates, then into the other set of plates. The rate of surging or the frequency of oscillation is the frequency to which the tank circuit is tuned.

**Oscillation Distorts the Signal.** This one frequency will be very strong, far stronger than the other frequencies of the signal. This will make the signal sound badly distorted. Some method is needed for controlling the amount of energy fed back from the plate coil to the grid coil, so that the grid circuit can be brought just to the point of oscillation. This will allow the signal to be made tremendously stronger without being distorted.

**How the Condenser Controls Regeneration.** The amount of energy fed back to the grid coil from the plate circuit must be accurately controlled so that the grid circuit can be brought just below the oscillation point where the signal is loudest and clearest. This is done by a variable condenser shunted across the radio frequency choke, the phones, and the B battery. This condenser acts as a by-pass for part of the energy in the plate circuit, and by changing the setting of the condenser the amount of energy that is by-passed is controlled.

The radio-frequency choke in the plate circuit stops the radio-frequency pulses of electrons but allows the slower audio-frequency pulses to reach the phones. Without a choke, the volume of the signal will be reduced and the set may not regenerate.

The size of the grid leak has an effect on regeneration. A high-resistance leak causes the grid to collect so many electrons on strong signals that the tube will cut off. The grid becomes so negative that the plate current is stopped. Too small a leak will make the music weaker.

### Question

1. Describe how the primary coil and the plate coil can act as two primaries which induce a current in the secondary (the grid coil) which is stronger than either primary alone could induce.

### 4. THE REGENERATIVE DETECTOR SET—RESISTANCE CONTROLLED

### How to Build and Wire the Set

**Set Changes.** Mount a variable resistor of 0–50,000 ohms and a 1-microfarad by-pass condenser in place of the regeneration control condenser. See Fig. 156 for the position of these parts. Space them so the wiring is easy to solder in place.

Make no other changes in the circuit.

**How to Wire the Set.** *The Aerial Circuit.* This circuit is the same as in the condenser controlled regenerative set (see Fig. 157).

*The Grid Circuit.* Make no change in this circuit.

*The Plate Circuit.* Run a wire to the radio-frequency choke from the end of the plate coil opposite to the end connected to the plate. Connect the radio-frequency choke to one phone terminal.

Connect the variable resistor in series with the other phone terminal and the B positive post.

Shunt a 1-microfarad audio by-pass condenser across the variable resistor and the B battery.
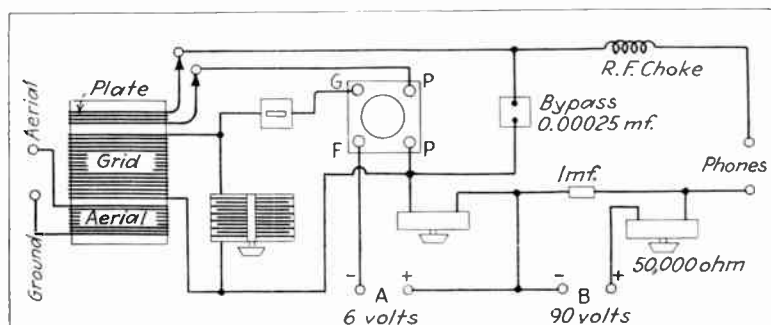


Fig. 156.   Regenerative detector set, resistance controlled.
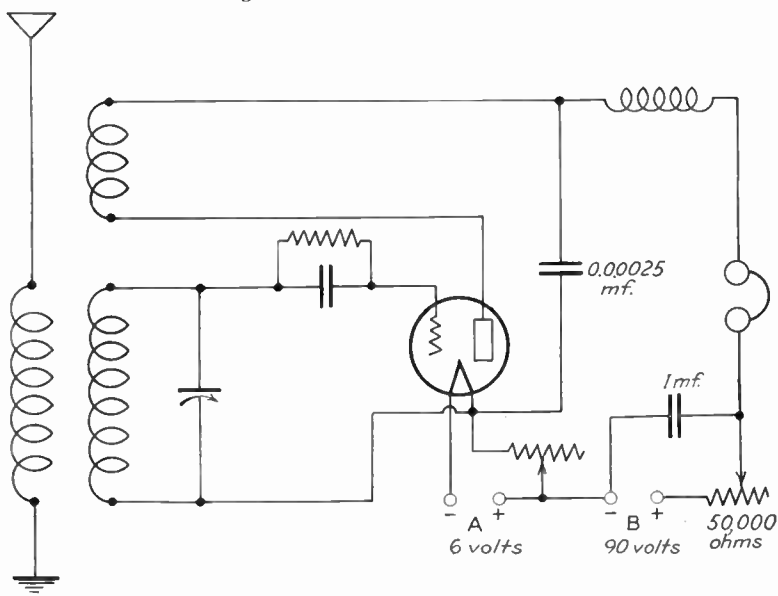


Fig. 157.   Regenerative detector set, resistance controlled.

Connect a radio-frequency by-pass condenser of .00025 microfarad between the radio-frequency choke and the positive side of the filament, as shown in Fig. 157.

**Wiring Check.** Go over the set one wire at a time to see that no mistakes have been made. The set, if carefully wired, should operate the first time it is hooked up.

## How to Operate the Set

*Step* 1. Connect the aerial and ground lead-in wires to the aerial and ground set posts.

*Step* 2. Test the filament circuit. Connect the A battery to the terminals. Put a type 01A tube in the socket. Turn the filament rheostat to the *off* position.

*Step* 3. Connect the B battery and phones. Connect the B battery to the plate terminals on the set. Connect a wire from the positive post of the battery to the positive post on the set. When this is done, the battery will be correctly connected. Attach the phone tips to the phone posts on the set.

*Step* 4. Make the set oscillate. Set the variable resistor at about half. It may be necessary to change the number of turns in the plate coil to get the oscillation point just right.

Check the plate voltage and the filament voltage. They both affect the oscillation point.

Test oscillation by touching your finger to the condenser wire or the stator plates of the tuning condenser, as in the first set we studied. The oscillation point will be heard as a soft thud.

*Step* 5. Tune the set.

Adjust the variable resistor until the set oscillates.

Turn the tuning condenser slowly. Listen for the carrier-wave whistle of a station.

Set the tuning condenser for zero beat on the carrier wave of the station to which you wish to listen.

Back up the variable resistor until the set just goes out of oscillation in order to clear up the signals.

Readjust the tuning and the regeneration control until the music is as loud and clear as possible.

### Troubles and Their Remedies

**The Set Will Not Oscillate.** *Cause.* The plate coil is wired backwards. Its field opposes that of the grid coil. *Remedy.* Reverse the wires leading to the plate coil at the coil.

*Cause.* Not enough turns on the plate coil. *Remedy.* Add 10 more turns. This may be too many, but you can cut down the number until the set operates correctly.

*Cause.* Loose or broken wire joints. *Remedy.* Go over the joints of the set to see if one looks good but is not well soldered. This may be caused by dirty wires that have not been carefully scraped. Solder will not stick to a dirty wire. Flux will not clean wires. The wire must be scraped bright before putting on the flux. Another cause of poor joints is due to the soldering iron or the joint being too cold. When the joint is hot enough, the solder runs into the joint quickly. Very little solder is needed to make a perfect joint.

*Cause.* Reversed A- or B-battery connections. *Remedy.* Check both A and B leads. The plate must be connected to the positive side of the B battery through the plate coil, the choke, and the phones. Trace this connection out carefully.

*Cause.* No radio-frequency choke or a shorted choke. *Remedy.* Hook a choke in the circuit or put in a new choke.

**The Set Will Not Stop Oscillating.** The regeneration point is just before the set starts to oscillate. Here the set is more sensitive. If it will not stop oscillating, signals are not as loud as they might be.

*Cause.* Too much B voltage. *Remedy.* Reduce the B voltage.

*Cause.* Too many turns on plate coil. *Remedy.* Take off turns, a turn at a time.

**The Set Oscillates Too Strongly.** *Cause.* Too much B battery. *Remedy.* Reduce the B voltage to 45 volts.

*Cause.* Grid leak too large. The set goes into oscillation with a heavy thud. *Remedy.* Try a grid leak with less resistance.

*Cause.* Too many turns on the plate coil. *Remedy.* Remove turns, one turn at a time.

**The Set Screeches and Howls.** *Cause.* B voltage too high. *Remedy.* Reduce the B voltage.

*Cause.* Too many turns on the plate coil. *Remedy.* The number of turns on the plate coil should be such that the set will go into oscillation with the condenser control half in. Set the regeneration control half in, put 45 volts on the plate, and take off turns on the plate coil a turn at a time until the set oscillates smoothly. Test the set after each turn has been removed.

*Cause.* Filament voltage too high. *Remedy.* Cut down the voltage as much as possible. It will often be found that the voltage may be cut almost in half and better signals will be heard. Refer back to the filament-emission tests for this reason.

**The Set Is Noisy or Scratchy in Operation.** *Cause.* Defective or old tubes; loose tube elements or loose wires in the tube base. *Remedy.* Get a new tube. Try another tube.

*Cause.* Loose connections in the set wiring. This is noticed as a pop or as scratching when the set is jarred. Poorly soldered joints may be the cause. *Remedy.* Tighten all connections at the binding posts. Move the soldered joints with the fingers while the set is operating to see if the joint is broken. A wire may be broken with the ends touching and scratching together. Scrape and resolder the joint.

*Cause.* The regeneration-control resistor may be old or defective. The noise then is caused by the small changes in resistance which cause voltage changes in the plate circuit. *Remedy.* Tighten the screw holding the resistor parts together. Try a better resistor. If a better resistor tried in the circuit stops the noise, a new one should be used.

### Questions

1. Give a list of reasons why a set will not operate.
2. Make a list of reasons why a set will not stop oscillating.
3. Give reasons why sets may oscillate too strongly.
4. Give a list of reasons why a set screeches and howls or is too noisy in operation.

## Why It Works

The control used in this regenerative receiver set is a 50,000-ohm resistor wired in series in the plate circuit.

The series resistor connection cuts down the voltage in the plate circuit and in this way controls the amount of feedback possible through the .00025-microfarad fixed by-pass condenser. The resistance-controlled circuit is essentially the same as the condenser-controlled circuit. In the resistance-controlled circuit the condenser is fixed and feedback is controlled by changing the voltage through a series resistor. As the voltage is changed, the amount of current flowing in the plate coil is changed, due to the increased or decreased pull of the B battery. When there is much resistance in the circuit, the voltage or the pull of the B battery is cut down and there is little feedback. When there is little resistance in the circuit, the voltage or the pull is stronger and there is more feedback.

### Questions

1. How is the resistor connected in a circuit for resistance-controlled regeneration?
2. Explain how the resistor controls regeneration.

## 5. AUDIO-FREQUENCY AMPLIFYING CIRCUITS

**Early Set Limitations.**    Radio was confined to the labo-
ratory for years while the circuits were being perfected and
simplified.    Only an electrician, an engineer, or a skillful
amateur was able to operate the sets, which were very
complicated and had many controls.    Amateurs sat for
hours wearing headphones, straining their ears for the faint
sounds and signals coming into their sets.    The sets had
many controls.    They overflowed from the table to the
floor.    This was not a type of radio that would appeal to
the average family who wanted music or other forms of
entertainment in the home.    After the operation of the
sets became simplified, amateurs began to experiment with
the different circuits, to design their own crude variations
of the laboratory apparatus used by the engineers, and
to simplify radio circuits and apparatus greatly.    They
demonstrated that it was possible for an ordinary person
to operate a set.

**Vacuum Tube Made Amplification Possible.**    Until the
radio tube made its appearance, amplification was an
impossibility.    There was no way to amplify the signals
from the crystal detector.    In working with the vacuum
tube, it was soon discovered that the ordinary tube had
two characteristics: it could be used as a detector, and it
also had the property of amplifying.    Weak currents flow-
ing on the grid of the tube were able to control strong
currents in the plate circuit.    This made a stronger signal,
of the same wave shape, in the plate circuit.

A new line of development was possible.    From then on
the radio science spread from the laboratory and amateur
fields into the home as a source of amusement and enjoy-
ment.    We shall study the simpler standard amplifying
circuits that were developed during these years of research

and experiment and are used for amplifying the output of the detector set.

**We Shall Add Audio Amplification.**   Now, we are ready to improve the performance of our set still further by increasing its volume by means of an amplifier.   We shall use the amplifier in the audio circuit first.   More than three stages of audio amplification are too difficult for us to handle in these hookups.

**Coupling between Detector and Amplifier Stages.**   The changes in strength of the pulsating direct current in the detector plate circuit must be transferred to the grid circuit of the amplifier tube in some way.

If we were to connect the plate circuit of the detector tube directly to the grid circuit of the audio-amplifier tube, we would find that the amplifier would not operate.   The B-battery voltage used in the plate circuit of the detector tube is so high that it would pull most of the electrons off the grid of the amplifier tube, and the tube would not amplify.   The circuit must be separated in some way so that the plate voltage of the detector tube does not exert this pull on the grid of the audio-amplifier tube.

**Transformer Coupling.**   By far the most common way is to connect between the circuits a small audio transformer with a turn ratio of from 1:2 to 1:6.   It is wound with many thousands of turns of fine wire so as to give a good transfer of energy to the secondary.   The direct-current detector tubes use about $22\frac{1}{2}$ volts and about 3 milliamperes of current.

The primary on the transformer is wound so it has approximately the same impedance to the flow of current that a pair of phones or a speaker would have.   The audio transformer steps up the voltage change in the secondary. That is, if the plate voltage changes 10 volts, a 3:1 transformer will give about 30 volts change in the secondary.

**Resistance Coupling.** This is an inexpensive form of coupling which uses a small resistor and a coupling condenser in place of the audio transformers used in transformer coupling.

Signals heard through the resistance-coupled set are of better quality than those from the transformer-coupled set.

**Impedance Coupling.** Impedance coupling, which is similar to resistance coupling, will be described in Chapter VIII.

### Questions

**1.** Why cannot the grid of the amplifier tube be connected directly in the plate circuit of the detector tube?

**2.** What determines the amount of resistance to be put in the primary of the audio transformer?

**3.** Compare the connections of a resistance-coupled set with those of a transformer-coupled set.

**4.** What is the purpose of the fixed condenser in the resistance coupling?

## A Transformer-coupled Audio Amplifier

**How to Wire the Set.** *Use a Small Baseboard.* Mount the audio-frequency amplifier parts as shown in Fig. 158 and Fig. 159. Use a 2:1 or a 3:1 audio transformer.

*The Filament Circuit.* Plug a type 01A tube in the socket.

Connect the A battery wires to the A negative and the A positive binding posts.

Test the filament circuit by turning the rheostat. If the tube lights, the circuit is correctly wired. .

*The Plate Circuit.* Connect the wires from the B posts on the set board to the B battery. Connect the B negative wire first to get these connections correct. The plate of the tube must be connected to the positive terminal of the battery.

Connect the phones or the loud-speaker to the output terminals of the board. Connect the phone tip marked by the colored insulation on the cord to the positive side of the battery. This is to prevent the direction of the current
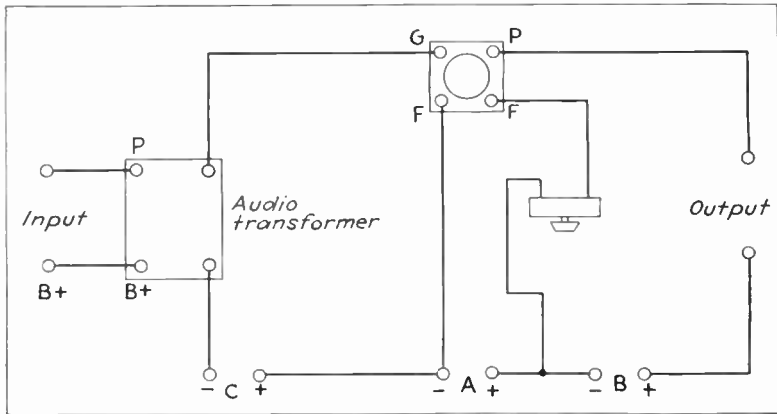


Fig. 158. Audio amplifier, transformer coupled.
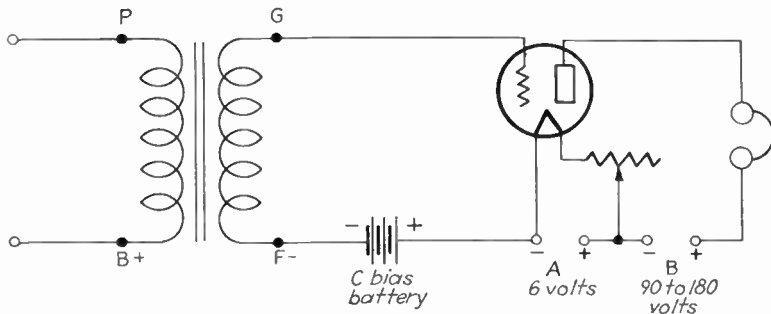


Fig. 159. Audio amplifier, transformer coupled.

flowing in the windings from gradually weakening the magnetism of the phones' permanent magnets.

*Connect the Amplifier to the Set.* Connect two wires between the output or phone posts on the detector board and the input posts on the amplifier board. The amplifier

set is now ready to operate. If it is connected correctly, the signal should be much louder than for the detector set alone.

**How to Operate the Set.** *B Voltages to Use on the Amplifier.* Try several different values of the B voltage. Start with 45 volts on the plate. Notice the volume of the signals; then step up the voltage to 90. Again try the volume. Continue up to the highest B voltage you have available from your B batteries or power pack.

These voltages run as follows:

| | |
|---|---|
| B negative.................... | 0 volts |
| B detector.................... | 45 volts |
| B amplifier................... | 90 volts |
| B power...................... | 135 volts |

*C Bias to Use.* Each different plate voltage will require a different C bias voltage on the amplifier stage to cause the tube to operate correctly.

Refer to the following charts to find the correct C bias voltage for the type 01A tube and the type 71A tube with different plate voltages. Try the set with no C bias and with more than 4.5 volts. There should be a difference in the quality of the signals. As the B voltage is raised higher, the bias must be increased. When the B voltage and the bias are changed, as shown in the chart for the Type 71A tube, the volume will be increased considerably and the quality improved.

| TUBE TYPE 01A | | TUBE TYPE 71A | |
|---|---|---|---|
| B Voltage | C Voltage | B Voltage | C Voltage |
| 90 | −4.5 | 90 | −16.5 |
| 135 | −9 | 135 | −27 |
| 180 | | 180 | −40.5 |

AUDIO TRANSFORMERS UNDER TEST
To produce music of fine quality, a transformer must perform equally well at many different frequencies.

*Several Stages of Amplifiers.* If you want still louder
signals from the set, add more stages of amplification. We
shall use two stages, one of which may be a power stage
using a type 71A tube. The higher voltage will be used
on the last or power stage which drives the loud-speaker.

Each stage of amplification is made by constructing
several boards and connecting them one after the other.
The connections of the board are the same as for the
amplifier just described.

**Why It Works.** *Each Tube Adds Energy.* Signals
received on a one-tube set are weak. Energy in the B
battery is controlled by current on the grid of the tube.

When we want to make the signals louder, we must add
more energy from another B battery controlled by another
tube. This is the audio amplifier. We now connect the
primary of the audio transformer to the detector circuit in
place of the headphones. The pulsating direct current
flowing through the primary of the transformer induces an
alternating current in the secondary. This alternating
current on the grid of the amplifier tube controls the flow
of a stronger plate current supplied by a B battery.

Changes of plate current in the amplifier are much
stronger than the current changes in the detector plate
circuit. The audio amplifier produces much louder signals
than those heard with the one-tube detector.

*The Audio Transformer—Why Used.* The detector B
voltage must not contact the grid of the amplifier tube.
By the use of a transformer, the plate circuit of the detector
with its high voltage is separated from the grid circuit of
the audio amplifier.

When the pulsating direct current from the plate of the
tube flows through the primary of the transformer, it
induces an alternating current in the transformer secondary.
All of these currents, both in the primary and in the sec-

ondary, are at audible or hearable frequency. The voltage changes on the grid of the amplifier tube are much stronger than those on the grid of the detector tube. Changes in the plate current of the amplifier tube will be much stronger than the changes in the plate of the detector on account of the amplifying ability of the tube. The signals will be louder.

*The Reason for the C Battery.* As the amplifier grid becomes positive and negative, it controls the flow of the current through the plate circuit. The performance curve we drew in the tube tests shows that when no signal or electrons are on the grid a certain amount of current is flowing in the plate circuit of the tube.

But to produce efficient amplification, the surges on the amplifier grid must have the same wave shape as the surges picked up by the aerial. If this amplifier grid ever becomes positive, say on strong incoming signals, it will draw electrons from the filament, and the positive part of the signal wave will be too strong. This produces distortion in the signals.

If a C battery is connected in the grid circuit, the grid cannot become positive, and the signals are free from distortion. This effect is very noticeable when two or more audio stages are used.

The surges in the audio-amplifier circuit are all at audio frequency. The audio amplifier increases the strength or amplitude of the surges without changing their wave shape.

### Questions

1. What is the source of power in the audio-amplifier set?

2. Can a pulsating direct current in the primary of a transformer induce an alternating current in the secondary?

3. Compare the voltage changes on the grid of the detector tube with the voltage changes on the grid of the audio-amplifier tube.

4. Are the currents in the secondary of the audio transformer at audio frequency or radio frequency?

5. Explain how a C battery prevents distortion in the audio amplifier.

## A Resistance-coupled Audio Amplifier

**How to Build the Set.** Mount the parts on a small baseboard as shown in Fig. 160.

**How to Wire the Set.** *The Input Circuit.* No transformer is used in this circuit. In its place are two resistors,
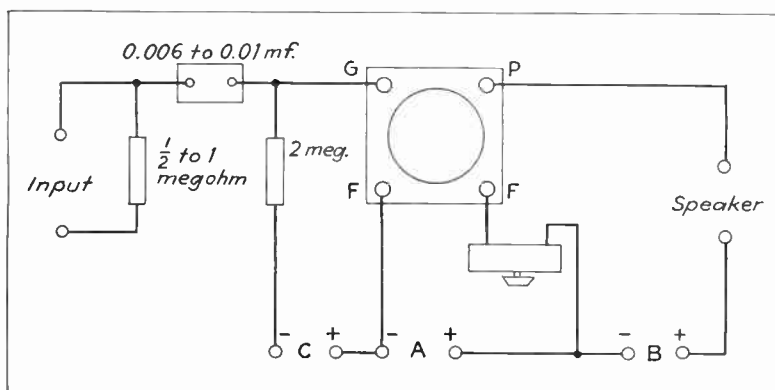


FIG. 160.    Audio amplifier, resistance coupled.
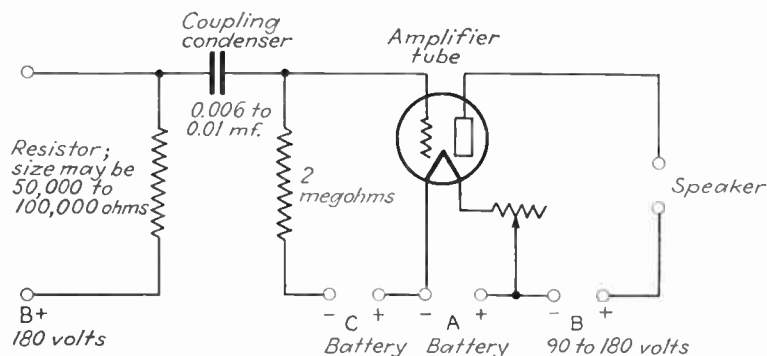


FIG. 161.    Audio amplifier, resistance coupled. See any standard tube chart for C bias voltage.

one a fixed resistor of 50,000 to 100,000 ohms and the other a 2-megohm grid leak (see Fig. 161). The fixed coupling condenser has from .006 to .01 microfarad capacity.

*Filament Circuit and Plate Circuit.* Wire the filament and plate circuits, as shown in Fig. 161.

**How to Operate the Set.** This amplifier is in operation when the A battery and B batteries are connected. There are no adjustments to make on this set. Use a type 01A tube when earphones are connected to the amplifier. Use type 71A for a speaker. Find the proper bias voltage from any standard tube chart.

**Advantages and Disadvantages.** The high resistance used in the detector plate circuit of this amplifier makes it necessary to have a high B voltage. For a type 01A tube you need 180 volts on the detector plate for resistance coupling, where 45 volts would do with transformer coupling.

No audio howls occur in the resistance-coupled amplifier, since there is no feedback from the transformer. The greatest advantage of this type of amplifier is that signals of a very good quality are obtained when it is used. There are no transformer losses in this circuit. However, the amplification is not high, being about $1\frac{1}{2}$, while with the transformer coupling a high amplification may be had.

Three resistance-coupled stages are needed to equal the output of two transformer-coupled stages.

Noninductive resistors must be used in this amplifier. Carbon resistors are satisfactory. The coupling resistance should be twice the plate impedance of the tube. If the coupling condenser is too small, below .006 microfarad, the bass notes will be weakened or cut out. A larger size may be used if several stages of resistance coupling are to be used; the same size condenser will do for each stage. This condenser must have good insulation, since leakage will destroy its efficiency. Current leaks through the condenser will affect the bias of the amplifier tube and will cause distortion.

"Motorboating" in a resistance-coupled amplifier is caused by a power supply with poor voltage regulation. This means that the power supply is overloaded, causing a fluctuating plate voltage. Motorboating is not noticeable with a one-stage amplifier but is bothersome when several stages are used. A B battery will stop the trouble, or a power supply which has very good regulation will stop it.

**Why It Works.** *The Coupling Resistor.* Electrons on the way from the detector plate in Fig. 162 to the B battery
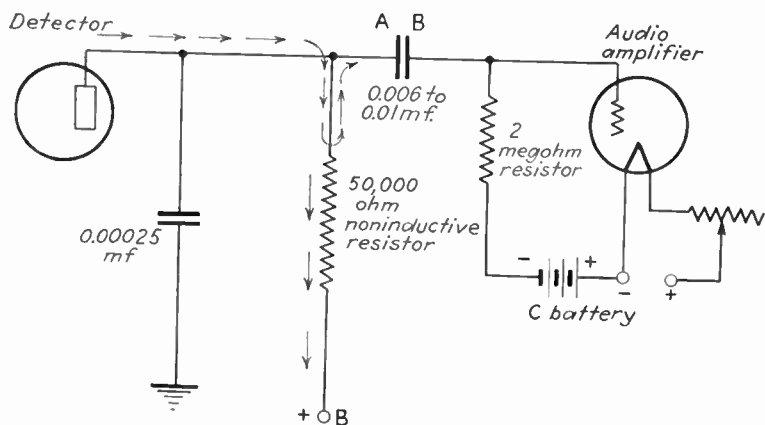


FIG. 162.   Operation of resistance-coupled amplifier.

are held back by the high resistance of the coupling resistor. The resistance here is steady. Surges from the detector tube, which cannot rush through the resistor, instead collect on the coupling condenser and the by-pass condenser. Surges on side *A* of the coupling condenser drive surges from side *B* to the amplifier-tube grid. The condenser capacity is large enough to allow all audio frequencies to get to the amplifier-tube grid.

This type of coupling produces signals of good fidelity, since the back pressure caused by the resistor is steady.

### Questions

**1.** Compare the quality of signals from a transformer-coupled amplifier with that from a resistance-coupled unit.

**2.** Compare the amount of amplification in the two types of amplifiers.

**3.** Compare the size of the coupling resistance with the plate impedance of the tube.

**4.** What effect does a coupling condenser which is too small have upon the quality of signals?

**5.** What is the cause of motorboating in these amplifiers?

## 6. THE TUNED RADIO-FREQUENCY AMPLIFIER

**The Limits of Audio Amplification.** In the effort to get louder signals we have added audio amplifier stages. We could use not more than three or four stages of audio-frequency amplification because the tube, battery, and circuit noises are amplified as well as the signals. This background of noise that cannot be tuned out and through which we cannot hear signals is called the noise level.

There are stations that we would like to hear that are still beyond our reach with all of this audio amplification. We can increase volume of sound in the audio stages, but we cannot increase the sensitivity of the set, nor can we change the selectivity by audio amplification.

**Why Not Amplify the Aerial Currents?** Let us turn our attention to the weak radio-frequency aerial currents that are fed into the detector set. If we could build up the strength of these signals before they reach the detector, we would increase the sensitivity of the set. We could hear and use the signals that had been too weak to understand.

From our study of the detector set we know that the vacuum tube will amplify signals fed into the grid circuit. We know that if we adjust a tube correctly the signal in the plate circuit is increased in strength but not changed in wave shape. This is the amplifying property of the

tube. We know that this is true with audio-frequency signals going through the tube.

Now we shall build one or two stages of radio-frequency amplification to amplify the weak signal voltages picked up by the aerial. These greatly strengthened signals now go through the detector and are again greatly amplified in the audio stages. By properly adjusting the voltages of the tube circuits we get an amplified signal that has not been distorted or changed in shape in passing through the radio-frequency amplifier circuits.

One stage of radio-frequency amplification amplifies the signal strength about as much as the regenerative detector. Two radio-frequency stages will increase the signal about as much as one audio stage.

**Advantages of Tuning Radio-frequency Stages.** By tuning the amplifier circuit, we not only can increase the strength of the signal but we can pick out the signal we want to get. This kills the unwanted signals where they are weakest in the circuit. We not only get better selectivity but also better volume of the signal that does get through. Untuned radio-frequency amplifiers build up atmospheric, tube, and circuit noises with little gain in the strength of the signal. They are not as desirable as the tuned amplifier.

One or two radio-frequency amplifier stages improve reception from both distant and local stations. It is easier to select the signals from several local stations. These signals are often strong enough to force their way through a detector tuning circuit. The radio-frequency stages help to tune out these stations. Distant stations of extreme weakness are amplified until they are strong enough to be heard clearly.

**Disadvantages of the Radio-frequency Amplifier.** There are more tubes to get out of order, more batteries to cause

noises, and more wiring to cause feedback troubles. More B battery power is needed. This is another disadvantage although the same batteries may be used for the whole circuit. There are one or two added sets of controls to adjust. Tuning is somewhat more critical.

More care in wiring is necessary since any noise from loose connections is amplified and adds to the noise level.

Two stages of radio-frequency amplification are enough for ordinary purposes using type 01A tubes. More than this are too difficult to neutralize.

### How to Build the Set

Fasten the parts to the base as shown in Fig. 163.

The transformer has 20 turns on the primary and 60 turns on the secondary. This is the same coil we have used in the detector set.

The variable condenser is a 23-plate 500-micromicrofarad condenser.

### How to Wire the Set

**The Aerial Circuit.** Wire the set as shown in the circuit diagram in Fig. 164.

Connect the rotor of the condenser to the A negative wire. Keep all wires of the tuning and the grid circuits under 4 inches in length to keep the set from oscillating and howling or squealing.

### How to Operate the Set

**Wire the Battery Circuits.** *The Filament Circuit.* Put a type 01A tube in the socket. Attach the wires for the A battery to the A binding posts.

*The Plate Circuit.* Use 90 volts from the B battery. Connect wires from the B posts to the B battery.

Connect the output posts of the board to the aerial and ground posts of the detector set.
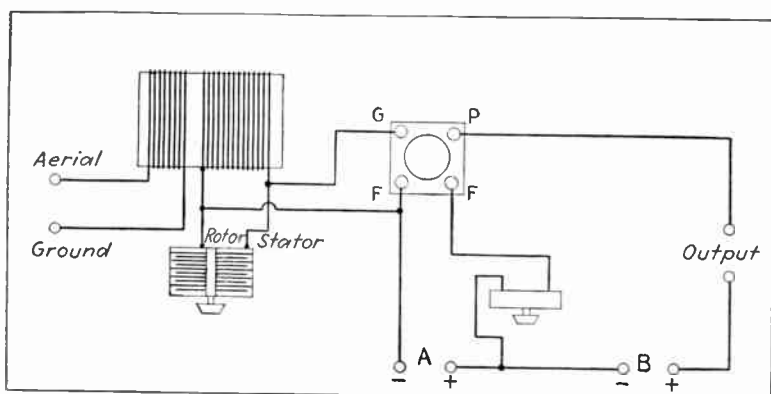


Fig. 163.    Tuned radio-frequency amplifier.
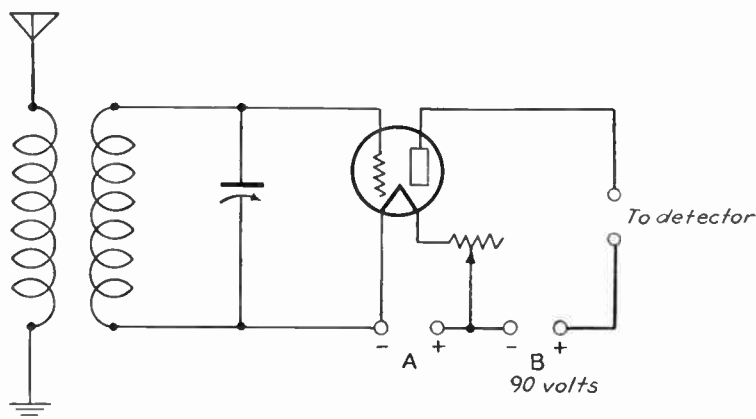


Fig. 164.    Tuned radio-frequency amplifier.

Check to see that the B positive battery post connects to the plate of the tube through the primary of the coil on the detector set.

**How to Tune the Radio-frequency Amplifier.**    Light both tubes.    Adjust the filament voltages.

Tune the detector and the amplifier together for the first rough tuning. The settings for any station should be about the same on both dials. It will be found that the amplifier dial will turn somewhat faster than the detector dial. When the station is first heard, adjust the detector set for the loudest and best signal.

Now tune the radio-frequency amplifier for the loudest signal. Retune both the detector and the amplifier by making a last fine adjustment. This must be done since tuning one set affects the other somewhat.

The rheostats will be found to have some influence on the tuning of both sets since their setting affects the heat of the filament and changes the position of the signal on the characteristic curve.

### Why It Works

When a radio wave strikes the aerial, it sets up a current in the aerial-ground circuit which flows through the primary of the radio-frequency transformer. The many different frequencies flowing in the aerial circuit are transferred to the secondary tuning circuit by induction. These currents are extremely weak. Only a few microamperes or millionths of an ampere flow in the tuning circuit.

When you tune the secondary circuit, you select one radio-frequency current flowing in the aerial circuit, and it is amplified and passed on to the detector circuit much stronger than the original aerial current.

If the tube and circuit are correctly wired and the voltages are adjusted correctly, the wave form of the current in the plate circuit is the same as the wave form of the current in the grid circuit, but the plate wave is much stronger than the wave on the grid.

Amplification occurs only at radio frequency in the radio-frequency amplifier tube.

The increase in signal strength comes from the power supplied by the B batteries in both the radio-frequency amplifier stage and in the detector plate circuit.

### Questions

**1.** Compare the voltage changes on the grid of the detector tube when it is operated by the aerial and when it is operated by one stage of radio-frequency amplification.

**2.** Compare the voltage changes on the grid of the radio-frequency amplifier with the changes on the grid of the detector tube which is connected to this amplifier.

**3.** Compare the size and wave shape of the radio-frequency currents which flow in the aerial with those of the currents which flow in the plate circuit of the radio-frequency amplifier.

#### 7. NEUTRALIZING RADIO-FREQUENCY AMPLIFIERS

**Radio-frequency Stages Cause the Set to Squeal.** In operating the direct-current receiving set with one stage of radio-frequency amplification ahead of the detector, trouble may be noticed from squealing which is difficult to control. The squeal will sometimes be heard when tuning the radio-frequency and detector stages to resonance with some desired station. At other times this squeal builds up with no apparent reason.

But when two or more stages of radio-frequency amplification are added ahead of this detector, the problem of controlling this squealing becomes acute, and something must be done about it. This squeal is often so bad that signals cannot be received at all.

**Reasons for the Squeal.** There are several causes for this audio-frequency squealing. The wires in the radio-frequency amplifier circuit may be long enough to pick up the magnetic fields set up by radio-frequency currents flowing in other parts of the circuit. If this coupling

between the two circuits is strong enough it will set up the audio oscillation or feedback which causes the squealing.

Another reason for squealing is the capacity between the plate and grid of the type 01A tube.  This capacity is extremely small (8 micromicrofarads), yet it is enough so that changes of voltage in the plate circuit influence the grid of the tube.  The feedback from the plate to the grid causes the audio oscillation or howl that is so annoying.

**Methods of Stopping the Squeal.**  This squeal cannot be tuned out.  Good circuit arrangement and placing of wires helps to cut it down.  Shielding will not stop this audio-frequency squeal in the radio-frequency stages.  A small suppressor resistor placed in the grid circuit of the offending tube will stop the radio-frequency squealing. But the resistor cuts down the gain in signal strength from that radio-frequency stage.

The only satisfactory way to kill the squeal is to neutralize the effect of the voltage fed back from the plate to the grid circuit with an opposing voltage of equal strength, using one of several methods.

**Neutralizing Methods.**  The fundamental feature of each of the three methods that we shall use depends on picking up electron surges from either the plate circuit or the grid circuit which are traveling in opposite direction to surges in the other circuit.  The surge is wired back to the other circuit so as to oppose and neutralize the surge fed back through the tube.  A small variable condenser controls the amount of neutralizing voltage accurately.  The small condenser in effect is the same size as the plate-grid "condenser" in the tube, but is opposed to it.

Circuits shown here are used not only for neutralizing tubes in the radio-frequency stages of receiving circuits but also later in neutralizing tubes used in transmitting circuits and in phone circuits.

## Construction and Wiring of the Neutralizing Circuits

Circuit A.    *The Grid-circuit Method—End Tap* (Fig. 165).
This circuit probably is the handiest to build and the easiest
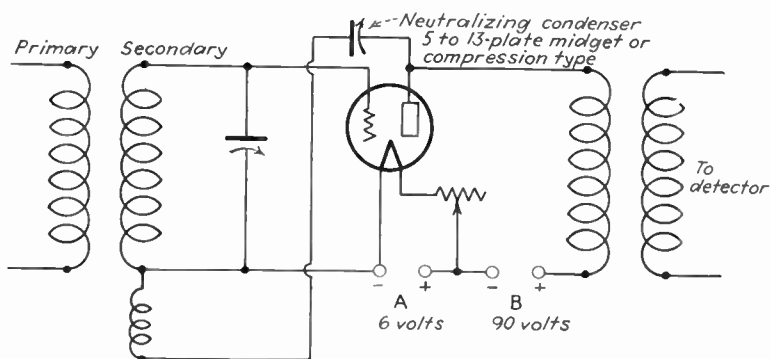


Fɪɢ. 165.    Circuit A; neutralizing radio-frequency amplifier by end tap on
grid coil.

to make work.    Add from 10 to 20 turns of wire on the
ground end of the grid coil of the tube to be neutralized.
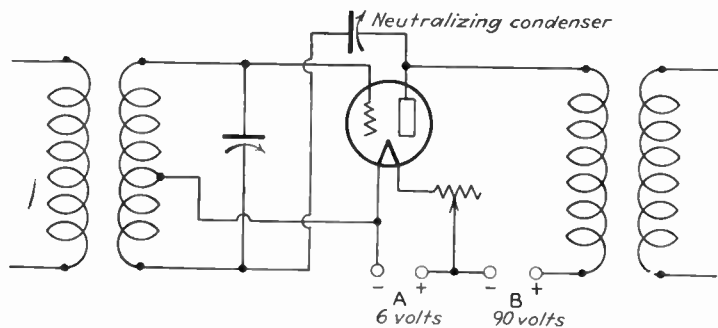


Fɪɢ. 166.    Circuit B; neutralizing radio-frequency amplifier by center tap on
grid coil.

From the end of this added coil, run a wire to the neu-
tralizing condenser, then to the plate of the tube.

**Circuit B.** *Another Grid-circuit Method—Center Tap* (Fig. 166). In this circuit the grid return wire is connected to the center tap of the grid coil of the radio-frequency tube to be neutralized. The neutralizing condenser is connected in series with the ground end of the secondary coil and the plate of the tube. No change is made in the rest of the circuit.

**Circuit C.** *The Plate Method—End Tap* (Fig. 167). In this circuit the neutralizing voltage is taken from the plate coil of the tube to be neutralized.
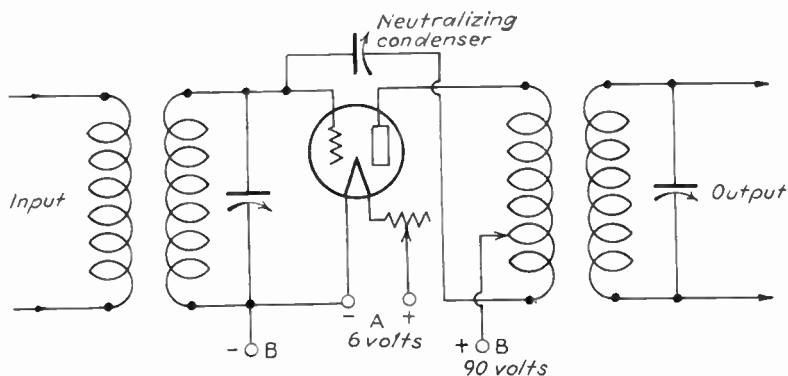


FIG. 167. Circuit C; neutralizing radio-frequency amplifier by tap on plate coil.

Run a wire from the end of the plate coil to the neutralizing condenser and on to the grid of the radio-frequency tube. Connect the B positive lead to a center tap on the plate coil. The neutralizing condenser is a midget condenser of from 3 to 13 plates.

**Kinds of Neutralizing Condensers.** Several kinds of neutralizing condensers are used. For experimental sets where many adjustments are to be made, the 3- to 13-plate midget is used. The small compression-type condensers used for neutralizing commercial broadcast receivers are better for a set where few changes are to be made. These

condensers are made of two small curved metal plates separated by a sheet of mica. They are adjusted by a screw which pulls the plates together.

Still another type of condenser is made of a piece of No. 14 wire over which about a 3-inch piece of spaghetti tubing has been slipped. A copper or brass tube is pushed over the spaghetti to form the other plate of a small condenser. The capacity of this condenser is adjusted by moving wire in or out of the tube.

**Wiring the Circuit.** Wires connecting the neutralizing condenser to other parts of the circuit carry radio-frequency currents and should be placed so as to have the least amount of feedback to the circuit. Keep the wires away from other circuit wires, condensers, coils, and tubes. Place the wires at right angles to the other parts of the circuit.

### Questions

1. Give two reasons why radio-frequency amplifiers often squeal while being tuned.

2. Make a list of possible methods for stopping this squeal.

3. Examine the diagram for the end-tap–input-circuit method of neutralizing the condenser effect of the grid and the plate. Show how the end-tap method picks up surges which oppose and kill surges fed back to the grid circuit by the capacity of the grid-plate condenser. (See Fig. 165.)

4. Examine the center-tap method and show how it picks up a current that opposes the grid-plate current.

5. Examine the end-tap–output circuit to find out how it picks up a current to oppose the grid-plate current.

6. In all of these methods how do you control the neutralizing current to make it the same as the capacity of the grid-plate condenser?

## How to Neutralize a Radio-frequency Amplifier

When there are several stages of radio-frequency amplification, each stage must be neutralized separately. The set

is tuned to the highest frequency it will receive. This is the station having the shortest wave length that will be received on this set.

Here are the steps in neutralizing a radio-frequency circuit. Each tube is neutralized separately by this process:

*Step* 1. Turn on the filaments of both amplifier tubes and the detector tube. Tune in a station that is weak but clear.

*Step* 2. Pull out the radio-frequency tube to be neutralized and place a piece of paper under the filament prong. If the type of socket used will not allow this to be done, turn off the filament rheostat. This will produce the same result. Push the tube back in the socket.

*Step* 3. Turn the neutralizing condenser slowly back and forth. Listen for a sudden drop or decrease in the strength of the program or signal in the phones. Tune slowly on both sides of this point until the position where the lowest volume of signal heard is accurately found.

*Step* 4. Remove the paper under the filament prongs or turn up the rheostat to light the tubes. The station will now be heard without the squeal. The adjustment of the neutralizing condenser is now correct. This radio-frequency tube is said to have been neutralized.

### Question

1. Explain briefly how to neutralize a radio-frequency amplifier.

### Technical Terms

**aerial coil**—The coil connected in the aerial-ground circuit.

**amplification**—The process of increasing the strength of signals.

**audio transformer**—A step-up transformer used to couple detector and audio-amplifier circuits.

**detector**—As used here, a vacuum-tube circuit used to convert radio-frequency pulsations into audio-frequency pulsations which will produce sound in the phones.

**gain**—A word used to mean amplification.

**grid bias**—A steady pressure of electrons kept on the grid.

**grid return**—A wire connecting the end of the grid coil to the filament circuit.

**grid coil**—The coil connected to the grid of the tube.

**grid condenser**—A .00025-microfarad fixed condenser connected in the grid wire.

**hand capacity**—There is enough capacity or condenser effect in the body to change the tuning of a regenerative set.

**impedance coupling**—Transferring energy between circuits through a condenser–choke-coil circuit.

**neutralization**—The process of balancing the capacity of a small condenser to equal the grid-plate capacity of a tube in order to prevent oscillation and squealing.

**oscillation**—The surging of a current back and forth in a circuit. Generally refers to a condenser-coil circuit.

**plate coil**—The coil connected in the plate circuit.

**pulses**—Changes in strength of a direct current, as in a pulsating direct current or as in the alternating-current component of a direct-current.

**regeneration**—A process of feeding energy from the plate circuit back to the grid circuit to increase the volume of the signals.

**resistance coupling**—Transferring energy between circuits through a resistor-condenser circuit.

**shielding**—A grounded piece of metal placed between the control knob and the set in order to prevent hand capacity from affecting tuning.

**surges**—The progressive electron motion along the wire caused by an alternating current.

**transformer coupling**—Transferring energy from one circuit to another by means of a transformer.

**voltage regulation**—A power supply whose voltage drops when connected to the plate circuit has poor regulation. When the voltage remains nearly steady, the regulation is good.

**zero beat**—A point where an oscillating receiver is adjusted to resonance with an incoming signal. At this point no carrier whistle is heard.

# CHAPTER VI

## PHONES AND SPEAKERS

In all of the radio sets we have studied so far, we have used earphones to hear the music or other signals picked up by the set. We have used earphones because in many of these sets the sounds were weak and earphones fit snugly on our ears and keep out unwanted noises.

But now that we are acquainted with circuits and understand how to assemble and operate more powerful sets, we are ready to discard the phones for speakers. We cannot use the phones in sets having much over three tubes, because the phones will not handle the current. The sounds will be unpleasantly loud.

So now we shall learn the principles of the operation of both the magnetic and the dynamic speakers and how to use them.

### Contents of This Chapter

1. New Symbols Used in This Chapter
2. Earphones Used for Radio Reception
3. Magnetic Speakers
4. The Dynamic Speaker

### 1. NEW SYMBOLS USED IN THIS CHAPTER

These symbols are shown in Fig. 168 (page 262).

type 80 tube—A rectifier tube used in the power supply.
output transformer—A step-down transformer used to couple a power tube to a speaker.

261

PICTURE                              SYMBOL

Type 80 tube

Output transformer

Dynamic Speaker

Cone

Field
coil

Voice
coil

Spider

Frame

Cross Section
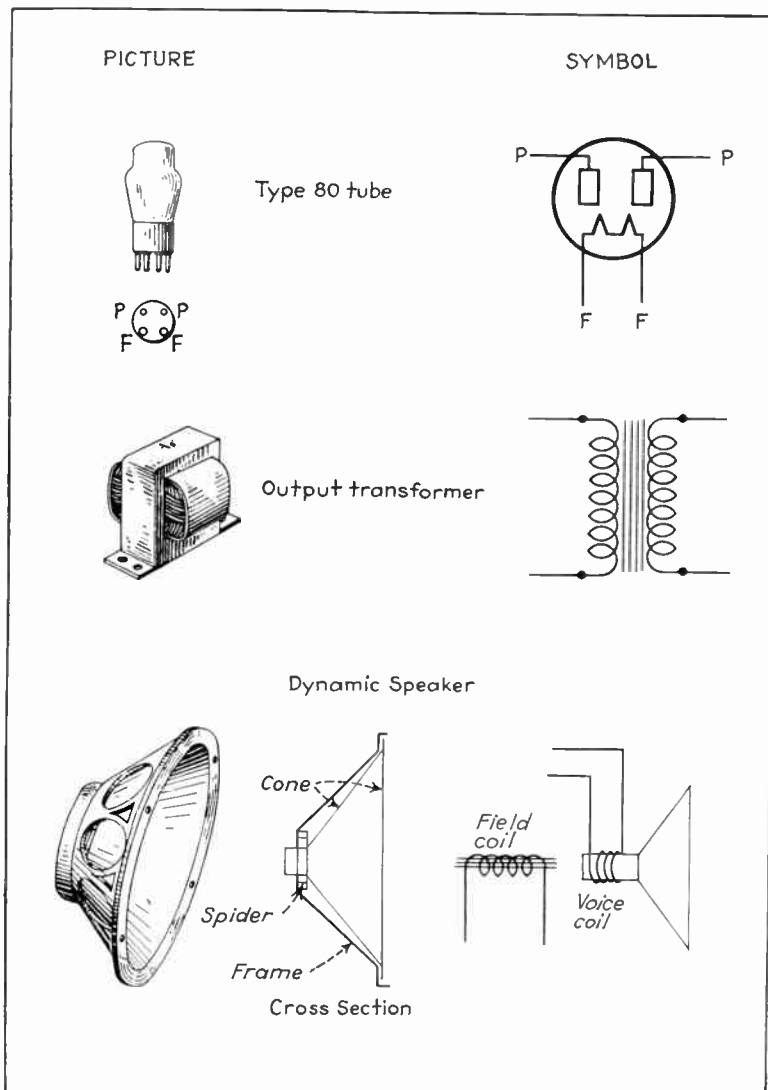
FIG. 168.   New symbols used in Chapter VI.

**dynamic speaker**—This shows the cone, the field coil, and the voice coil of the dynamic speaker.

## 2. EARPHONES USED FOR RADIO RECEPTION

### Steel-diaphragm Earphones

The metal-diaphragm type of earphone is used more for reception of code than for receiving voice or music. The quality of voice and music produced by an earphone is not as good as that produced by a speaker.

Rochelle-salts crystals make high-fidelity earphones used to test the quality of signals at broadcasting stations.

**Construction of the Earphone.** Take the receiver apart to find out how it is made (see Fig. 169). The hard-rubber cap comes off first. Next you take off the thin steel dia-



Fig. 169. Earphone.

phragm. Inside the case you will notice two small spools of very fine wire wound on steel cores or pole pieces.

The diaphragm is held on the case with considerable force by the magnetism of the steel poles on which the coils are wound (Fig. 169). The pole pieces are permanent magnets made of hardened steel. Their purpose is to keep the diaphragm under a light steady pull. The curved metal piece in the bottom of the case connects the pole pieces to form a U-shaped magnet which acts more uniformly than two single magnets.
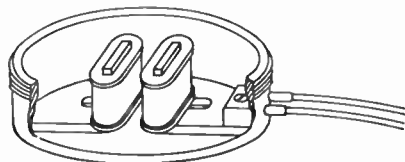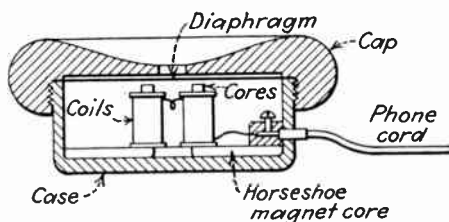
Small electromagnet coils wound with hundreds of turns of very fine wire are mounted on the ends of the iron core. The space between the diaphragm and the core ends is about .002 inch. The closer the diaphragm can be placed to the poles without touching them, the greater is the response of the diaphragm.

Fine modern phones use a permanent magnet made of a metal that collects many more lines of magnetic force than other metals before reaching the saturation point.

### Questions

1. Name each part of the headphone as you take it apart.
2. What is the cap or earpiece made of?
3. What is the composition of the diaphragm?
4. Why wouldn't a hard rubber diaphragm be just as good?
5. What is the composition of the magnet?
6. Is the magnet a temporary or a permanent magnet?
7. Is the diaphragm bent or pulled in slightly when no signals are being sent through the phones?
8. Make a drawing of a phone showing the wiring or path of the electricity as it flows from the cord through the phones and back to the cord again.
9. Make a list of things that might go wrong with a set of headphones.
10. Touch the tips of the phone cord together or tap the tips against the tongue; a sound will be heard. The phones are sensitive enough to produce a sound from the very weak current produced by the contact of the tips with each other or with the tongue.

**How to Operate the Earphone.** Connect the earphone to the phone posts of a set. When the set is turned on, the phones are in operation.

Connect the tip of the red or striped cord to the B positive side of the circuit. This will prevent B-battery current from gradually demagnetizing and shortening the useful life of the phone magnets.

Check to see if the phones are connected correctly when used on the detector or audio circuits. If reversed, the magnetism from the plate current opposes the magnetism of the permanent magnet cores and weakens the signals.

You can use earphones on any one-tube detector set or on a set using a detector and one stage of audio amplification. The phones should not be used on any set in which the tube in the last amplifier stage draws over 10 milliamperes of current. The current through the phones is the plate current flowing through the tube to which the phones are connected. You can find this current on a tube characteristic chart. More plate current flows through the phones when the plate voltage is increased.

**Why Earphones Work.** The changes of strength of plate current flowing in the detector or the amplifier circuit cause the motion of the diaphragm which produces sound.

The diaphragm must bend rapidly in and out near the pole pieces to force air out of the hole in the cap in the form of sound waves. The plate current from the receiving set flows through the coils of fine wire around the poles and makes the coil an electromagnet.

The pull on the diaphragm will be stronger when many turns are used or when a greater current flows.

Small wire is used to get many turns in a small space. Many turns of wire are needed in order to use all of the weak plate current to move the diaphragms.

The number of turns of wire which can be used effectively to produce sound is more important than the resistance of the magnets. A current will generate more magnetism when it flows through a coil of many turns of wire than when it flows through a coil having a few turns of wire.

When a strong current flows through the coils, it produces a strong pull on the diaphragm. When a weak

current flows, it pulls the diaphragm only a little way toward the poles.

The rapidly pulsating direct current that flows through the coils moves the diaphragm. The rapidly changing vibrations of the air are what we hear as sound. These air vibrations are as slow as about 20 cycles a second and as fast as from 15,000 to 20,000 cycles a second.

Phones receiving code signals operate best at a frequency of 1000 cycles a second. Other unwanted noises and sounds have a frequency of around 200 cycles a second. The phones operating at 1000 cycles a second bring out the code and diminish the static and unwanted noises. The noise background is reduced in this way.

The permanent magnet cores are used in phones to cause the diaphragm to respond faithfully to the electrical surges flowing through the magnet coils. The permanent steel magnet keeps the diaphragm under a steady pull. The effect of these permanent magnets is to make the phones more sensitive.

Poor-quality or old receivers lose the magnetism of the pole pieces and are no longer sensitive. The poles may be remagnetized to restore sensitivity to the phone.

Receivers used for ordinary telephone service in the home or office respond to frequencies of from 200 to 400 cycles.

### Questions

1. Which are more satisfactory for the reception of code signals, earphones or speakers?

2. Should the diaphragm be placed close to the poles of the electromagnet?

3. What harmful effect comes from connecting the striped phone cord to the B negative side of the set?

4. What is the maximum number of milliamperes of current which should be put on a set of earphones?

5. Most static and unwanted noises in a code set have a frequency of about how many cycles per second?

**6.** What is the advantage of having earphones which operate best at about 1000 cycles a second?

**7.** Why are permanent magnets used for the cores of the electromagnets in earphones instead of temporary magnets?

## Balanced-armature Earphones

An improved type of phone which overcomes some of the difficulties of the common earphones uses a mica diaphragm operated by a balanced armature in place of the steel diaphragm of the common type of earphone.
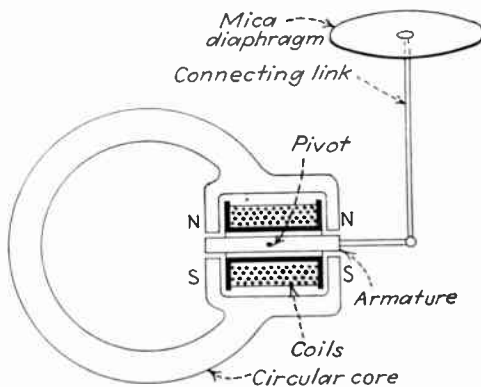


FIG. 170.  Balanced-armature earphone.

**Construction of the Magnet and the Armature.** *The Cores.* A heavy circular core is used in this phone. Two U-shaped cores are attached to the ends of the main core (see Fig. 170). This arrangement provides two magnetic paths between the ends of the U-shaped core.

The electromagnet coils are wound inside the U-shaped pole pieces attached to the ends of the heavy circular permanent magnet (see Fig. 171).

*The Armature.* A magnetic armature is balanced on a pivot between the pole pieces inside the coil. The ends of the armature are in the two magnetic paths between the ends of the U-shaped cores.

*The Diaphragm.*    The diaphragm in this phone is a thin
sheet of mica.   A wire connecting rod runs from one end of
the balanced armature to the center of the mica diaphragm.
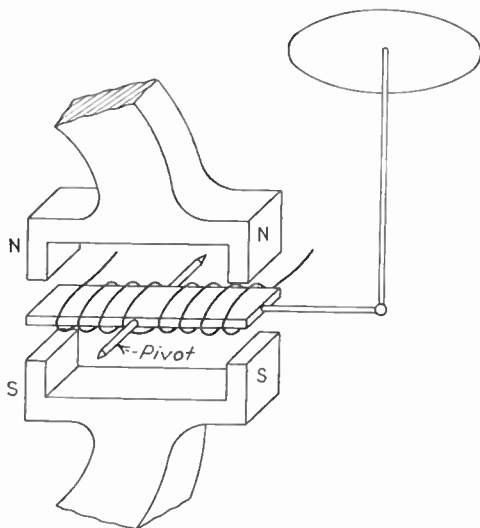


Fig. 171.    Enlarged view of armature, winding and magnet poles.

**How to Use the Phones.**    Use the balanced-armature
phones in the same way you would use a magnetic earphone.
Connect these phones to a one-, two-, or three-tube set.
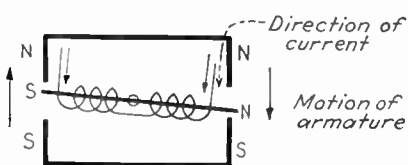


Fig. 172.    Motion of a balanced arma-
ture.

These phones should not
be used on sets that have a
power audio-amplifier
stage, as this overloads the
windings.   If overloaded,
the windings of the phones
will either be burned out
or excessive vibration will damage the moving parts of the
phone.

**How It Works.**    When a current flows through the
armature coil it makes one end of the armature magnetically

north and one south. This causes the diaphragm to move as shown in Fig. 172. When current flows through the magnet coils, it produces a double motion of the armature. This moves the mica diaphragm and produces louder signals from the same amount of energy flowing through the coils than does a steel-diaphragm earphone.

Mica is used for the diaphragm because it has a low resonant frequency. The resonant frequency of an iron diaphragm is near 1000 cycles. Whenever a current surging at 1000 cycles a second flows through the coils, the iron diaphragm is just heavy enough and large enough to vibrate strongest at this frequency. This means that the loudest sounds are produced at or around 1000 cycles per second. But sounds produced at frequencies above or below the resonant 1000-cycle frequency are not as loud. This produces music or speech that does not sound true; or, as radio technicians say, "The music has poor fidelity."

The resonant point of mica diaphragms is at a lower frequency than for iron diaphragms. This resonant frequency seldom occurs in musical sounds. Therefore, the mica-diaphragm phones produce music of better fidelity over a larger range of frequencies than do iron-diaphragm phones.

### Questions

1. Describe the core in a balanced-armature earphone.
2. Should these earphones be used on a power audio amplifier?
3. Why is mica used for the diaphragm in this type of earphone?

### 3. MAGNETIC SPEAKERS

**Simple Type of Magnetic Speaker.** A simple kind of loud-speaker is one made by placing a horn on a metal-diaphragm earphone to increase the loudness of the signals. In old radio catalogues you will see phones of this type offered for sale. Such earphones make the poorest kind of speakers. They produce signals of poor quality.

Horns were attached to the earphones in an effort to make them produce sounds of greater volume. Many interesting types of horns were developed. It was found, however, that a paper cone would produce better and louder music than a good horn.

Harmonics of the resonant frequency common in metal-diaphragm earphones are done away with in the cone speaker. Pressure between the diaphragm and the inside of the cap in the phones, which affects the signal quality, does not occur. Present-type magnetic speakers are only a refinement of this basic type of speaker.
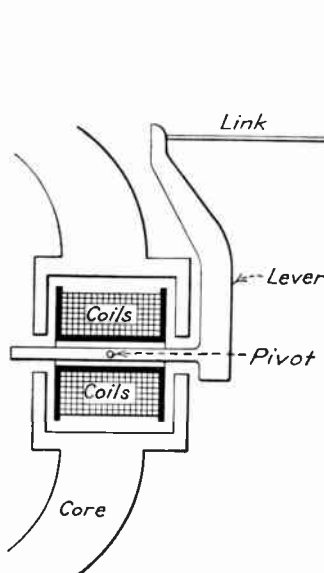


Fig. 173.   Magnetic speaker with balanced armature.

## Construction of Magnetic Speakers

The Magnets. Heavy horseshoe magnets are used in the magnetic speaker. The magnets can be large because they need not be built into a small space as in a watchcase type of earphone (see Fig. 173).

The Armature. A balanced armature is used as in the balanced-armature phones. The armature is connected to a bar to which the cone is also attached.

The Cone. A paper cone is suspended in a metal frame. The rim of the cone is cemented to the frame. Corrugations pressed into the rim of the cone permit the cone to

move freely and prevent any vibrations from the frame reaching the cone.

Chamois edges, used in some speakers, allow too much motion of the cone. This blends high and low frequencies and produces music of poor quality. Rubber compounds used for this flexible edge deteriorate, stiffen, and retard the motion of the cone. A leather edge is better. It does not age, and the speaker tone remains good. High-fidelity speakers used corrugated edges.

Holes are punched in the metal frame to allow free passage of air waves set up by the back of the cone.

## How to Use Magnetic Speakers

Connect a magnetic speaker as you would connect a pair of earphones. Connect it directly to a type 01A, and a type 71A tube. The plate current of none of these tubes is over 10 milliamperes in the power amplifier stage. If the amplifier-tube plate current is over 10 milliamperes in the power amplifier stage, the current will damage the speaker. An output transformer must be connected between the amplifier and the speaker when over 10 milliamperes of current flows in the plate circuit of the power audio-amplifier tube. Use an output transformer after a type 45 or a type 47 tube.

## How It Works

**How Motion Is Produced.** The operation of the balanced armature is the same as in the operation of the balanced-armature phones. Current flowing through the coils of the magnets moves the armature. Every motion of the armature produces a greater motion of the cone because of the lever to which the link the armature and the cone are connected (see Fig. 173).

**How the Cone Produces Sound.** When the cone moves outward, it pushes the air near the cone outward. This produces a compression in the air which travels away from the cone. When the cone is pulled back, the air is momentarily rarefied. The alternate compression and rarefaction of the air produces a sound wave.

## The Speaker Baffle

The horns once used on speakers were to concentrate and to direct sound waves so as to get the greatest effect from them. You can notice this effect by cupping your hands over a phone receiver. The sound is louder. Use a cardboard horn in place of your hands; and the sound will be still louder.

In the cone speaker the vibrations of the paper cone set air in front and in back of the cone in motion. Air waves started by the back of the cone mix with those from the front of the cone. The air waves from the back of the speaker cone may be absorbed and killed by a thick padding of felt or other sound-absorbent material, as is often done in speakers used in public address outfits where tremendous power is available to produce the sound. But in most receiving sets it is more economical to use the energy in the air waves from the back of the cone to build up the volume of the sound from the speaker. The sound waves that travel around the cone from the back and meet those from the front of the cone must be "in phase" when they mix so they will add and produce stronger sounds than could be produced by either wave alone. To be in phase the compressed part of the air wave from the front of the cone and the compressed part of the wave from the back of the cone must meet and mix at the same instant. Such a combined or mixed sound wave will be stronger than the original wave from either the front or from the back of the cone. If, instead, the air in one of the waves is rarefied,

then the combined sound will be weak. If we can make the distance from the back of the cone to the front of the cone correct, air waves from the front and from the back will mix in phase and will produce strong clear signals. We can do this with a baffle (see Fig. 174).

A baffle is a flat board or an open-backed box (often the radio cabinet) to which the speaker is attached. The speaker, operating in the open air with no baffle does not produce good signals, because the low-frequency sound waves mix too soon. The distance between the front and back of the cone is too short.

The wave length of low-frequency sound waves is quite long, so the air waves must travel several feet between beats. A 4-foot baffle will permit sounds as low as 300 cycles to be produced without distortion. Baffles used in theaters are as wide as 13 feet.



FIG. 174. Baffle used on loudspeaker.

High-frequency sound waves are little affected by the baffle. They travel such a short distance between beats that the distance around the cone itself may be sufficient to prevent distortion.

## Qualities of Good Speakers

A good speaker must deliver signals as near as possible to the same frequency as the signals picked up by the

microphone at the broadcasting station. The loudness or volume of any certain frequency must not be stressed over that of any other frequency. A speaker that will produce the overtones in music has better quality than one that kills the overtones. Overtones (a tone "over the fundamental tone") and harmonics are much the same. The overtones and the harmonics give music its quality or richness. The fundamental is the basic tone that is produced. The overtones are harmonics produced by the fundamental tone. A violin, the voice, good pianos, are all rich in overtones.

As reproduced music approaches perfect reproduction of pitch and of overtones, with neither high or low frequencies stressed, the music sounds more real. A speaker that does this is said to reproduce music of high fidelity or of fine quality. A good magnetic speaker will reproduce equally well all frequencies from 200 to 5000 cycles. No frequency will be stressed, nor will the volume, or loudness, of any frequency be stressed.

### Questions

1. Compare the construction of present-type magnetic speakers with balanced-armature earphones.

2. What effect did the long horns have upon high notes in music?

3. Describe the construction of a paper cone for loud-speakers.

4. Explain how a cone produces sound.

5. Explain how to connect a speaker to an amplifier which carries over 10 milliamperes of current in the plate circuit.

6. Explain how to construct a speaker so that the sound waves from the back of the cone will reinforce the sound waves coming off the front of it.

7. What is meant by saying a speaker has high fidelity?

### 4. THE DYNAMIC SPEAKER

Neither earphones nor magnetic speakers produce signals, especially music, of better than medium fidelity or quality. The development of the cone improved the quality of the

CHESTER W. RICE AND EDWARD W. KELLOGG
These two men developed the dynamic speaker which brought new quality into
music. Here they are adjusting one of their early models.

music; but the high notes were prominent and were often quite "tinny." The low notes were missing or were weak. The volume was not great enough for large rooms or for auditoriums.

A new type of speaker, called the dynamic speaker, was developed which supplied the low tones and which was capable of producing music of great volume. It operates on an electrical principle different from that of either the earphones or the magnetic speaker. It operates as does a meter or a motor, on the fact that a wire carrying a current will move when placed in a magnetic field.

The dynamic speaker is essentially a cone moved by a small coil of wire suspended in a powerful magnetic field. The dynamic speaker produces music of fine quality. It produces the deep low tones of the organ as well as the high tones of the violin.

## Construction of a Dynamic Speaker

**The Field Coil and Shell.** A powerful magnetic field is produced by a field coil of thousands of turns of fine wire. A metal case *A* is a cup or shell with the main core *B* at its center (see Fig. 175 and Fig. 176). The field coil slips into the shell around the central iron core. The core, shell, and winding form an electromagnet.

An iron disk *C* fits over the field coil on the top of the shell. The central core *B* fits through the hole in the disc *C*, with space for the voice coil *D* to fit between the core and the iron disk.

**The Speaker Cone.** The cone, made of a light durable paper, is supported by an open metal frame. The edges of the cone are cemented to the frame (see Fig. 176). Corrugations are pressed into the paper around the rim of the cone. These corrugations on the rim of the cone have several purposes. They allow the cone to move freely and
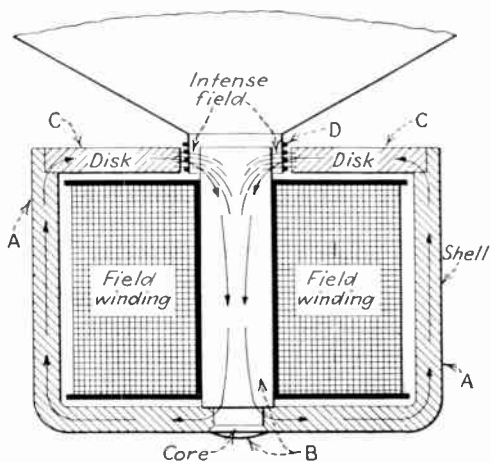
FIG. 175. Field coil and magnet.
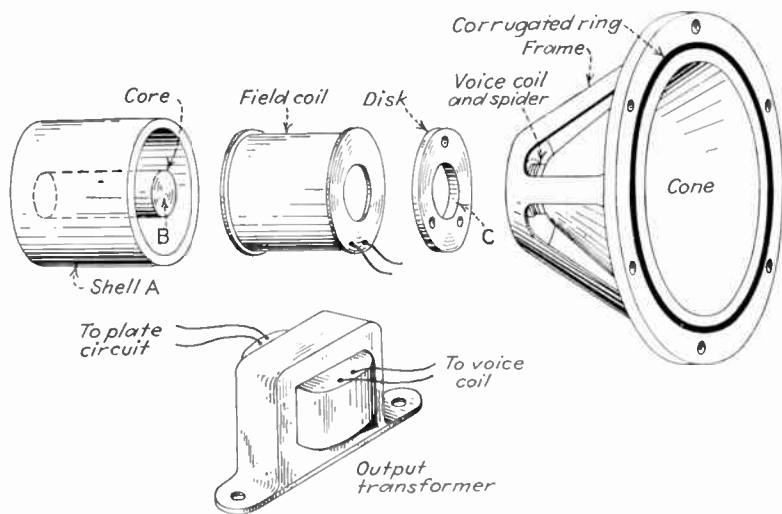


FIG. 176. Parts of a dynamic speaker.

to follow the motion produced by the weak currents flowing
through the voice coil.    They must transmit no vibrations
into the paper from the supporting frame.

The resonant frequency of the cone is lowered by the
corrugations.    A stiff, tight supporting ring stresses the
high notes.

The Voice Coil.    A few turns of wire, called the voice
coil, are wound on a small cylinder attached to the small



FIG. 177.    Spider and voice coil for dynamic
speaker.

end of the cone.    The
voice coil must be very
light, so small wire
wound closely is used
for the winding.    A
heavy coil will have a
certain resonant fre-
quency at which signals
will be extremely loud,
as was the case in the
metal-diaphragm ear-
phone.    Yet from 1 to
50 turns of wire must be
wound on this coil to carry the current from the amplifier
stage of the set.    The voice coil in one good make of speaker
is a thin flat ribbon wound layer on layer instead of wire.
Sometimes the voice coil is a single turn of copper con-
ductor.    Aluminum wire is sometimes used to keep the
weight of the coil low.

Between the cone and the voice coil is attached a center-
ing device called the spider.    It is a disk of fiber or thin
micarta punched to the shape shown in Fig. 177.    It is
made of a material that has a low frequency response.

Metal spiders are used because they do not change in
stiffness.    Rubberized spiders, once used, were poor.    As
the rubber hardened with age, it hindered the freedom of

cone vibration and spoiled the tone of the music produced by the speaker. A great improvement in tone was noticed when a new cone and spider were installed.

The spider is adjusted by three screws to center the voice coil accurately, so that it will move freely without rubbing on the core or the disk. There is only a few thousandths of an inch clearance between the voice coil
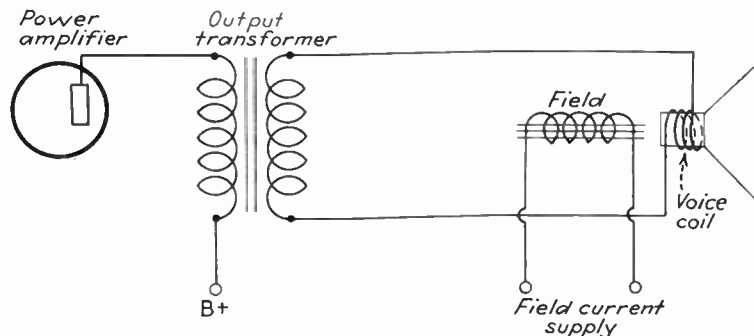


FIG. 178. Wiring diagram of dynamic speaker.

and the core, and between the voice coil and the outside iron disk.

### Questions

1. What effect does a stiff supporting ring on the cone have upon the quality of music or other signals?

2. What effect does a heavy voice coil have upon the quality of signals reproduced?

3. What was the objection to using hard-rubber spiders in dynamic speakers?

4. About how much clearance is there between the voice coil and the core?

## How to Wire the Speaker

Connect the speaker in the circuit as shown in Fig. 178. Connect the wires from the voice coil to the proper terminals on the output-transformer secondary. Instructions

for making these connections come with the speaker or with the output transformer. The output transformer generally is mounted on the speaker.

**The Source of Field Current.** *Storage Battery Field Supply.* Speaker field coils wound to operate on 6 volts have a resistance of about 20 ohms. The field winding requires about 300 milliamperes of current. They are designed to operate from a storage battery (see Fig. 179).



Switch

6 volts
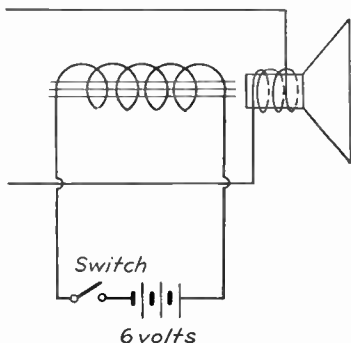
Fig. 179.   Direct-current field supply.

**Speakers Built for Use with Alternating-current Sets.** The field coil for use on alternating-current sets has a resistance of about 2500 ohms. This coil is designed to operate on 90 volts from the B supply. The speaker field coil is connected as shown in Fig. 180. It takes the place of one choke coil in the power supply. This is a popular circuit for midget receiving sets where space is small. The speaker field winding can be used as a choke coil when the current used by the set is not too great.

### Question

1. Is the field coil supplied with alternating current or direct current?

## How It Works

**The Field Coil Produces a Powerful Magnetic Field.** When a direct current flows through the thousands of turns of the field coil, it produces a powerful magnetic field in and around the coil. This field is concentrated by putting a core through the coil. A core in the shape of a horseshoe magnet will have an intense magnetic field across the small gap between the poles. If the voice coil were placed

between the ends of the cores, only part of the coil would be in this intense field.

The speaker will be more efficient if all of the voice coil is in a strong field. The core inside the coil, the shell around the coil, and the iron disk on top of the coil form a continuous horseshoe magnet entirely surrounding the field coil. A very small gap or space is left between the hole in
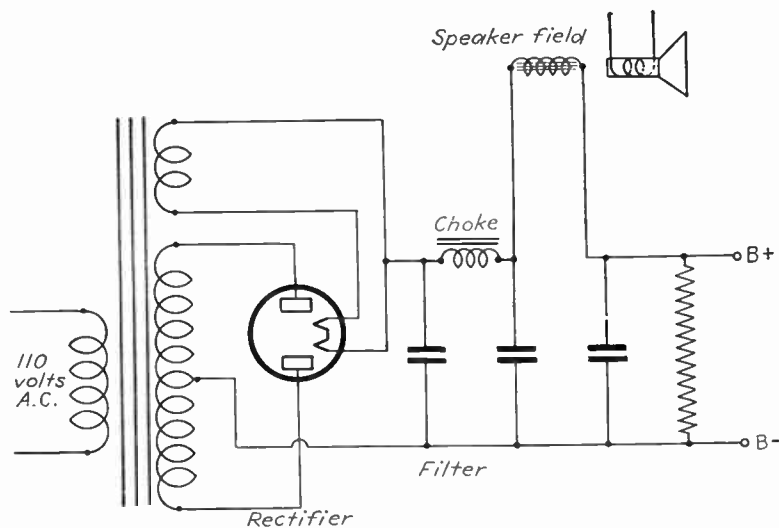


Fig. 180. Speaker field supply from the power pack; speaker field used as a choke coil.

the disk and the top of the central core. The magnetic lines of force produced by the field coil are concentrated across this small gap. The voice coil, placed in this gap, is in a powerful magnetic field, evenly distributed around all of the coil.

**What Causes the Voice Coil to Move?** When a current from the power-amplifier stages of the set flows through the turns of the voice coil, a magnetic field is produced around the voice coil.

A strong current flow will create magnetism that will
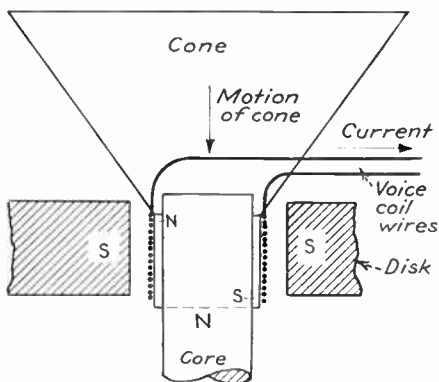


FIG. 181.   Voice coil, action.

force the voice coil either in or out of the field across the gap, depending on the direction of the current flowing through the coil. See Fig. 181 and Fig. 182.

**The Source of the Voice-coil Driving Current.** The power tube in the set can be connected directly to the voice coil.   But not enough current flows in the tube plate circuit to operate the voice coil.   Connected this way, the speaker would work very inefficiently if it would work at all.   The reason for this is that the resistance between the filament and the plate of the power tube is around 8000 ohms. The resistance of the voice coil is from 3 to 20 ohms.   To work efficiently the plate resistance of the tube and the resistance of the coil to which it is connected must be the same.
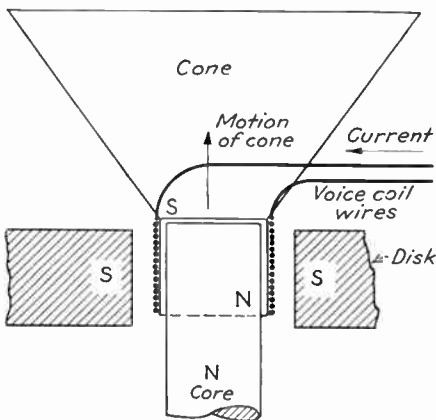


FIG. 182.   Voice coil, action.

We can make the speaker operate efficiently if we connect a step-down transformer having a ratio of about 50:1 between the plate of the tube and the voice coil.

The primary of the transformer is wound so that it has the same impedance as the plate of the tube. The secondary of the transformer is wound so that it has the same impedance as the voice coil. This transformer is called an output transformer. A special output transformer must be used which fits the voice coil and the plate of the tube in the circuit in which it works.

**Why the Tube and Transformer Resistance Must Be the Same.** *Condition* 1. *When the Primary Has a Low Resistance.* A low-resistance primary cannot use much of this varying current to induce a current in the secondary, because a low-resistance primary has few ampere turns.

Energy in the pulsating current flowing through the primary is used to induce a current in the secondary. Since there are few turns in the primary, little energy is transferred from the tube to the secondary, and the voice coil receives but little current. The signal is weak.

Much energy is available in the B battery and under control of the tube, but this type of transformer is not using the energy. The maximum current possible flows through the tube, but the transformer primary cannot use it at all to produce a current in the secondary.

*Condition* 2. *When the Primary Has More Resistance Than the Resistance of the Tube.* A given B voltage can only pull so much current through the tube. In the case of a type 45 amplifier tube, 250 volts can pull 30 milliamperes of current through the tube. But the resistance of the primary, which is higher than the resistance of the tube, limits the flow of current so that only a part of the 30 milliamperes of current can flow through the tube and the primary coil. Now, not enough current flows through the primary to get the maximum transfer of energy through the transformer. Again, the speaker does not receive all of the energy that the tube can control.

The current which can be delivered by the tube will not go through the coil, so the maximum transfer of energy to the voice coil does not occur in this case.

*Condition 3.   Primary Resistance Is Equal to the Tube Resistance.*   All of the current that flows through the tube is used by the transformer.   When the primary has a resistance equal to the tube plate resistance, the greatest amount of useful current flows in the plate circuit.

**Power Delivered by the Tube and the Speaker.**   You have learned that electrical power is found by multiplying volts (pressure) times the current in the circuit.   The power is expressed in watts.   Volts times amperes equals watts. The type 45 power tube requires 250 volts on the plate and uses a plate current of 30 milliamperes.   Power used by the type 45 tube will be equal to 250 volts times 30 milliamperes which would equal 7500 milliwatts.   The milliwatt is a thousandth of a watt.   Dividing 7500 milliwatts by 1000 gives $7\frac{1}{2}$ watts of power used by the power tube.

If the step-down transformer has a ratio of 50:1, it will reduce the voltage from 250 on the primary to 5 on the secondary.   The power delivered by the secondary will be practically the same as the power delivered to the primary.

Divide 7500 milliwatts by 5 volts to find the current delivered by the secondary; this gives 1500 milliamperes of current.   It is plain, therefore, that the wires in the voice coil must be heavy enough to carry 1500 milliamperes or $1\frac{1}{2}$ amperes of current.   Yet they must be small enough so that the central core and the shell can be very close, in order to get the greatest effect and motion in the speaker. But since the tube as used in this experiment is only 20% efficient, the current will be reduced.

## Questions

**1.** Explain what causes the voice coil to move back and forth?

**2.** Is a weak or strong current needed in the voice coil?

**3.** Why is the plate of the tube not connected directly to the voice coil?

**4.** In order to show why the resistance of the tube and the transformer must be carefully matched, explain the result on the power output: (1) when the primary has a low resistance; (2) when the primary has more resistance than the resistance of the tube; and (3) when the primary resistance is equal to the tube resistance.

## Technical Terms

**acoustic**—Referring to sound.

**baffle**—A flat board or an open-backed box to which the speaker is attached.

**cone**—The paper cone-shaped element of a speaker which sets air in motion to produce sound.

**cord tips**—Metal tips at the ends of the phone cords for making connection to binding posts or other terminals.

**diaphragm**—The thin metal piece in a receiver which sends out sound waves as it is caused to move by the current flowing through the windings in the phone receivers.

**dynamic**—Moving.

**fidelity**—Accuracy. A signal has high fidelity when most of the original frequencies are reproduced by the phones or speaker.

**field coil**—A coil of many thousands of turns of wire used to produce a powerful magnetic field in a speaker.

**fundamental**—The original or basic frequency.

**harmonics**—Multiples of the basic frequency. When the basic frequency is 1000 cycles, the first ($\times$1) harmonic is 1000 cycles, the second ($\times$2) harmonic is 2000 cycles, the third ($\times$3) 3000, and so on.

**in phase**—The condition when like surges join at the same instant.

**micarta**—A phenol insulating material.

**milliwatt**—A thousandth of a watt.

**output transformer**—A small step-down transformer connected between the power tube and the speaker.

**overtone**—Same as Harmonic, except that it refers usually to musical tones.

**phone cord**—The insulated flexible wires used to connect the earphones to the set.

**pole pieces**—Steel cores used in earphones.

**quality**—*See* Fidelity.

**resonant frequency**—A frequency at which a diaphragm vibrates most easily.

**saturation**—When the core of a magnet cannot be magnetized further, it is said to be saturated.

**spider**—A device used to adjust and to center the voice coil in the gap between the cores of the dynamic speaker field magnet.

**voice coil**—A coil of a few turns of wire through which the current from the last stage of the receiver flows.

# CHAPTER VII

## POWER SUPPLY

**Source of Power for Alternating-current Sets.** The alternating-current set, as its name suggests, is designed to operate entirely from the alternating-current house lighting supply, so as to do away with any form of batteries. An alternating-current set receives power for heating filaments from step-down secondaries on the power transformer. Several secondaries are used because different voltages are needed to operate different tubes in the set. The B voltage for the different amplifier and detector stages is obtained from a special power pack built into the receiver. In this chapter we shall examine a separate power-supply unit which is easy to study.

**The Power-supply Unit.** The power-supply unit consists of a transformer one secondary of which steps up the voltage, a rectifying tube which converts the high-voltage alternating current into a pulsating direct current, a filter system which smooths out the pulsations of direct current and delivers a steady flowing direct current to the voltage-distributing system. Here the high voltage delivered by the filter is reduced to the proper value for each B positive connection. In the alternating current set this is all built in the one unit.

**Sources of Power for Direct-current Sets.** We have used storage batteries and B batteries for supplying A and B power to direct-current-tube sets.

### Contents of This Chapter

287

3. Alternating-current Receiver Power Supply Using a Type 80 Tube
4. Power Supply for Low-powered Transmitters
5. The Voltage Divider

### 1. HOW THE VACUUM TUBE RECTIFIES AN ALTERNATING CURRENT

A vacuum tube not only controls and amplifies, but it also has the ability to convert an alternating current into a pulsating direct current. We shall now use the vacuum tube as a rectifier.

We shall study the use of the familiar type 01A tube or of the type 71A tube in a circuit which shows how the tube rectifies. This is the same circuit that we used on the direct-current tube-test board, which can be used instead of building a new board.

### How to Build and Wire the Set

**The Board Layout.** Use the circuit board and the apparatus that was used in part 3 of Chapter III without change (see Fig. 43). Try the type 01A tube first and then substitute the type 71A if the plate current is not high enough to read on your meter.

**Other Apparatus Needed.** You will also need a step-down transformer that will deliver a 30- to 45-volt alternating current from the secondary. You can get a higher reading by using a 110-volt alternating current.

Two meters will be needed to test the step-down transformer output voltage. One meter is a direct current 0–150 voltmeter. The other meter is an alternating-current 0–150 voltmeter. You will also need a direct-current 0–50 milliammeter.

Test points with spring clips are useful for making the connections to the meters.

**The Plate Circuit.** We shall use alternating current from the step-down transformers for B power. Measure

the amount of current flowing in the plate circuit with a direct-current 0–50 milliammeter connected in the plate circuit, as shown in Fig. 183.

Check to see that the B positive post on the set is connected to the positive post on the meter.
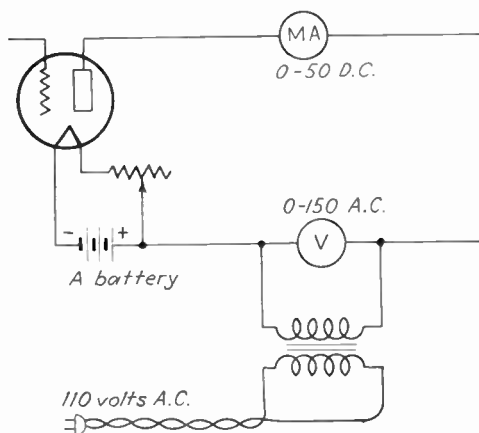


Fig. 183.  Simple rectifier circuit.

**The Grid Circuit.**  Make no connection to the *G* binding post.  The grid is not used in this test.

### How to Operate the Set

**Test 1.  Will a Direct-current Meter Read an Alternating Current?**  *How to Run the Test.*  Plug the cord for the step-down transformer into the light socket.

Clip the wires from the test points to the meter posts.

Touch the test points to the transformer-secondary terminals.

Is the output of the transformer an alternating current or a direct current?

Does the meter hand move?  Why?

*Why It Does Not Work.*  The current from the secondary of the transformer is an alternating current.

A direct-current meter will not operate on an alternating current. The same meter will give a reading at once on a 45-volt B battery, which delivers a direct current.
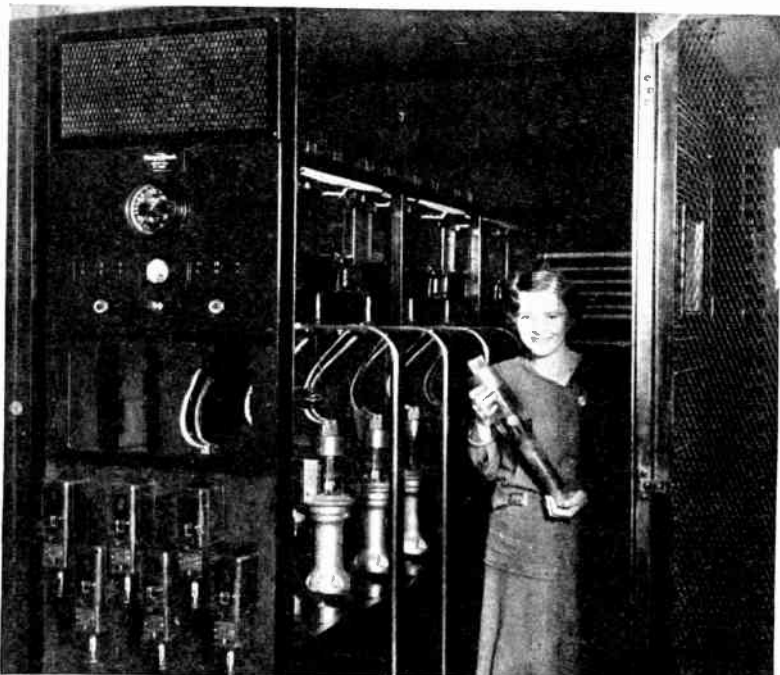


*Courtesy Pacific Telephone and Telegraph Co.*

POWER SUPPLY

This girl is holding a 10,000-watt rectifier tube. The cage in which she stands is part of the sending equipment in the transpacific radiotelephone station. The cage encloses the 10,000 volts six-phase rectifier for supplying direct current to the transmitter.

**Test 2. Substitute an Alternating Current on the Plate for a Direct Current.** *How to Run the Test.* Connect the 45-volt secondary of the transformer to the B positive and the B negative posts on the set board. Is the current supplied to the plate now an alternating current or a direct current?

Leave the direct-current milliammeter in the circuit to read current flowing in the plate circuit.

Light the tube; then plug in the transformer. Does the direct-current milliammeter show a reading when the filament is heated?

*Why It Works.* The hand on the direct-current milliammeter now moves. This shows that a direct current is flowing in the plate circuit because we just found in Test 1 that a direct-current meter would not operate on an alternating current.

Why does a direct-current flow through the meter when an alternating current from the transformer is flowing in the plate circuit?

The tube has changed the alternating current from the transformer into a direct current. We know that electrons can flow only from the filament to the plate in a vacuum tube. When the current tries to flow from the plate to the filament, it is stopped. So current only flows through the tube during half of the alternating-current cycle.

## 2. CONSTRUCTION OF THE TYPE 80 RECTIFIER TUBE

**Description of the Tube.** *Tube Base.* A four-prong tube base is used. Connections are shown in Fig. 184.



FIG. 184. Type 80 tube and base.

*Tube Elements.* A heavy coated filament is built inside of each of the two plates. The filaments, which are in series, operate at 5 volts, alternating current.

**How the Tube Operates.** For a description of how the tube operates, see How It Works in part 3 of this chapter.

### Questions

1. Are the filaments in type 80 tube connected in series or in parallel?
2. How many volts are used on the filaments of this tube?

### 3. ALTERNATING-CURRENT RECEIVER POWER SUPPLY USING A TYPE 80 TUBE

## How to Build and Wire the Set

**The Power Transformer.** Use a power transformer with a high-voltage secondary capable of delivering 350 volts or more on each side of the center tap. There should be a secondary delivering 5 volts for the heater of the type 80 tube and either one or two secondaries, each delivering $2\frac{1}{2}$ volts, for the filaments of the detector and amplifier tubes. One $2\frac{1}{2}$-volt secondary should be center tapped. Separate secondaries are used so each winding will need to carry but little current.

Transformers taken from old B eliminators have only a center-tapped high-voltage secondary. They have no filament windings. A rewound burned-out power transformer can be used for the 5-volt filament winding for the type 80 and for the $2\frac{1}{2}$-volt tubes in the receiving set. This power supply may be used for a small set having up to 4 tubes. If you wish to use it on a larger set, you should purchase a power transformer capable of supplying the current demanded by more tubes.

**The Rectifier Tube.** Use a type 80 rectifier tube. Place a four-prong socket in the position shown in Fig. 185. The method you use in mounting the different parts on the board will depend on the parts which you use.

**Condensers.** Use three dry electrolytic condensers, one of 4 microfarads capacity and two of 8 microfarads capacity, with a working voltage of at least 600 volts. Condensers with lower voltage rating will burn out too quickly.

**The Choke Coils.** Use two 30-henry choke coils. The choke coils must carry from 60 to 120 milliamperes of current, depending on the number of tubes in the set that will be used with this power supply. Use a choke coil taken from an old B eliminator. Use one which has two 30-henry units on the same core.
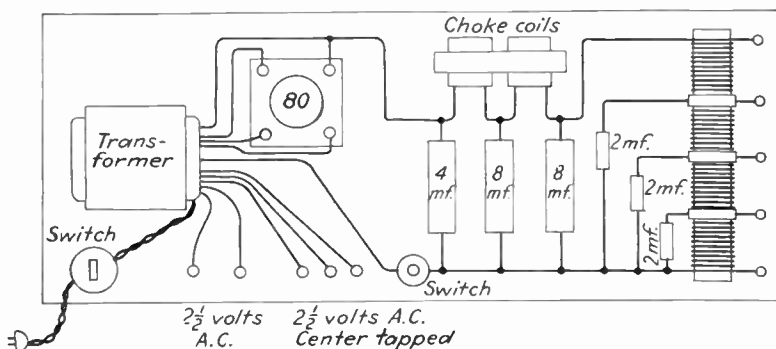


Fig. 185. Power-supply board.

**The Bleeder Resistor.** A power supply to be used for experimental work should have several high-voltage direct-current terminals. The bleeder resistor may be made up of several variable carbon-pile resistors if the voltages are to be variable. If several fixed direct-current voltages are needed, the bleeder may be several 5-watt fixed resistors of 25,000–50,000 ohms resistance, connected in series across the output of the filters. If no bleeder resistor is used, the filter condensers are apt to burn out easily when no load is connected to the power supply.

**Arrangement of the Parts.** Arrange the parts for an experimental power supply, as shown in Fig. 185, bread-

board style; but if the power supply is for use in a set, mount the parts on a metal chassis in any convenient fashion.

**How to Wire the Circuit.** Figure 186 shows the wiring of the various parts of this power-supply unit. Wires from
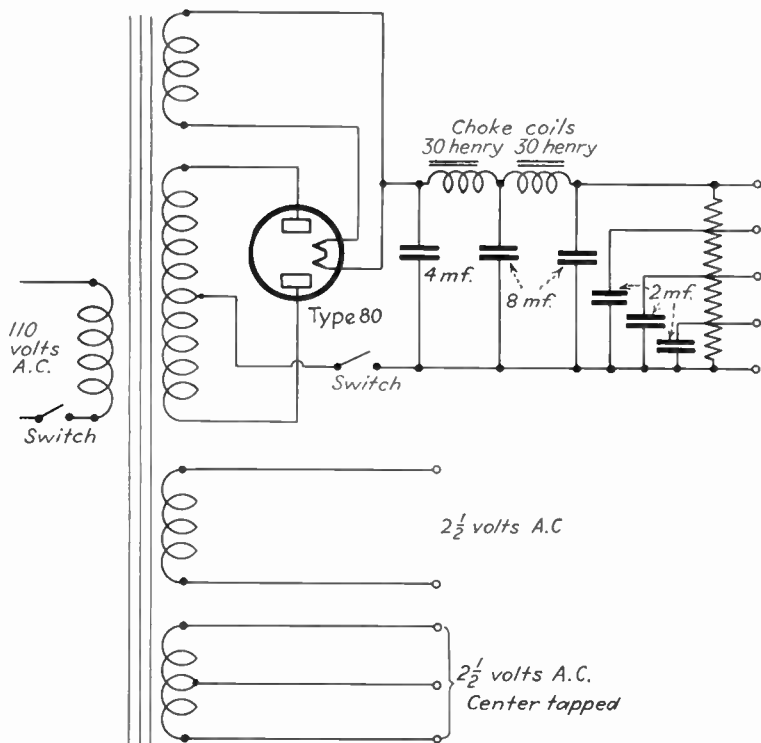
Fig. 186. Power-supply circuit.

the ends of the high-voltage secondary to the plates of the type 80 tube must be well insulated. They carry about 300 volts. Connect an off-and-on switch in the primary leads to the transformer and also one in the negative lead to the filter.

### Questions

1. How many condensers should be used in the power supply?
2. What size condensers should be used?
3. How many volts should they be able to carry?
4. How many choke coils should be used?
5. How many milliamperes of current should they be able to carry?

## How It Works

**The Power Transformer.** The 110-volt alternating current surging through the primary of the power transformer
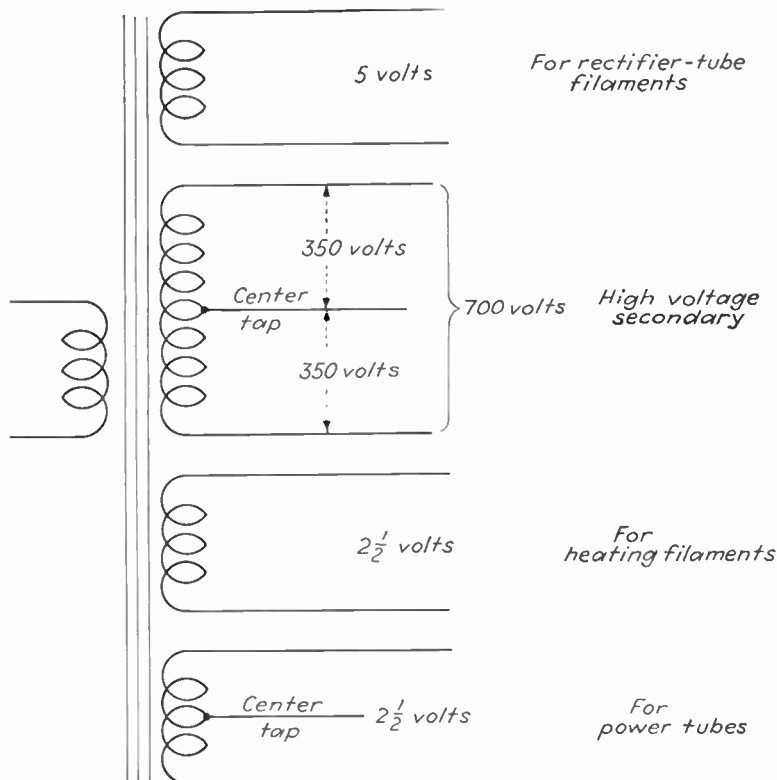


Fig. 187. Use of secondaries in power transformers.

induces an alternating current in each secondary winding (see Fig. 187). An alternating current of 5 volts induced

in the one primary heats the filaments of the type 80 tube, causing them to give off electrons.



An alternating current of $2\frac{1}{2}$ volts or of 6 volts induced in the other two low-voltage secondaries is used to heat the detector- and amplifier-tube filaments on the radio set.

An alternating current of 700 volts is induced in the high-voltage secondary (see Fig. 187). The many thousands of turns of fine wire in the high-voltage secondary set up a high pressure forcing the electron surges back and forth through this winding.

FIG. 188. Electron flow through high-voltage secondary and through type 80 tube.
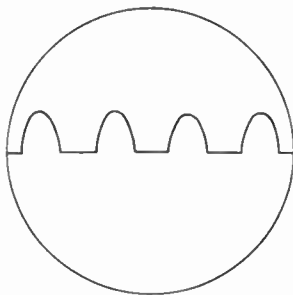


FIG. 189. Wave form of direct current to each plate.

**How the Type 80 Tube Rectifies the Alternating Current.** When the secondary draws the electrons off plate 1 of the rectifier tube, plate 1 becomes highly positive. Plate 1 now attracts electrons from the space charge around the filament and current flows from the filament of the rectifier tube to plate 1 (see Fig. 188).

At the next instant the secondary current reverses and draws electrons off plate 2, which becomes positive. Electrons now rush from the space charge around the filament
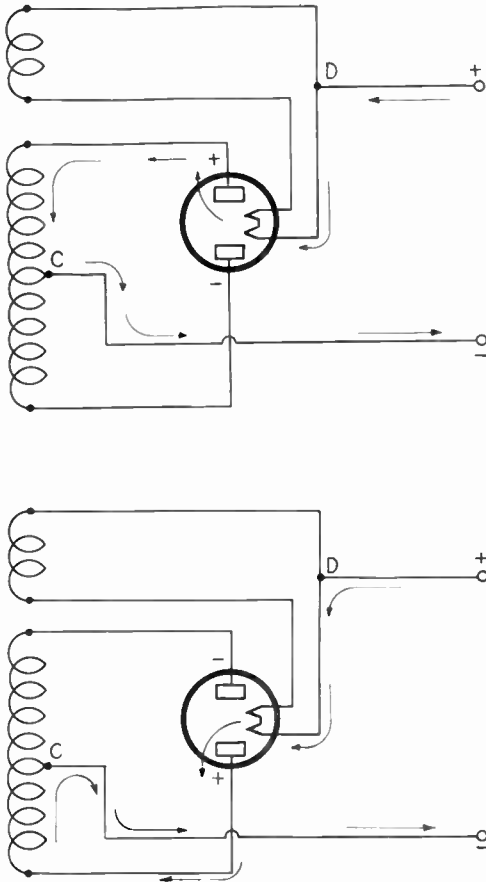


FIG. 190.   Electrons flow to set from secondary center-tap connection.

to plate 2. No electrons flow to plate 1, which now is negative.

The resulting electron flow, as shown in Fig. 189, is a pulsating direct current. Electrons alternately flow from

the space charge around the filament to plate 2, then to plate 1, as first one plate and then the other becomes positive.

But the electrons which flow to the secondary of the power transformer from the tube must have some place to go. Electrons surge to the receiving set from the center



tap of the secondary winding as shown at *C*, Fig. 190. This is the negative connection. Electrons from the receiving set come back through the wire *D* to the rectifier tube filament. This is the positive terminal.

The pulsating direct current delivered by the rectifier tube and the secondary of the power transformer is shown in the wave picture in Fig. 191.
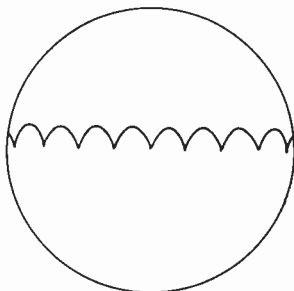
FIG. 191. Wave form of direct current from a full-wave rectifier.

The output of the rectifier tube cannot be connected directly to the receiving set because nothing would be heard but a terrific roar caused by the rapid changes in the strength of the plate voltage.

The pulsating direct current from the rectifier tube must pass through a filter (which consists of two choke coils and three dry electrolytic condensers) before it can be used in the plate circuits of the receiving-set tubes.

The purpose of the filter is to smooth out the pulsations of the current delivered by the rectifier tube so that a steady flowing direct current will be delivered to the set.

### Questions

1. Is the type 80 a full-wave or a half-wave rectifier?

2. How are the two plates connected to the transformer?

3. Why do the electrons flow only one-half of the time to each plate?

**4.** Why is the negative lead connected to the center of the secondary coil of the transformer?

**5.** Electrons from the receiving set return to what terminal in the rectifier tube?

**6.** What is the objection to connecting the rectifier tube directly to the radio?

**The Action of the Filter.** The standard connection for the power-supply filter is as shown in Fig. 186, with the chokes in the positive side of the circuit. No difference will be found in the operation of this circuit if connected as shown in Fig. 192 with the chokes in the negative lead. We will show it this way for ease in explanation.
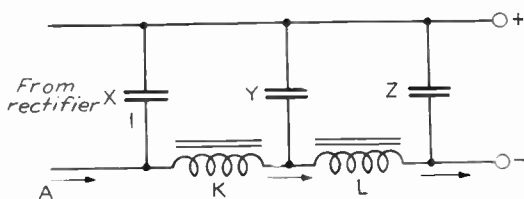


Fig. 192.   Filter action.

When a surge of electrons from the rectifier tube and the high-voltage secondary flows as shown by the arrow at $A$, it will meet the opposition of the choke $K$.   Since the back voltage set up by the choke coil $K$ opposes the surge, the electrons will flow into side 1 of condenser $X$.   As the surge overcomes the back resistance of the choke coil, the current flow starts through the coil.   When this surge dies down, the flywheel action of the choke coil tries to keep the current flowing, but there is no current remaining in this surge of electrons.

Now the electrons in side 1 of the condenser flow out and through the choke coil.   The result of the action of the condenser and the coil on the first surge of electrons is to reduce the strength of the current somewhat but to deliver a more even flow.   This action repeats in condenser

Reservoir R

A

X

K

Y

L

Z

O

Nozzle
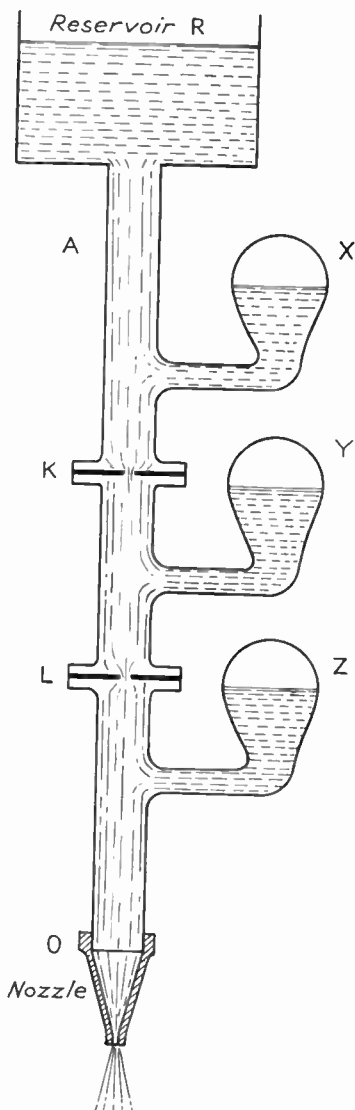
FIG. 193.    Filter action shown by
water flow.

$Y$ and choke coil $L$, which evens the flow further and reduces the pulsation. Any remaining pulsations are killed by the action of condenser $Z$, leaving a steady flow of direct current.

**Electron Flow Compared to Water Flow.** Electrons surging through the filter act like a flow of water. In Fig. 193 is shown a reservoir $R$ from which water flows into the system of glass tubing in surges. Two flexible dams through which there is a small opening are in the glass tube at $K$ and $L$. These represent the choke coils which hinder current surges but which tend to allow the current to flow as soon as it starts. The three large bulbs at $X$, $Y$, and $Z$ represent the condensers. They act as storage space.

When a surge of water from the reservoir at $R$ flows into the main pipe at $A$ the dam at $K$ opposes its flow. This stops the surge; so the water, which is retarded in its flow through the system, fills bulb $X$ until it can force its way through the dam at $K$.

Now as soon as the water begins to flow through $K$ the pressure on it at $X$ forces the water in $X$ out and assists the flow through the first dam. There still is some surge effect to the water flowing between $K$ and $Y$. The first surge travels on and meets the opposition of the second dam $L$ and flows into the bulb $Y$ until the flow builds up through the second dam $L$ when the reservoir $Y$ empties. Bulb $Z$ will still further smooth out any remaining pulsations. Nozzle $O$, which represents the resistance of the set, now receives a steady flow of water.

A second surge begins to flow from the source of supply at $R$ just as the first surge flows out of $X$ through $K$. The effect of this system is to produce a smooth, steady flow of water through the resistance at $O$. This system operates in a manner similar to the action of the filter used in the power supply for a radio set.

### Questions

1. Trace a path of the electrons through the chokes and condensers of the filter.

2. Trace the path of the water from the reservoir to show how the electron surges through the filter are similar to the surges of water through the pipe.

### 4. POWER SUPPLY FOR LOW-POWERED TRANSMITTERS

**Parts for the Power Supply.** Use a heavy-duty power transformer, one capable of delivering 150 milliamperes of current or more at 350 volts, 500 volts, or 750 volts. The higher voltages will give you a greater power output in your transmitter or power oscillator. If you wish to use the set for experimenting, use either a 350-volt or a 500-volt transformer.

**Rectifier Tube.** Use a type 80 tube for the 350- or 500-volt transformer.

**The Filter.** Use a heavy-duty filter. The condensers must have a voltage rating a quarter to one-half higher

than the rated voltage of the high-voltage secondary of the power transformer. Select choke coils that have a current rating of 50% higher than the current rating of the transformer, to allow for surges, accidental incorrect connections,
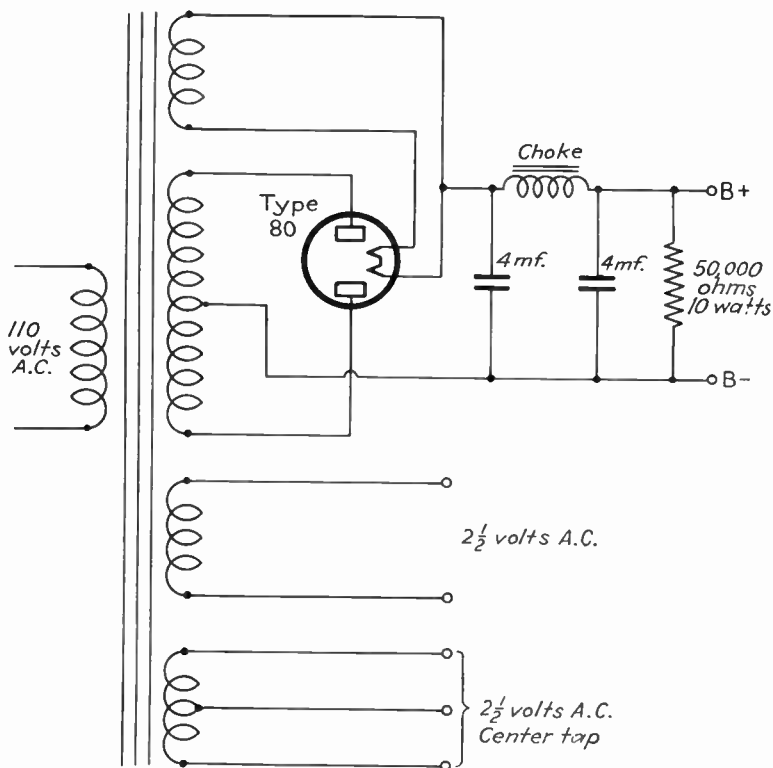


FIG. 194.   Circuit of power pack.

and adjustments. Use two 4-microfarad condensers in the filter.

## How to Wire the Set

Wire the circuit as shown in Fig. 194. Allow sufficient insulation on the high-voltage leads from the secondary of

the power transformer and all through the filter. Mount
the condensers and choke coils so that they will be insulated
from the metal chassis if one is used. Not as much care is
needed if you mount the parts on a breadboard.

Be sure that the dry electrolytic condensers are correctly
connected. If these condensers are reversed, they will be
destroyed when the current
flows into them.

Connect a 50,000-ohm
10-watt resistor across the
output of the power supply
as a bleeder resistor.

### Questions

**1.** Why should the choke coils
have a higher current rating than
the power supply usually delivers?

**2.** Does it make any difference
in which direction the current
flows through an electrolytic con-
denser?

### 5. THE VOLTAGE DIVIDER

**Potentiometer Used to
Reduce Voltage.** Connect



Fig. 195.   Potentiometer used to show
principle of the voltage divider.

a 5000-ohm potentiometer across a 45-volt B battery (see
Fig. 195). Connect a direct-current 0–50 voltmeter and
two test points to read the drop in voltage across the ends
of the potentiometer resistance element, *A* to *E*. When
you touch one of the test points at *B*, you will find only a
fourth of the drop in voltage that you found between *A*
and *E*. Step the test point along the resistance to find the
drop between the different points on the resistor.

**Voltage Divider.** A voltage divider is a resistor large
enough to carry the entire current that will be used by the

set. By connecting to points along the resistor, the approximate voltage needed for each B connection can be had (see Fig. 196).

Another method of getting different B voltages is to use several small resistors in series. See part 7 of Chapter IX for an example.
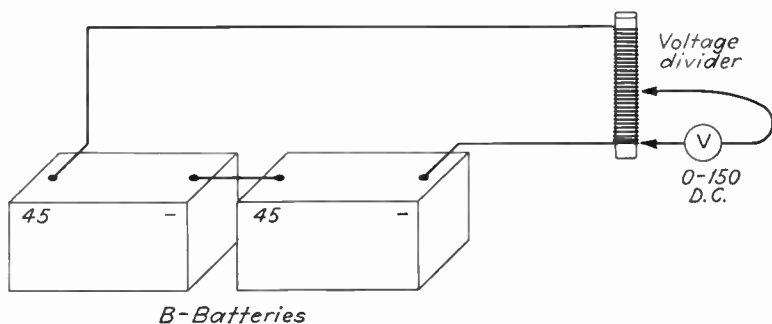


FIG. 196. Method of testing different voltages along voltage divider.

### Technical Terms

**bleeder resistor**—A resistor connected across the power supply to discharge the condensers in the filter and to act as a load when the power supply is temporarily disconnected from the set.

**center tap**—A connection made to the center of a transformer winding. Also a connection made to the center point of a resistor.

**filter**—A combination of choke coils and condensers which changes a pulsating direct-current into a steady or pure direct current.

**full-wave rectifier**—A vacuum-tube rectifier which delivers a pulsating direct current from both loops of the alternating-current cycle.

**metal chassis**—A base made of heavy sheet metal on which the parts of the power supply are mounted.

**power pack**—A unit which consists of a transformer, a rectifier, and a filter which supplies both low voltage alternating current to heat filaments and high voltage direct current to operate plate circuits.

**power supply**—*See* power pack.

**rectifier**—A vacuum tube which changes an alternating current into a pulsating direct current.

# CHAPTER VIII

## ALTERNATING-CURRENT TUBES AND RECEIVING SETS

In this chapter we study the changes which the use of tubes heated by alternating currents made necessary in receiving circuits.

We shall first learn the changes in tube construction made necessary by the use of an alternating-current heater circuit. Then we shall study the new-type tubes developed for other classes of service as sets and circuits improved.

The alternating-current detector and amplifier circuits are easily recognized as the same circuits used in the direct-current sets (chapter V). But the circuits for the screen-grid tube, both when used as a radio-frequency amplifier and when used as a detector, are new. You will be delighted with the increased sensitiveness of the screen-grid tube and its possibilities in these circuits. If you want to hear distant stations, its use is recommended.

The advanced audio and power amplifiers bring signal volume that was beyond the possibilities of the first direct-current tubes. These audio circuits can later be used to develop simple basic circuits for public-address systems which, however, are not taken up in this text.

A simple superheterodyne circuit is developed out of units used in earlier circuits.

### Contents of This Chapter

305

PICTURE                    SYMBOL

Type 27 tube

Control-grid cap

Type 24 A tube

Type 47 pentode
tube

Suppressor
grid

FIG. 197.    New symbols used in Chapter VIII.

PICTURE                    SYMBOL

Center-tapped
resistor

Potentiometer



Push-pull transformers

Input

*Primary*    *Secondary*

Output

*Primary*    *Secondary*
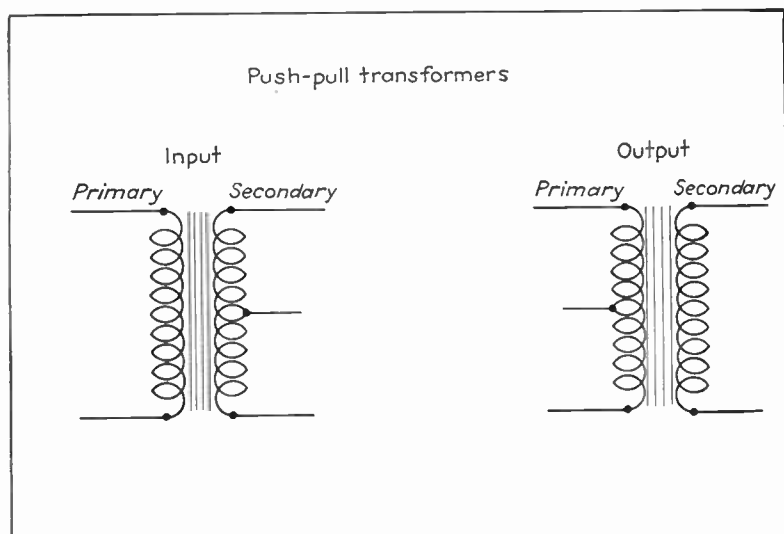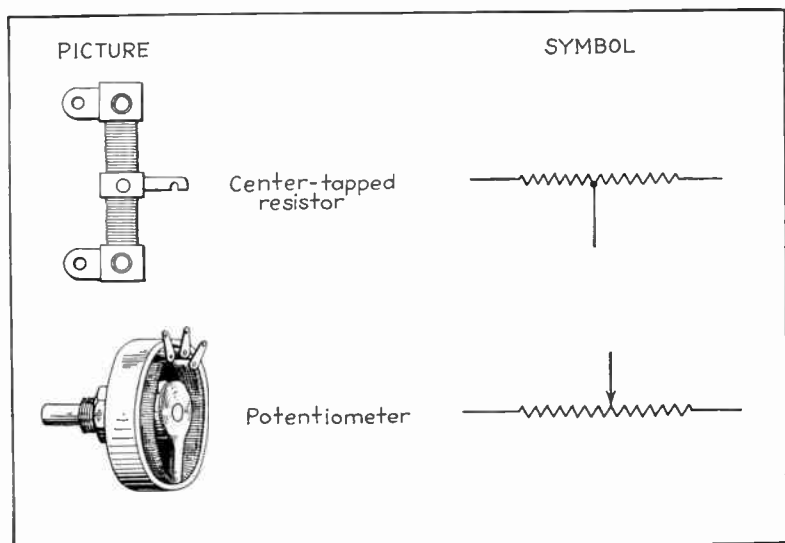
FIG. 197 (*continued*).   Symbols used in Chapter VIII.

4. The One-tube Alternating-current Detector Set Using the Type 27 Tube
5. The Center-tapped Resistor
6. The Alternating-current Audio Amplifier
7. The Power Amplifier Circuits
8. Coupling Between the Power Tube and a Magnetic Speaker
9. The Alternating-current Radio-frequency Amplifier Using the Type 24A Screen-grid Tube
10. The Alternating-current Detector Set Using the Type 24A Tube
11. The Superheterodyne Receiver

### 1. NEW SYMBOLS USED IN THIS CHAPTER

These symbols are shown in Fig. 197 (pages 306–307).

**cathode-type tube**—The symbol shows the type 27 tube. The cathode is shown by a curved line placed near the heater filament.

**screen-grid tube**—The symbol is for the type 24A tube. The new grid is drawn between the control grid and the plate.

**pentode tube**—The symbol shows a type 47 five-element tube. The third grid, the suppressor, is shown between the screen grid and the plate. The suppressor grid is connected to the filament.

**center-tapped resistor**—The resistor in use is connected across the leads to the filament with a wire from the center of the resistor to the negative B lead.

**potentiometer**—A variable resistor which has a connection at each end of the resistance element.

**push-pull transformer**—The audio transformers used for push-pull circuits are center-tapped. The input transformer secondary has a center-tap connection, and the primary of the output transformer has a center-tap connection.

### 2. CHANGES IN TUBES FOR ALTERNATING-CURRENT CIRCUITS

**Early Alternating-current Tubes.** The alternating-current tube was developed to replace the direct-current tube

and to eliminate the nuisance of batteries.    You will under-
stand the difficulties the tube designer had if you attach a
6-volt alternating current to the battery terminals of a set
using the type 01A for the detector tube.    The tube fila-
ment will heat properly, but the resulting roar is enough to
discourage any person from using such an alternating-



Fine wire filament                              Ribbon filament
for direct current                         for alternating current
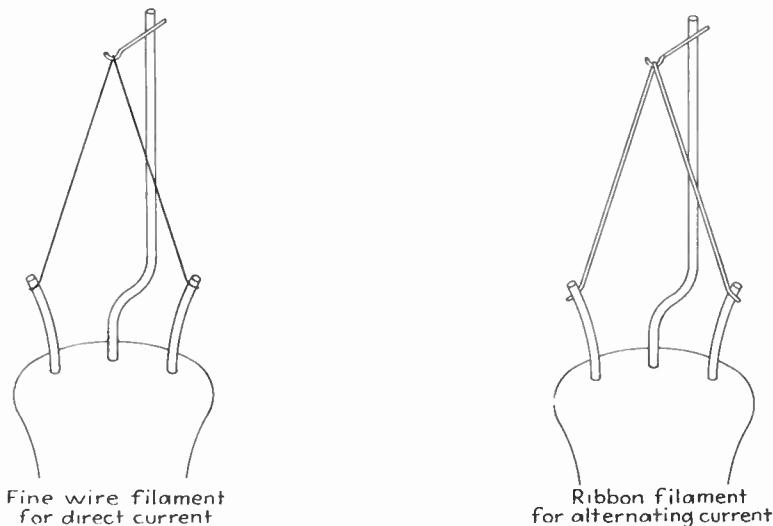
Fɪɢ. 198.    Directly heated filaments.

current heater supply on a direct-current tube.    The early
attempts at designing an alternating-current tube were
centered around some way to avoid this terrific hum or
roar caused when an alternating-current was used for heat-
ing the filament.

The type 01A filament for direct current is a fine wire
(see Fig. 198).    You learned in Chapter V that the hotter
the filament the more electrons it will give off.    When you
connect an alternating current to the type 01A filament, a
pulsation of alternating current flows through the wire in
one direction and heats the wire.    Many electrons are

thrown off the wire. Then for an instant the current stops and the fine wire cools. Now few electrons are thrown off the filament. When the current reverses, another pulsation flows through the fine wire. The wire again becomes hot, and many electrons are thrown off.

As the fine-wire filament heats and cools, the quantity of electrons thrown off the wire is constantly changing. This increase and decrease of the plate current occurs at a steady rate, 120 times a second, the frequency of the alternating-current supply. The first alternating-current tubes overcame the tendency of the filament to heat and cool too rapidly by using a filament wire that was very much heavier than the light 01A filament wire.

The heavy filament used in the early alternating-current tubes was a ribbon about as wide as the narrow end of a toothpick (see Fig. 198). The type 26 tube used an alternating current on the filament successfully only because the filament was so heavy. This filament is heavy enough to remain at the same heat during the time the alternating current is reversing. It has a high *thermal inertia*, or heat laziness. The filament is so heavy it refuses to change heat rapidly. It is not sensitive to quick heat changes. The electron surges of the 60-cycle alternating-current are too rapid to affect the heat of the heavy filament. The roar you heard in the type 01A tube when $1\frac{1}{2}$ volts was used on the filament is reduced to a low hum in the type 26 tube.

The filament heat remains steady enough for the tube to be used in the radio-frequency or audio amplifier stages. But there is still enough hum left in this tube to bar its use as a detector. The hum can be reduced by connecting a 20- to 40-ohm rheostat across the filament leads of the tube and grounding its center point to the B negative connection.

### Questions

**1.** What is the effect of putting an alternating current on the filament of a direct-current tube?

**2.** Why is it that a direct-current tube does not emit a steady stream of electrons when the filament is heated by an alternating current?

**3.** What was the first successful method used to get a filament to emit a steady stream of electrons when it was heated by an alternating current?

**4.** Was the type 26 tube free enough from hum to be used as a detector?

**5.** What additional method could be used further to remove hum from the type 26 tube?

## The Cathode-type Tube

A detector tube must be entirely hum free. The filament-type tube still left some hum in the signals, so another kind of electron source was needed that would deliver a perfectly steady stream of electrons. This problem was solved by separating the two jobs of the filament. The filament no longer was used both as a stove or heater and as an electron emitter.

**What the New Tubes Will Do.** The first alternating-current tube you will use is the type 27 tube. You can use it either in the detector or in the audio amplifier circuit. If used in the radio-frequency amplifier circuits, it will oscillate or squeal and must be neutralized, as was the type 01A tube.

## The Type 27 Tube

**How It Is Used.** The type 27 tube is a general-purpose three-element tube used in alternating-current sets to replace the type 01A tubes.

The characteristics of the type 27 and the type 01A tubes are nearly the same. The type 27 tube may be used in the type 01A circuits with no changes in B voltage. The

difference in the circuit is the cathode wire and wiring for the heater current now supplied by a filament transformer. The type 27 tube has a five-prong base and must be supplied with a $2\frac{1}{2}$-volt alternating current for the heater.

**How It Works.** *The Source of Electrons.* The filament in this tube is a tiny stove. It now heats the cathode.

The cathode is a small metal sleeve coated with alkaline-earth oxides, rich in materials that give off electrons when heated (see Fig. 199). The cathode fits over the heater filament. There are several methods of fitting the filament in the cathode. In some tubes the filament is run through tiny holes in a ceramic, or porcelain-like, substance; in others the filament is twisted and is suspended tightly in place.

The hairpin filament must be insulated from the metal cathode sleeve. The metal sleeve shields the other tube elements from the alternating-current magnetic field around the filament wires. This prevents hum in the tube.

*How the Alternating-current Hum Is Killed.* When the current is turned on, the light filament heats quickly and acts as a stove or heater for the cathode, which is so much heavier than the filament that it heats slowly. The heat changes of the filament occur as rapidly as the surges of the alternating current change, but they do not affect the slow, steady heat of the cathode. It is too heavy and

Heater filament
Porcelainlike filler
Cathode sleeve
Oxide coating
Support
Heater filament leads to base prongs
Glass stem

FIG. 199.   Cathode and heater.

large to heat up or to cool off that fast. Its thermal inertia is very high.

The steady heat of the cathode drives off a stream of electrons sufficiently steady that the type 27 tube can be used as a detector as well as an amplifier. The hum has been cut out by substituting the cathode for the filament as the source of electrons. See Fig. 197 for its connections.

Plug in a type 27 tube and watch the filament heat up when the current is first turned on. You can see the effect of the high thermal inertia of the cathode. Watch the filament heat and notice how long it takes the tube to get into operation so signals can be heard in the earphones. Compare the time of heating in a type 01A, type 26, and type 27 tube.

*A Transformer Supplies Filament Current.* A step-down power transformer heats the filaments; no storage battery is used. Several secondaries on the transformer deliver the alternating current to the heaters or filaments of the different tubes in the circuit. In a set that has several stages of radio-frequency and audio-frequency amplification, different heater windings are sometimes used for each set of tubes. This reduces feedback from amplifier to detector or audio circuits by induction.

### Questions

1. What is the cathode like in a type 27 tube?

2. What is the purpose of the cathode?

3. Explain why it is that the cathode remains at an even temperature.

4. Why are separate heater windings generally used for each set of tubes?

## The Type 24A Screen-grid Tube

Neutrodyne circuits, which were quite popular before the alternating-current tubes were developed, stopped oscillation and squealing by means of small balancing or neu-

tralizing condensers. This circuit was patented. In order
to avoid paying royalty for the use of it, other companies
developed a new type of tube of which the type 24A and
type 35 are common examples. In these tubes a second
grid or screen was placed between the grid and the plate,
as well as outside of the plate (see Fig. 197). No neu-
tralizing circuit is necessary when the screen-grid tube is
used. The construction of the tube prevents oscillation.
Incidentally, this type of tube makes possible a set of
greatly increased sensitivity, since the amplification with
the type 24A tube is very much higher than when the type
01A and the type 27 tubes are used.

### Question

1. Is it necessary to neutralize a set when type 27 tubes are used in
the radio-frequency amplifier?

## The Type 24A Tube

**Used as a Detector.** The type 24A tube is a sensitive
detector. It is stable and efficient in operation. Sensi-
tivity and regeneration are controlled by changing the
screen voltage by a variable resistor.

**Used as an Audio Amplifier.** When the type 24A tube
is used in audio circuits, resistance coupling must be used.
Impedance coupling produces signals of poor fidelity.
Transformer coupling is not used between a type 24A
detector tube and the audio stage because the plate resist-
ance of the type 24A tube is too high. The quality of the
signals produced would be very poor.

**How It Works.** The thorium-oxide–coated cathode
emits electrons when heated by the heater filament. A
space charge forms around the cathode.

The positive plate attracts electrons from the space
charge. The control grid, which is close to the cathode,
controls the flow of electrons through the tube as in the

other tubes we have discussed.    When the grid is positive,
it attracts and speeds up electrons, resulting in more cur-
rent flowing through the tube; when the grid is negative, it
cuts down the plate-current flow by repelling space-charge
electrons.    Few electrons reach the plate because it is so
far from the cathode.

Electrons flying away from the cathode into the space
charge have too little speed to reach the part of the tube
where the plate pull is strong enough to draw them to the
plate (see Fig. 200).    The instant the screen grid is made
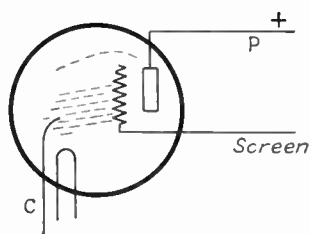


FIG. 200.  Screen neutral; few
electrons reach the plate.
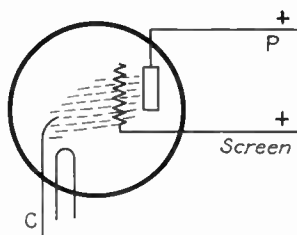
FIG. 201.  Screen positive;
many electrons reach the
plate.

positive it boosts the speed of the electrons enough for
them to reach the plate.    Many more electrons now reach
the plate (see Fig. 201).

A few of the electrons are controlled by the screen grid.
This is shown by the screen current of 1.7 milliamperes
when there are 90 volts on the screen.    The more powerful
attraction (250 volts) of the plate collects most of the elec-
trons, resulting in a plate current of about 5 milliamperes.
The surges in the direct current on the screen grid are
by-passed to the cathode.    (For an explanation, see Why
It Works in part 6 of this chapter.)    A .01-microfarad
by-pass condenser is used in the radio-frequency circuits.
A $\frac{1}{2}$- to 1-microfarad by-pass condenser is used in the audio
and detector circuits.

**The Screen-grid Tube Used as a Radio-frequency Amplifier.** When the screen-grid tube is used in the radio-frequency circuit, its construction eliminates the necessity for the neutralizing condensers to prevent oscillation (howling and squealing), such as occurred in a set using the type 01A tube in the radio-frequency amplifier stages.

The capacity between the plate and grid of the screen-grid tube is very small because the plate is so far from the grid. The grid is connected to a metal cap on top of the tube by a short connection which further reduces the capacity between the grid and the plate.

The screen grid, placed between the grid and the plate, acts the same as a series condenser to reduce the capacity between the grid and the plate of the tube (see Fig. 202). We know that the capacity of two condensers in series is less than the capacity of either. The result, in this tube, is to reduce the grid-to-plate capacity to .01 micromicrofarad. This is 800 times less capacity than that of the type 01A tube.



Fig. 202.  Capacities of tube elements are in series.

Neither the plate nor screen-grid voltages are critical. Excessive screen voltage may cause hum.    Amplification is controlled by changing the grid bias by a variable resistor. Coils and tubes in the radio-frequency circuit must be carefully shielded to get the full gain made possible by the tube.    Unshielded sets work fairly well.

## Questions

1. What effect does the screen grid have upon the speed of the electrons which travel from the filament to the plate?

2. Explain how the screen grid in the type 24A tube operates.

## Power Tubes

The type 71A power tube was used in the early alternating-current circuits. It can be used with either alternating- or direct-current filament supply. But the more efficient type 45 tube soon replaced it. The type 45 is a three-element filament-type tube which delivers much power to the speaker with surprisingly small input voltage on the grid. The type 47 is a power pentode or five-element tube.

## The Type 45 Power-amplifier Tube

**How It Is Used.** The type 45 tube is a low-*mu* tube; that is, its amplification factor is low—3.5. It delivers much current but has low voltage amplification. It is designed to deliver a large amount of undistorted power to the speaker. It is used as a power tube in the last, or power, stage of the set. If more power output is wanted, two type 45 tubes are connected in a push-pull circuit. One stage of audio amplification, such as a type 27 amplifier, must be connected between the detector and the type 45 power audio amplifier. The voltage changes from the detector circuit are too small to operate the power amplifier. The voltage changes delivered to the grid are called the grid excitation.

The output of the type 45 tube must not be connected directly to the speaker. It must be coupled through an output transformer or an impedance.

**How It Works.** The operation of the type 45 tube is the same as that of other three-element tubes. The plate current is nine times as great as the type 24A or of the type 27 tube.

The type 45 tube will heat somewhat in use on account of the heavy current handled. Mount the tube so the filament is in a vertical position. Ventilation is necessary

around the tube on account of the heat developed in operation.   The filament is generally heated by an alternating current.

## The Type 47 Pentode Tube

**How It Is Used.**   The pentode was developed to meet the demand for a tube having a large power output with



*Courtesy General Electric Co.*

DR. IRVING LANGMUIR

Dr. Langmuir is examining one of the vacuum tubes developed as the result of his researches.

reasonably low distortion which would take the place of two tubes in the audio stages of midget sets.

The control grid is placed next to the filament.   The wires of the control grid are spaced more closely than the grid wires of the type 45 tube.

Around the plate is a screen grid as in the type 24A tube.

A third grid, called the suppressor, is placed between the screen grid and the plate. The spacing between the wires of the suppressor grid is greater than the spacing between the control grid wires. See connections in Fig. 197.

*In Audio Stages.* The type 47 tube will give as much output as the type 45 tube, but it has more distortion.

The type 47 tube is used as the last audio stage following a power detector. This is possible on account of the high *mu*, 150, of this tube. When used following a grid-leak–condenser detector, one stage of audio amplification is used to build up the excitation voltage ahead of the type 47 amplifier stage.

**How It Works.** A heavy filament, heated by an alternating current, supplies the electrons for the operation of this tube. When the plate is made positive by the B battery, it attracts electrons from the space charge surrounding the filament, causing a current of electrons to flow through the tube.

Electrons, pulled toward the positive plate, are speeded up by the grid pull when the control grid is positive. If the grid is negative, the electrons are slowed up. The control grid, wound with closely spaced wires, is placed near the filament. The close spacing of the grid wires gives great voltage amplification.

The plate in this tube is so far from the filament that some of the electrons lose speed and never reach the plate. The screen grid, which is next to the control grid, is made positive by the B battery and pulls on the slowing-up electrons. The screen grid operates at as high voltage as the plate in this tube. These electrons, now speeded up, flash onto the plate.

*Secondary Emission.* The electrons reach the plate traveling so fast that they knock other electrons off the

plate. This is called secondary emission (electrons leaving a cold surface). These electrons would fly to the screen, which is positive enough to attract them. The suppressor grid prevents this from happening.

*The Suppressor Grid.* This grid, between the plate and the inner screen grid, has its wires spaced farther apart than either the control grid or the screen grid. The suppressor, made negative by its connection to the filament inside the tube, repels the electrons knocked off the plate and so prevents secondary emission. In this way the tube will handle a heavy current for power and will have high amplification as well.

**Effects of Secondary Emission.** Current will flow from the plate to the screen (secondary emission) of a screen-grid tube when the plate voltage becomes lower than the screen voltage. This occurs only on strong signals. The knocked-off electrons cut down the strength of plate voltage changes and reduce the power output of the tube. With secondary emission, stopped by the suppressor grid, high gain is possible with a pentode tube.

### Questions

1. In the pentode tube discuss the action of:

(*a*) The control grid, and state also the source of electricity for this grid.

(*b*) The screen grid, and state also the source of electricity and charge on it.

(*c*) The suppressor grid. Also state the source of electricity and charge.

2. What is secondary emission and what causes it?

## What Is Plate Resistance?

The plate resistance of a tube is the opposition to the flow of alternating-current electron surges from the fila-

ment or cathode to the plate, measured when the grid is neutral. Plate resistance is also called plate impedance because it is measured with an alternating current instead of a direct current. The plate resistance of a tube is fixed when no voltage is on the grid. But when the tube is operating with an alternating-current voltage on the grid, the number of electrons flowing to the plate changes, and this changes the internal or plate resistance of the tube. The plate resistance depends on the size of the tube elements and the distance between them.

**Tubes with Low Plate Resistance.** The tube with low plate resistance has a large cathode or filament which can supply many electrons, and has the plate close to the cathode (see Fig. 203). With this construction, the plate can collect all of the electrons easily. The type 2A3 tube has had the lowest resistance of any tube made. It delivers from 40 to 60 milliamperes of plate current depending on the circuit in which it is to be used. It handles from 3 to 15 watts of power. The type 45 tube has very high plate current and low plate resistance. These tubes are used in power audio-amplifier circuits.



Fig. 203. A tube with low plate resistance has the plate close to the cathode.

**Tubes with High Plate Resistance.** A high plate resistance comes from the fact that few electrons are able to reach the plate from the cathode. There is a small supply of electrons, and the plate is far from the cathode or filament in a tube that has high plate resistance (see Fig. 204). The type 24A tube has very high plate resistance and low plate current.

## The Amplification Factor of a Tube

One valuable factor of a vacuum tube is the ability of a weak voltage on the grid to control the flow of the much heavier current between the filament and the plate.

A small voltage change on the grid increases or decreases the plate current as much as a large change in plate voltage would change the plate current. An example will make this clear. If you make the grid of the familiar type 01A tube 1 volt more positive, this will increase the plate current as much as if you were to increase the plate voltage by 8 volts. This effect is known as amplification. The ability of the tube to amplify is called the amplification factor (abbreviated to *mu*) of a tube. The amplification factor, or *mu*, of this tube is 8.

Fig. 204. A tube with high plate resistance has the plate far from the cathode.

**High-*mu* Tubes.** A high-*mu* tube is one which has a very high amplification factor. An example of this is the type 24A tube, which has an amplification factor of from 400 to 600, depending on the plate voltage. The type 24A is so sensitive that a change of 400 volts is required on the plate to equal the effect which a change of 1 volt in the grid will produce. This type of tube is very sensitive when used as a detector or as a radio-frequency amplifier, since it is possible to operate well when the grid is driven or excited by a very low voltage.

The high amplification of this tube is obtained by building the tube with the grid wires very close to the cathode and with the grid wires closely spaced together (see Fig. 205).

With a *mu* of 400, a voltage amplification of 200 per stage is possible. But such a set is so unstable that its use is not practical. Even the screen-grid tubes will oscillate if too high amplification is used. Voltage amplification of as high as 100 may be used for one stage. The amplification should be much less in each stage for two- and three-stage radio-frequency amplifiers.



Fig. 205. Grid-wire spacing in a high-*mu* tube.

**Low-*mu* Tubes.** A low *mu* tube is one which produces a comparatively small voltage increase but which will handle much current. The type 45 tube with a *mu* of $3\frac{1}{2}$ operates so that 1 volt change on the grid needs $3\frac{1}{2}$ volts change on the plate to keep the plate current the same. The grid wires are farther from the filament or the cathode and are spaced farther apart (see Fig. 206). This is possible because more current flows through the tube. Low-*mu* tubes are generally used as amplifiers. An example of a low-*mu* tube is a type 45, which handles about 30 milliamperes of current with an amplification factor of $3\frac{1}{2}$.

## Coupling between Stages

You will find that the extremely high plate impedance of the type 24A tube, 400,000 ohms, makes necessary the

use of either impedance or resistance coupling between the
detector and the audio amplifiers.   Impedance coupling
uses lower B voltage than resistance coupling, but resistance
coupling produces signals of better quality.   These coupling
methods will be explained in detail in part 7 of this chapter.

The type 24A tube, used both as a radio-frequency
amplifier and as a detector, brings to your finger tips dis-



tances that were impossible
with the type 01A tubes.
When you use the type 24A
tube as a detector in regen-
erative circuits, its possibil-
ities are almost unlimited.
The type 24A tube operates
well as an audio-amplifier
tube.

### Special-purpose Tubes
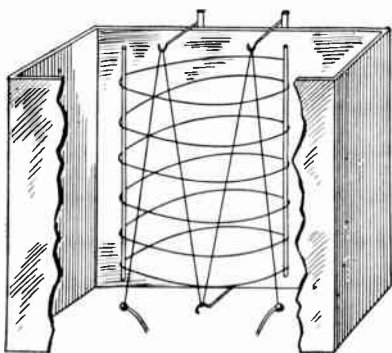
Fig. 206.   Widely spaced grid wires
in a low-*mu* tube.

All of the tubes that we
have mentioned are known
as general-purpose tubes.    Each tube can be used as a detec-
tor or as an amplifier in the circuit with fair results.    The
demand for a tube which could be used in small receiving
sets, but which was capable of high performance, brought
out the special-purpose tubes.    These tubes were developed
around the superheterodyne circuits and for various special
uses.    They have several grids, and in some cases we find
two or three complete sets of elements—of which one may
act as an oscillator, one as detector, and one as amplifier—
in the same glass envelope, serving in place of several tubes.

### Questions

1. What is plate resistance?

2. Is the plate resistance constant in an alternating-current tube?

3. How is the type 2A3 tube made so that it will have a low plate
resistance?

**4.** What types of circuits use tubes with low plate resistance?

**5.** Does the type 24A tube have low plate resistance or high plate resistance?

**6.** Explain what is meant by the amplification factor of a tube.

**7.** How is a tube constructed so that it will have a high amplification factor?

**8.** Is an amplification of 100 satisfactory for each stage when several stages of radio-frequency amplifiers are used?

**9.** What types of coupling are necessary between the detector and the audio amplifier when tubes with high plate impedance are used?

### 3. THE ALTERNATING-CURRENT DETECTOR CIRCUIT

The direct-current–tube detector circuit and the alternating-current–tube detector circuit are very similar. Figure 207 shows circuits for the simple direct-current detector set and for the corresponding detector set using an alternating-current tube.

The aerial coil and the aerial-ground connections are the same. The receiving transformer and the tuning condenser used on each set are the same. The grid leaks and condensers are of the same size on both sets. There is no difference in the tuning circuits.

**The Tube and the Heater Circuit.** *The Socket.* A five-prong socket is used for the type 27 tube. The new prong is for the cathode connection.

*The Heater Circuit.* The alternating-current heater wires run directly from the socket to the heater binding posts. No rheostat is used. The heater current is obtained from a $2\frac{1}{2}$-volt transformer secondary on a power transformer. If the voltage is low at the socket, too few electrons are thrown off the cathode and the signals are weak. For this reason the wires from the filament-heating transformer to the set generally are about size 14. These wires are kept as short as possible. The voltage drops in long heater wires. The wires should be less than 24 inches long from the power transformer to the tube so there will be $2\frac{1}{2}$ volts across the filament wires at the terminals of the tube socket.
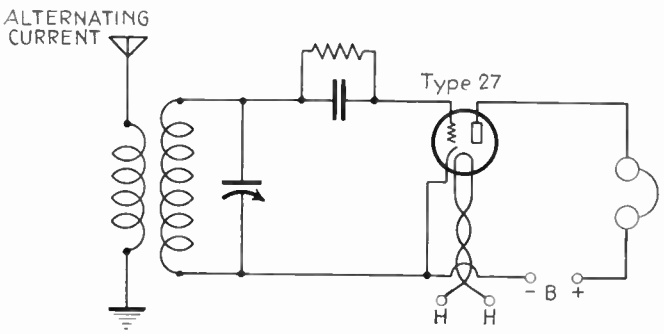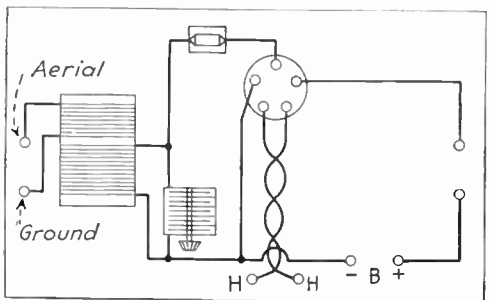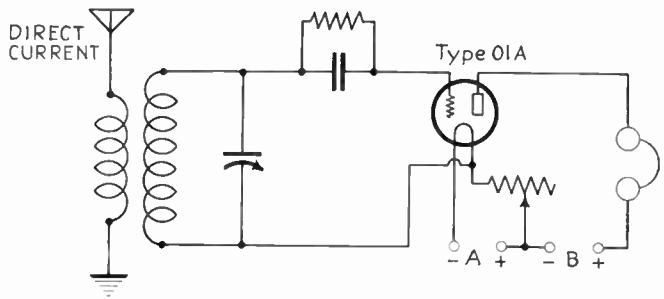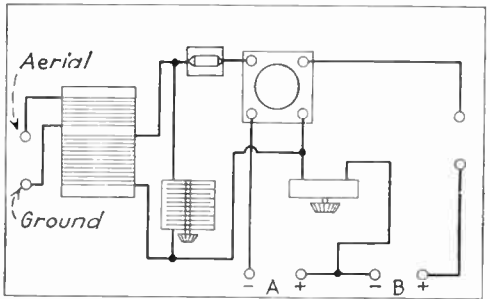
FIG. 207. Detector circuits for alternating-current and for direct-current tubes are similar.

**The Plate Circuit.** The plate circuit and the B supply are the same in the direct-current and alternating-current sets.

### Question

**1.** What changes are made in the circuit to convert a direct-current detector into an alternating-current detector?

## 4. THE ONE-TUBE ALTERNATING-CURRENT DETECTOR SET USING THE TYPE 27 TUBE

### How to Build and Wire the Set

**Parts for This Set.** This is the same board and circuit used for the direct-current detector set. The only new parts needed for this set are a five-prong socket and a type 27 tube (see Fig. 208).

**Changes in Wiring from a Direct-current Set to the Alternating-current Set.** *The Aerial Circuit.* Make no changes (see Fig. 209).

*The Grid Circuit.* Connect the grid return to the cathode terminal of the tube socket.

*Cathode Wire.* Connect a wire from the grid-return and B negative connections to the cathode terminal on the tube base. Connect a wire from the cathode wire to one heater wire if there is any hum.

*Heater Circuit.* Use twisted drop-cord or rubber-insulated wires, not smaller than size 16, long enough to reach from the heater terminals on the tube socket to the board binding posts.

### How to Operate the Set

**Connect the Aerial and Ground.** Connect the aerial and ground lead-in wires to the aerial and ground posts on the set base.

**Connect to the Filament Transformer.** Connect a short piece of twisted drop cord from the $2\frac{1}{2}$-volt alternating-

current posts on the set to the $2\frac{1}{2}$-volt terminals on the
filament transformer.   This drop cord should be not over
2 feet long.

Plug the transformer into a light socket to turn on the set.
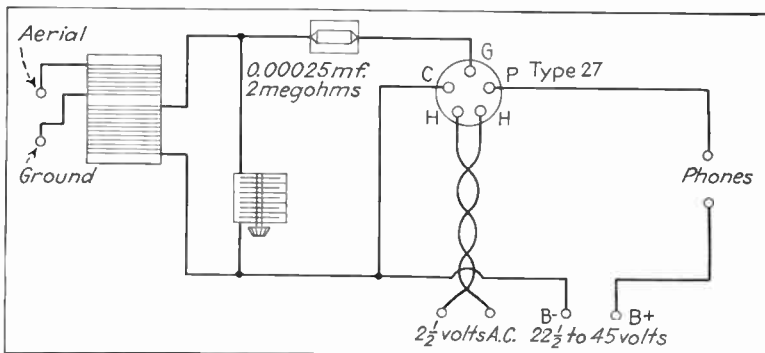


FIG. 208.   Detector set.
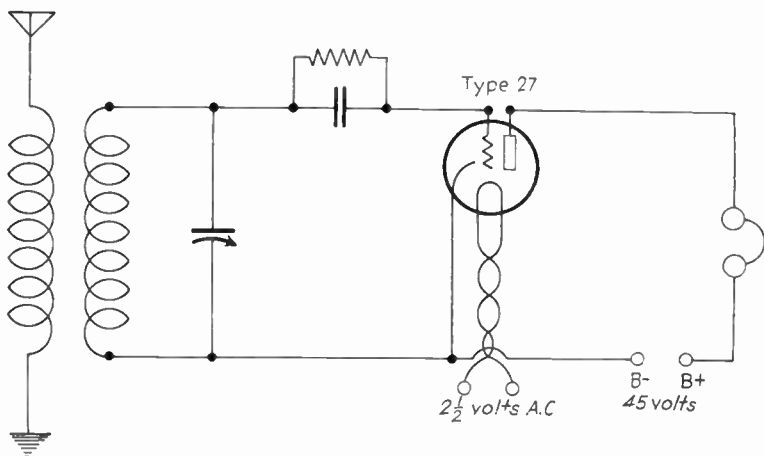


FIG. 209.   Detector set, circuit diagram.

**Connect the B Battery and Phones.**   Connect the B
negative wire first.

Connect the B positive wire to the 45-volt tap on the
B battery.

Connect the phones, and the set is ready to operate.

**Tune in a Station.** The type 27 tube does not change the operation of the set at all. The process of tuning is the same as for the direct-current receiving sets. Adjust the tuning condenser until the desired station is heard the loudest. The tube is somewhat more efficient and the volume should be better.

**Other Tubes that You May Use.** You will find the type 56 a good detector tube. It may be used in the same circuit as the type 27 tube. The type 56 tube will produce slightly louder signals on account of its higher amplification factor.

## Why It Works

The explanation of the operation of this circuit is covered in other circuits we have studied.

**Tuning.** Tuning was explained in Chapter IV. Also, see the explanation for tuning the one-tube detector set in part 2 of Chapter V.

**Cathode.** The purpose of the cathode is explained in part 2 of this chapter; see the explanation of alternating-current tubes in alternating-current receiving sets.

### 5. THE CENTER-TAPPED RESISTOR

In the direct-current receiving sets, the grid-return wire is connected to either the negative or positive side of the filament at the tube socket. Connection is made at the same point from the plate circuit.

The cathode, in alternating-current tubes, is the electron emitter, so the connection from the grid and plate circuits is made to the cathode lead instead of to the filament or heater lead. For alternating-current tubes *that have no cathode* the connection is made to the center tap of a resistor connected across the filament leads.

## How to Wire It

Connect the ends of a 20- to 30-ohm rheostat to each heater terminal on the type 45 tube socket (see Fig. 210).
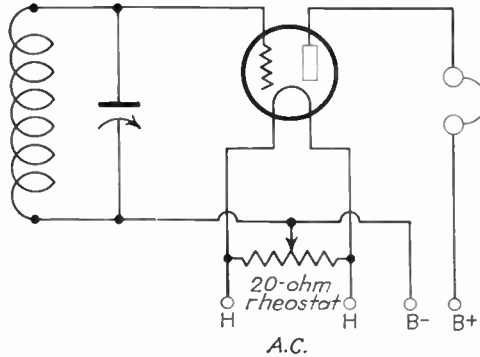


Fig. 210.    Filament-heater tube.

Connect a wire from the rheostat arm to the ground or
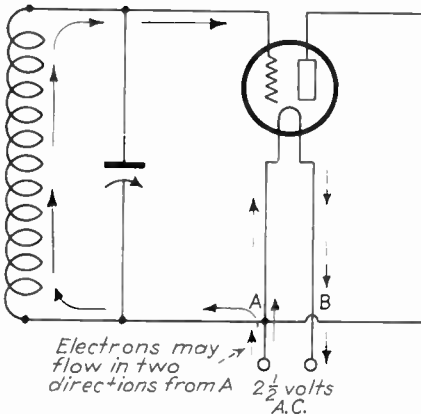


Fig. 211.    This circuit will hum.

B negative wire.

## How to Operate It

Turn the set on.   Set the rheostat contact arm near one end of the resistance element.   Notice the hum in the phones. Move the contact arm to the other end of the resistance element.   Set the contact arm somewhere near the center of the resistance element, until you find a point where you hear the least hum.   Replace this resistor with a standard make of center-tapped resistor.

## How It Works

The filament shown in Fig. 211 is heated by a $2\frac{1}{2}$-volt alternating current.   During one surge of the alternating

current the electrons flow into the filament in the direction
shown by the arrow at *A*.    The resistance of the filament
causes a pressure of electrons at *A*.    As a result electrons
are forced on the grid through the wire connected to the
grid circuit at *A*.    This

makes the grid more neg-
ative and cuts down the
flow of current between
the filament and the
plate.    When the fila-
ment current reverses
and draws electrons from
*A*, the electron pressure
on the grid is less and
more plate current flows.
The alternating current
in the heater wires forces
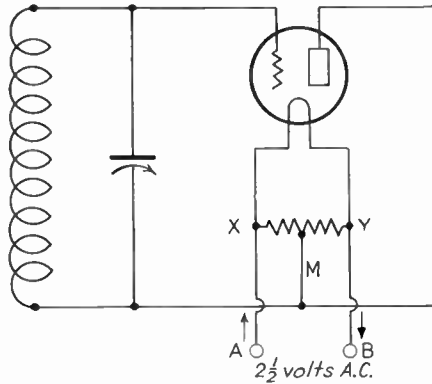


FIG. 212.    This circuit is quiet.

electrons on and off the grid and causes the objectionable
60-cycle hum.

The Center-tapped Resistor Stops Hum.    A 20- to
30-ohm resistor is connected across the filament, as shown
in Fig. 212.    When a surge of electrons flows to the fila-
ment from *A*, it causes a pressure of electrons at *X*.    Some
electrons flow through the resistor toward the center-tap
wire *M*.    But at the same instant there is a demand for
electrons at *Y* as electrons surge away toward *B*.    The
electron pressure from *X* will try to push electrons on wire
*M*, and the electron demand from *Y* tries to pull electrons
off wire *M*.    No electrons will flow from the resistor at *M*
since there is no pressure there to force them to flow.
Instead, nearly all of the electrons will flow through the
low resistance of the filament.    Now you can hear no hum
in the phones because the constant surging of electrons on
the filament does not affect the grid.

Electrons, under pressure of the high B voltage, can flow through the center-tapped resistor quite easily to reach the filament.

### Questions

1. During one cycle of the alternating current, the electrons will flow onto the filament at $A$ (see Fig. 211). When they reach point $A$, they will branch out and flow in two directions. Show these two directions by means of arrows.

2. When the alternating-current surge is on the $A$ side of the filament (Fig. 211), will the grid be made more positive or more negative?

3. When the surge enters on the $B$ side of the filament (Fig. 211), will the grid be made more positive or negative?

4. When a center-tapped resistor is used, as in Fig. 212, the electrons entering the filament on the $A$ side will have a choice of flowing through the filament from $X$ to $Y$ or of flowing through the resistor from $X$ to $Y$. Which path will most of them take? Explain why they choose this particular path.

5. Explain why point $M$ on the resistor will always remain neutral.

### 6. THE ALTERNATING-CURRENT AUDIO AMPLIFIER

We shall now learn how to change the direct-current set into an alternating-current amplifier using type 27 tubes.

## The Set Wiring Changes

**Heater Wires.** Leave off the rheostat. Run two twisted wires to the $H$ posts on the tube socket (see Fig. 213).

**Tube Socket.** Use a five-prong wafer socket in place of the four-prong socket used on the direct-current set.

**Audio Transformer.** The same as on the direct-current board.

**The Grid Bias.** The bias is obtained by a resistor in the cathode lead. Each different B voltage requires a different resistor size for best results. These sizes can be found in any standard tube chart. A 2000-ohm resistor will give fair results.

Shunt the bias resistor with a fixed by-pass condenser of from $\frac{1}{2}$ to 2 microfarads capacity. If the bias resistor is not shunted by a condenser, the set may squeal.
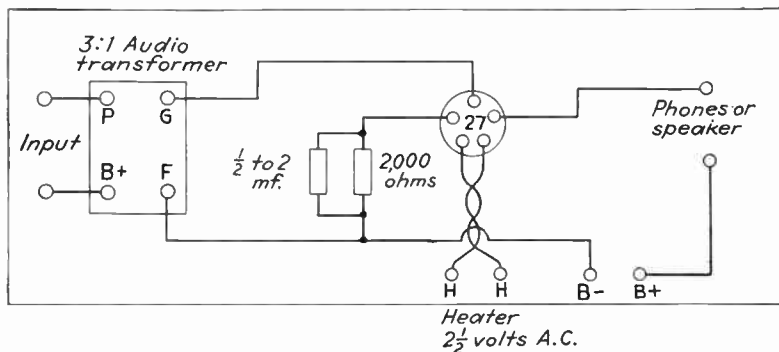


FIG. 213. Alternating-current audio amplifier.
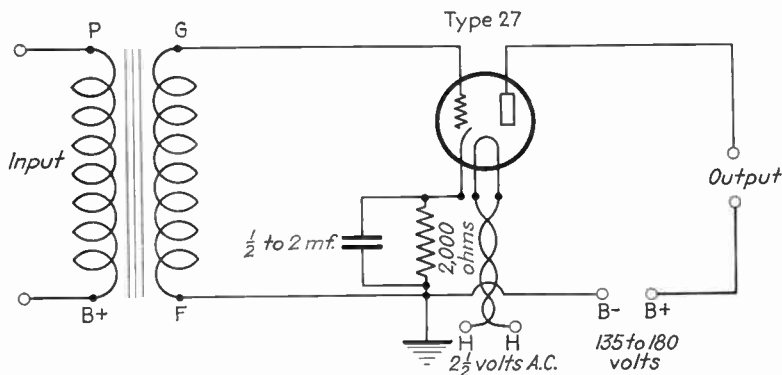


FIG. 214. Alternating-current audio-amplifier circuit.

**The Plate Circuit.** Make no change.

Connect a bias resistor in the cathode lead (see Fig. 214).

**The Heater Circuit.** Twist the heater wires or tie them together parallel to reduce hum. Connect one side of the heater circuit to the cathode lead to reduce hum.

## How to Operate the Amplifier

Connect the $2\frac{1}{2}$-volt alternating-current heater wires to the heater binding posts.

Connect the B battery to B binding posts. Use from 135 to 180 volts in the plate. Find this voltage on a tube chart for the type 27 tube.

The B voltage on the amplifier plate depends on the ability of the audio transformer to carry current. See a tube chart to find the plate current at the voltage you plan to use on the amplifier plate. Not over 10 milliamperes of plate current should be used.

Higher plate voltage causes more plate current to flow. Too much voltage causes distortion of the signals.

Connect the amplifier input terminals to the output of the detector set.

Connect the amplifier output either to phones or to a speaker, and the set is ready to operate.

Turn on the heater current. When the cathode heats, the set is in operation.

**Other Tubes that Can Be Used.** The type 56 tube can be used in this circuit. It uses the same plate voltage. It has a higher amplification factor than has the type 27 tube and so will give somewhat louder signals.

## Why It Works

**Grid Bias Prevents Distortion.** Any effect that changes the wave form of signals that reach the grid is heard in the phones or the speaker as distortion. Distortion is caused by unwanted frequencies in the signals.

When the grid becomes positive, it collects electrons from the filament. This means that during every positive cycle the grid adds electrons to those the signal puts on the grid. This makes the positive loops of the wave stronger than the negative loops, and the signals are of poor quality.

But if enough electrons are kept on the grid, even the strongest positive surge of the signal wave cannot make the grid positive. Now the plate-current wave will be similar to the signal wave, and the signal will be without distortion.

This steady electron pressure which keeps the grid negative is called the grid bias. The grid bias was produced by a C battery in the direct-current audio amplifier.

If the grid bias does not furnish a steady pressure, it will cause variations in the signal which will also produce distortion.

**Purpose of the Cathode Resistor.** In this circuit electrons from the B battery reach the cathode through a resistor, instead of running direct to the cathode as in the detector circuit. Its resistance holds back the flow of electrons enough so that some are forced to flow through the secondary of the tuning transformer to the grid. The resistor keeps a pressure of electrons on the grid. The larger the resistor the higher the voltage of the grid bias. The negative grid bias on the tube causes it to operate very efficiently. Distortion of the signal will occur if no bias is used.
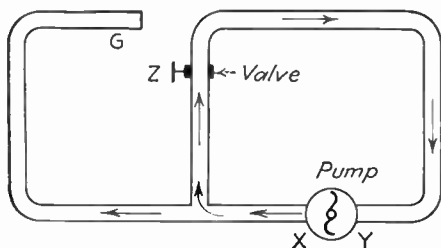


FIG. 215. Pressure changes at *G*.

**Purpose of the By-pass Condenser.** The current flow in the audio-amplifier circuit is similar to the flow of water through a circuit, as shown in Fig. 215. Water flows from *X* to *Y* through the system. We want a steady pressure at *G*. When the valve at *Z* is suddenly closed, there is a sharp jar caused by the sudden stopping of the water flow. This jar causes an increase in pressure at the dead end *G* of the pipe. But

(see Fig. 216) an air chamber at $C$ will act as a shock absorber to absorb the jar. Now, the water can surge into $C$, and the pressure at $G$ will be steady. The grid bias
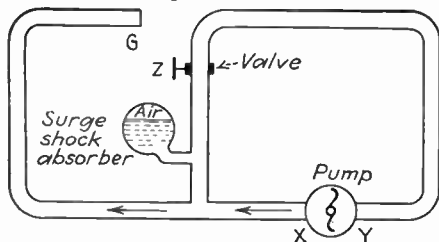


FIG. 216. Pressure constant at $G$.

must be steady. A by-pass condenser is used for this purpose.

**The Current Flow in the Radio Circuit.** When the grid becomes positive, there is a surge of current to the plate. The electrons from the B battery reach the resistor, where they are held up. This throws a sudden pressure of electrons on the grid. But the condenser across the resistor
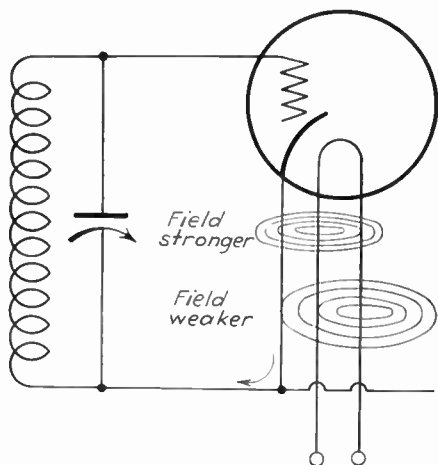


FIG. 217. Induced hum.

acts as a reservoir which absorbs the shock and keeps the pressure steady on the grid.

**The Heater Wires.** The 60-cycle alternating current in the heater wires induces currents in the cathode wire which

is connected to the grid circuit. These currents reach the grid and produce a 60-cycle hum in the phones.

If the heater wires lie parallel, as in Fig. 217, one wire is farther from the cathode wire than the other and will induce a weaker current in the cathode wire than does the closer wire. The weaker current cancels out most of the induced current from the near wire, but enough alternating
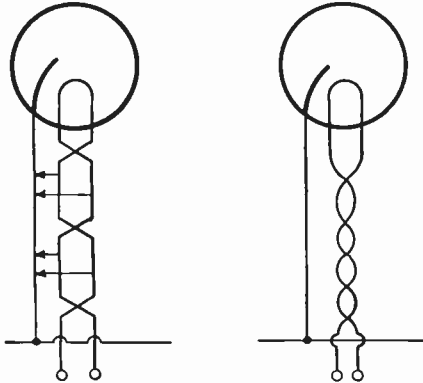


FIG. 218. Overcoming induced hum by twisted heater wires.

current is left in the circuit to affect the grid. The result is a hum.

If we cross, or transfer, the two wires, as shown in Fig. 218, each wire is near the cathode wire for an equal distance.

The field around one heater wire will now induce a current in the cathode wire. But the field around the other heater wire, where the current is flowing in the opposite direction, will induce an opposing current in the cathode wire. One current cancels the other current. The same result may be had by twisting the wires, also shown in Fig. 218.

### Questions

1. Electrons from the B battery have a choice at point $A$ (Fig. 211) of flowing in two directions. Which path will most of them take? Give

reasons for your answer. Explain why any will flow in the other direction.

**2.** Is the grid kept slightly positive or negative in this circuit?

**3.** If there is no condenser connected around the cathode resistor, where will the surge of electrons from the B negative try to go when the grid suddenly decreases the current from the cathode to the plate?

**4.** When the by-pass condenser is in the circuit, show the two possible paths for the electrons when the grid suddenly decreases the current from the cathode to the plate.

**5.** Explain why the electrons choose one of these paths in preference to the other.

**6.** Explain why the wires carrying alternating current to the filament are twisted.

### 7. THE POWER AMPLIFIER CIRCUITS

**Overloading Produces Distortion.** The type 27 tube is overloaded when used as a power amplifier. Increasing the plate current spoils the fidelity of the signals. A power tube should be used.

Audio-amplifier tubes such as the type 71A, type 45, and type 47 power tubes deliver enough power to operate a speaker with good fidelity.

**Power Tubes Produce More Volume.** A power tube, which is designed to handle more current in the plate circuit than a type 27, will produce much louder signals without distortion. The type 27 tube will handle about 5 milliamperes of current, while the type 45 tube (a good power tube) will handle around 30 to 35 milliamperes without distortion. These tubes take the place of the type 71A tube that was used in the direct-current sets. The type 47 power tube will handle even more current; but the quality of the signals produced by the type 47 tube is not as good as that produced by the type 45 tube. The Type 45 is a low-*mu* tube and the type 47 is a high-*mu* tube with considerable current amplification.
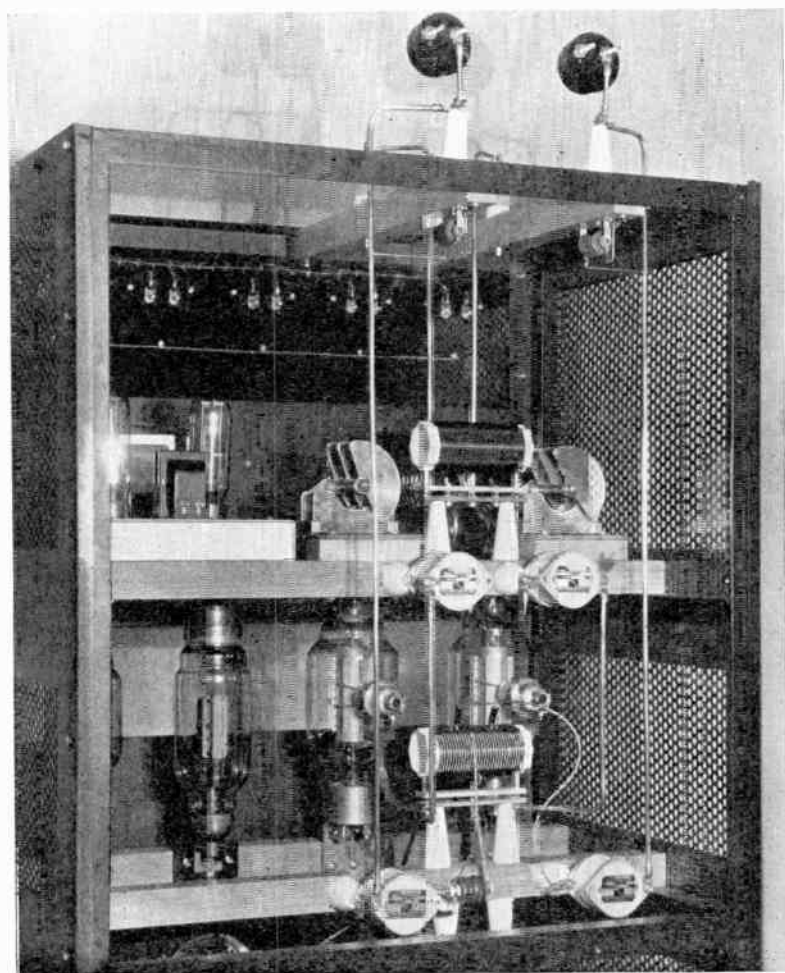
TRANSMITTER FOR A BYRD EXPEDITION TO LITTLE AMERICA
This view behind the panel of the transmitter shows a close-up of the power amplifier.

**Coupling of Speakers.** The current output of either the type 45 tube or the type 47 tube is so high that phones or a speaker should not be connected directly in the plate circuit of either. Neither phones nor speaker should carry over 10 milliamperes of current.

The output of these tubes must be coupled to the speaker so that the speaker or phones will not carry the full plate current.

Two ways of coupling the power tubes to the speaker are given in part 8 of this chapter. The impedance coupling circuit uses a condenser and a choke coil. The more common circuit uses an output transformer. The transformer secondary delivers the proper voltage to the speaker coils.

**Coupling to Detector or Amplifier Stage.** The type 45 power amplifier follows a type 27 audio amplifier because there is not enough power in the detector output to operate the type 45 tube well.

The type 47 tube can be connected direct y to the detector, since the type 47 requires less grid voltage for its operation.

You may couple both the type 45 and the type 47 power tubes either to the detector or to the audio amplifier by transformer coupling.

### The Power Amplifier Using Type 45 Tube

The power audio amplifier using the type 45 tube produces signals of good quality at loud-speaker volume. The board layout is shown in Fig. 219 and the circuit in Fig. 220.

**How to Operate It.** When the A and B voltage is turned on, this set is in operation.

**Why It Works.** The operation of this set has been covered in explanations earlier in this chapter.

## Push-pull Power Audio Amplifiers Using Type 45 Tubes

**Advantage of Push-pull Audio Amplifiers.** The push-pull circuit shown in Fig. 221 is used as the power audio
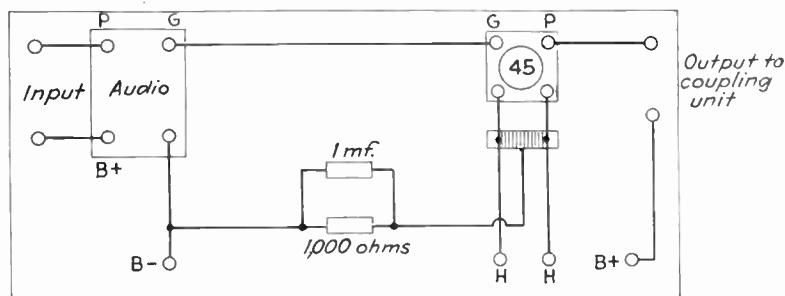


FIG. 219.     Power audio amplifier.

stage. Signals of greater volume can be had with much less distortion by using power audio tubes with these circuits than by using the straight single-tube power amplifier circuit. Higher B voltage can be used on the plates.
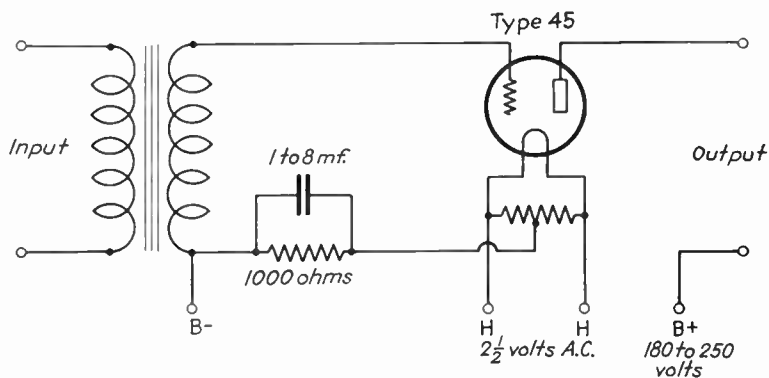


FIG. 220.     Power audio-amplifier circuit.

**How to Wire the Circuit.** Mount the parts on a small board as shown in Fig. 221. Two special push-pull transformers are needed with this circuit.

The bias resistor has half the resistance used for the same
tube in a single-tube circuit.    The size of this resistor must
be correct.    The same push-pull transformers can be used
with any tube combination.    Distortion and loss of power
will occur if the bias is incorrect.

**How to Operate It.**    Turn on the heater and B power.
The set is in operation.    There are no adjustments for this
circuit.
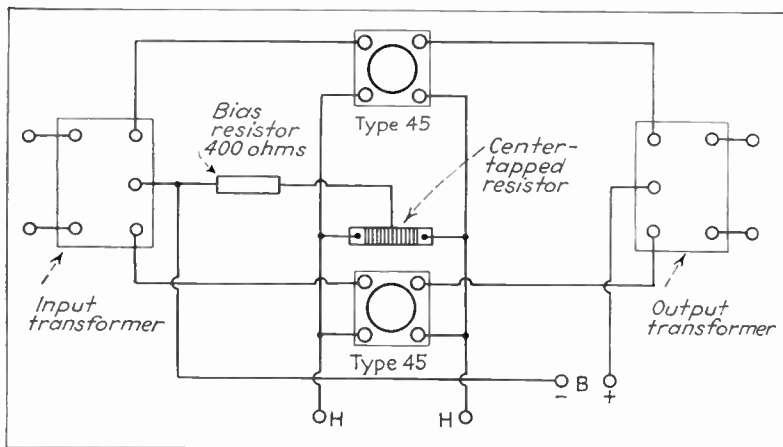


Fig. 221.    Push-pull audio amplifier.

**How It Works.**    A coupling transformer is connected
between the first audio-amplifier stage and the push-pull
amplifier stage, as shown in Fig. 222.    Each end of its
secondary is connected to the grid of one amplifier tube.

The input-transformer primary $P_1$ is connected in the
plate circuit of an audio-frequency amplifier.    Let us follow
the effect which electron surges in the audio-amplifier plate
circuit have in the push-pull amplifier circuit.

*The Grid Bias.*    The electron pressure put on both grids
by the grid-bias resistor makes both grids negative.    The
grids must never become positive, or they will draw current
and will distort the signals.

*The Effect of a Surge of Increasing Strength.*    When a
surge of electrons flows through the primary $P_1$ of the
coupling transformer (Fig. 223), it causes electrons to surge
through the secondary as shown by the arrows, while the
primary surge is growing in strength.    Electrons surge to
the grid of tube 1 and make it more negative.    The negative
grid shuts off most of the flow of electrons through tube 1.
This causes a weak current to flow, as shown by the light
arrows in Fig. 223.
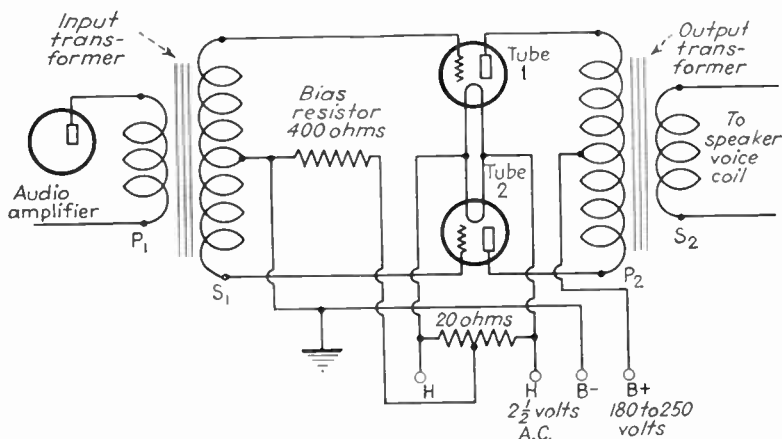


FIG. 222.    Push-pull audio-amplifier circuit.

The secondary has pulled some electrons off the grid of
tube 2 during this surge, making the grid less negative.
The less negative grid makes more current flow to the plate
of tube 2, and a strong surge of electrons from the plate
circuit of tube 2 flows through the primary of the output
transformer and back through the center-tap connection
to the B battery, as shown by the heavy arrows.

*The Current in the Output-transformer Secondary $S_2$.*
When the current flow through tube 2 (Fig. 223) is increas-
ing in strength, it induces a current in secondary $S_2$, as
shown by the heavy arrow.

At the same instant the current through tube 1 is decreasing in strength. It induces a current in $S_2$ that adds to the first current.

When the surge of electrons through $P_1$ reverses, as shown in Fig. 224, the increasing current through tube 1 induces a current in $S_2$ as shown by the heavy arrows. At the same time the decreasing current through tube 2 induces a helping current as shown by the light arrows. Again, both currents in $S_2$ add.
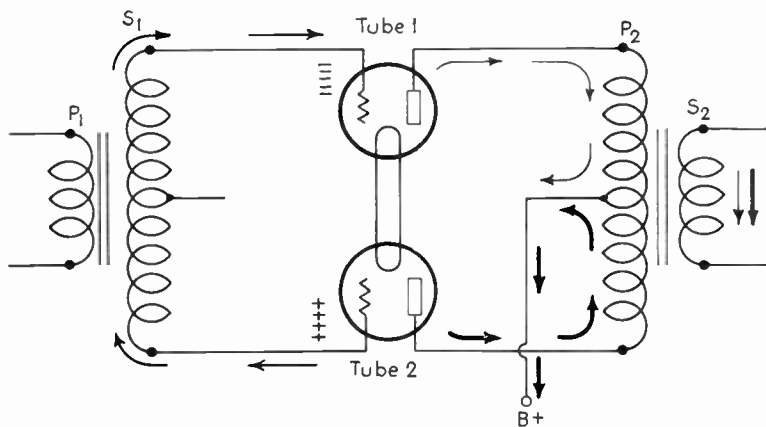


Fig. 223. Current surge in push-pull circuit.

*The Tubes Act as an Electric Switch.* The two tube grids switch the plate current from one tube to the other so that much current flows through one tube during one half cycle. During the other half cycle the other tube works. A much higher power output is possible with this circuit than with a straight amplifier. Higher B voltage can be used without heating the tube plates. Heavy plate current flows only for a half cycle, and the plate cools during the other half cycle. A half of each input surge cuts down the current flow through one tube and allows much current to flow to the plate of the other tube.

*The Second Harmonic.* Harmonics are developed in the transformers of all circuits. The second harmonic is twice the fundamental frequency. The fundamental is called the first harmonic. A 500-cycle note will have a second harmonic of 1000 cycles. It will have many other harmonics which are so weak that they are disregarded.
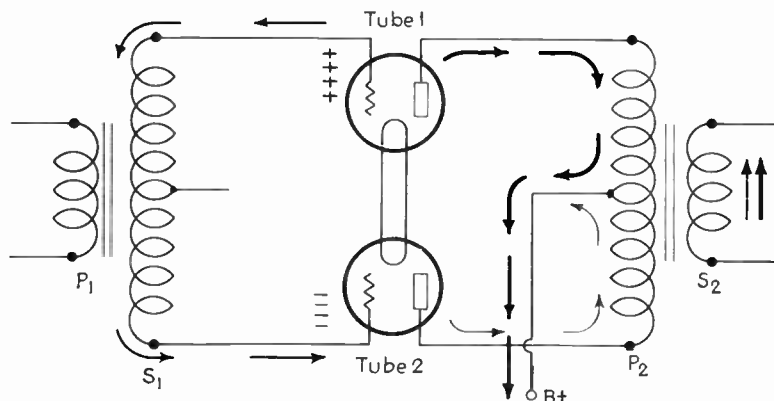


Fig. 224.   Current surge in push-pull circuit.

The second harmonic is the strongest. It stresses frequencies double the frequency of the signal that is being amplified.

In the push-pull amplifier the second harmonic is eliminated by the circuit.

### Questions

1. What causes the grids of the push-pull circuit to remain negatively charged?

2. Does the current flow in the same direction all the time through the secondary of the coupling transformer?

3. Does a strong current flow through both tubes at the same time?

4. Does the current always flow in the same direction through the center tap of the primary of the output transformer?

5. Why can a much higher power output be used with a push-pull circuit than with a single-tube amplifier?

## Power Audio Amplifier Using Type 47 Tube

**The Circuit.**　This circuit is similar to the type 45 circuit (see Fig. 225).　Here both the screen grid and the plate are attached to the same B positive post.

**How to Operate It.**　Attach from 180 to 250 volts to the plate.　When the set is turned on, this amplifier is in operation.
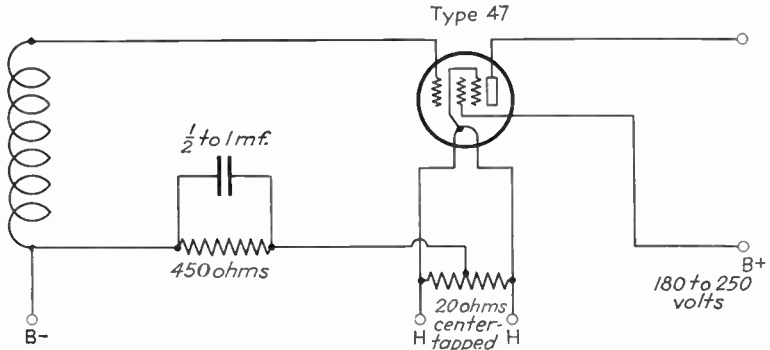


Fig. 225.　Type 47 power audio-amplifier circuit.

**How It Works.**　See the explanation for the type 45 audio amplifier.　See also the explanation of the operation of the type 47 tube.

### 8. COUPLING BETWEEN THE POWER TUBE AND A MAGNETIC SPEAKER

## Output-transformer Coupling

The magnetic speaker must not be connected in the plate circuit of a power tube when the plate current is over 10 milliamperes.　This much current will burn out the windings of the magnetic speaker.　The plate currents of both the type 45 and the type 47 power tubes are over 30 milliamperes.

Connect the speaker to these power tubes either by an output transformer or by an impedance coupling.

**How to Wire the Transformer Circuit.** Use a special output transformer wired as in Fig. 226 and Fig. 227. An audio transformer is not satisfactory.
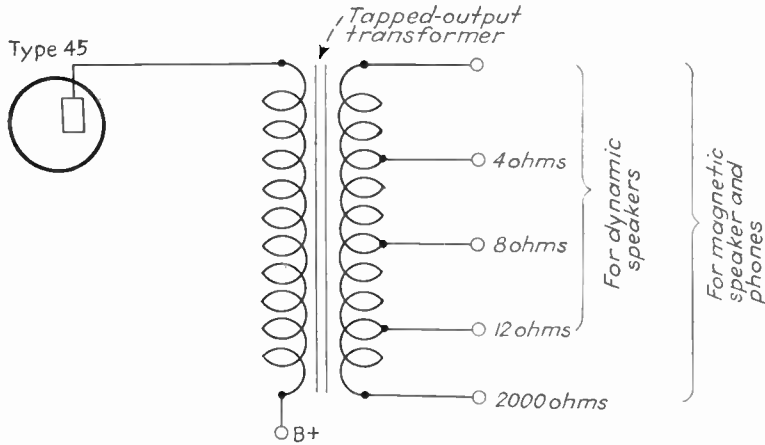


FIG. 226. Speaker connections through universal-output transformer with type 24A tube.
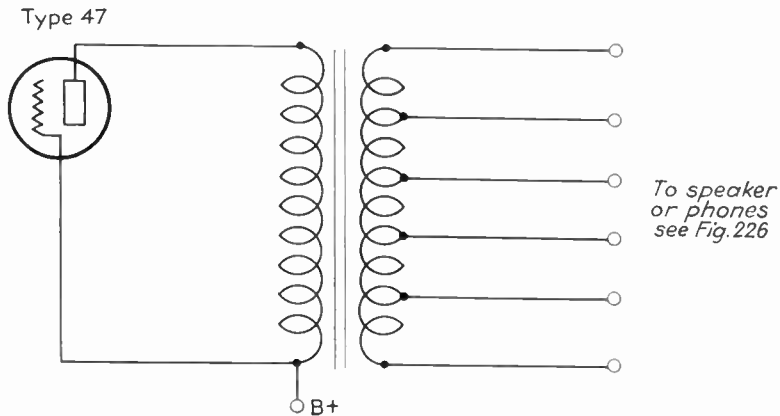


FIG. 227. Speaker connections through universal-output transformer with type 47 tube.

The resistance of the primary must be the same as the plate resistance of the tube to which the transformer is to

be connected.    The impedance of the secondary must be
the same as the impedance of the voice coil for best volume
and quality of signals.    An output transformer for the type
45 tube can also be used for a type 12A or type 71A tube.

**How It Works.**    Surges of plate current through the
primary induce an alternating current in the secondary of
the output transformer.    This current flows through the
windings of the speaker and causes the diaphragm or the
cone of the speaker to move and to produce sound.

### Question

1. What size output transformer should be used with the type 45 or
47 tubes?

## Impedance Coupling

If you do not have the right output transformer for the
tube you wish to use, you may use a condenser and a choke



Fig.    228.    Speaker    connections    through
impedance coupling with type 45 tube.

coil to form an output
impedance coupling unit
which will take the place
of the transformer.

**Parts Needed.**    Use a
choke coil which has an
inductance of from 10 to
30 henrys.    This coil
may be one taken from
an old power supply.
Use a coupling condenser
of from 1 to 8 microfar-
ads capacity rated at 400

volts or over.    Connect the parts as shown in Fig. 228 and
Fig. 229.

**How It Works.**    Electrons flowing from the plate of the
power tube reach the B battery through the windings of

the choke coil. The choke coil must be wound with wire large enough to carry the current handled by the tube.

When no signals are coming through the circuit, there is a steady flow of current (direct) from the filament to the



Type 47

180 to 250 volts
B+
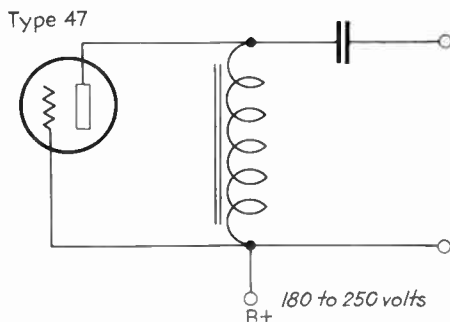
FIG. 229. Speaker connections through impedance coupling with type 47 tube.

plate of the tube, through the choke coil, through the B battery, and back to the filament of the tube. But when signals come through the circuit, the plate current becomes a pulsating direct current. Instead of letting the surges flow directly to the B battery, the back pressure caused by the inductance of the choke coil resists the sudden change in the quantity of electrons trying to flow through the coil. So electrons are forced to flow to side *A*



P          A  B          Speaker
                          coil

Audio
amplifier
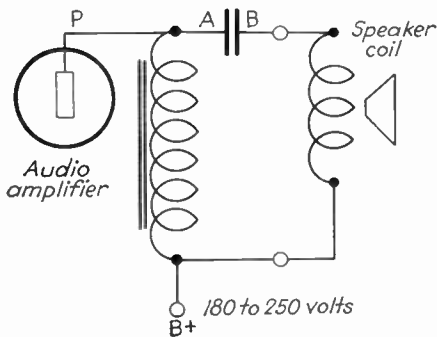
180 to 250 volts
B+
FIG. 230.

of the coupling condenser (see Fig. 230). Electrons from side *A* drive electrons off side *B* through the speaker coil. This causes the speaker cone to move, which produces sound.

The capacity of the coupling condenser must be large to allow the surges of the plate current to be transferred to the speaker. The size of the choke coil must be selected so the electrons can flow through the choke rapidly enough to prevent distortion of the surges. Yet the choke must have enough back pressure to drive electrons through the coupling condenser to make the speaker operate well.

### Questions

1. Trace the path of the electrons through the choke and condenser at the beginning of a surge from the plate.

2. Trace the path of the electrons through the choke and condenser at the end of a surge from the plate.

### 9. THE ALTERNATING-CURRENT RADIO-FREQUENCY AMPLIFIER USING THE TYPE 24A SCREEN-GRID TUBE

**Type 24A Tube.** The screen-grid tube is a very sensitive detector as well as an excellent amplifier tube in the radio-frequency stages. The screen grid prevents oscillation which causes howling and other annoying effects.

By varying the voltage on the screen, you can change the sensitivity of the tube and thus control the gain in signal strength of that stage of amplification. You can also control the gain of the tube by changing the grid bias. Since this tube is so sensitive it may be necessary to provide better than ordinary shielding to prevent induction from circuit wires from affecting its operation.

### How to Wire the Set

**The Tuning Circuit.** Keep the grid wire leading from the tuning coil or condenser to the cap on the tube as short as possible and placed well away from the other wires to prevent pickup.

**The Bias Resistor.** A fixed bias resistor is used in place of a C battery. Connect a noninductive 500-ohm 1-watt

resistor in the cathode lead as shown in Fig. 231 and Fig. 232.

## How to Operate the Set

*Step* 1. Tune the amplifier. Turn on the heater current. The amplifier and detector are in operation as soon
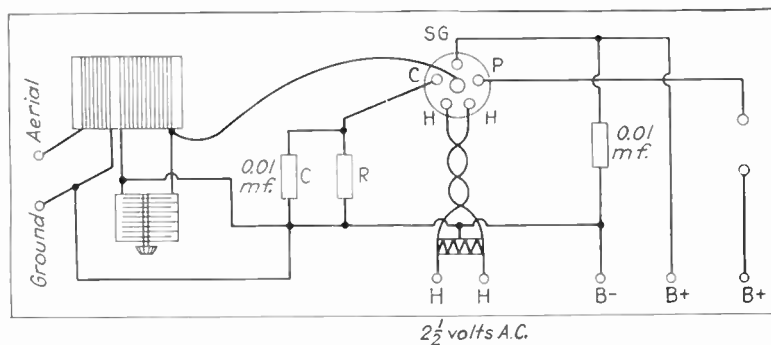


FIG. 231. Radio-frequency amplifier with screen-grid tube.
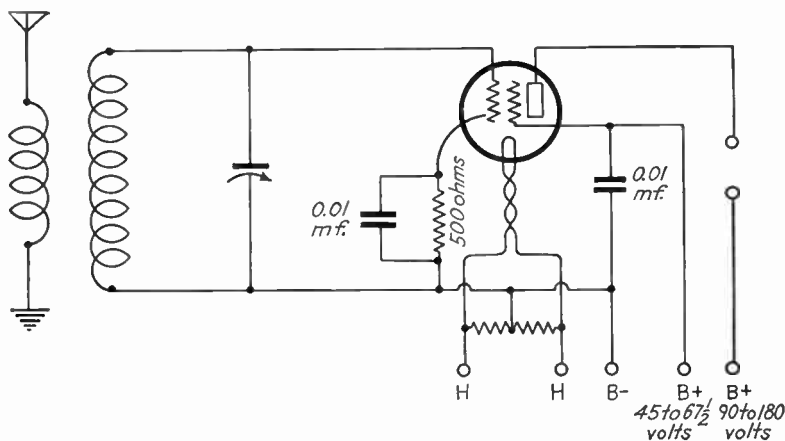


FIG. 232. Radio-frequency amplifier circuit with screen-grid tube.

as the cathodes of the tubes are hot and the B voltage turned on. There are no adjustments for the tubes. Tune

this set with the variable condenser as in the direct-current radio-frequency amplifier.

*Step* 2. Tune the detector set. Tune in stations on the detector set. If a regenerative receiver is used, it should be in oscillation while you tune in the station. Turn the detector regeneration control back just below the oscillating point after the station is tuned in.

Tune the radio-frequency stage and the detector stage together, since the tuning of one affects the tuning of the other. A type 24A radio-frequency amplifier will give you considerable gain in signal strength.

**The Effect of Shielding.** Shield the radio-frequency amplifier from the sensitive detector set either by tube shields or by a metal plate or box, if the set squeals or has dead spots in tuning. Connect the shield to the ground.

## How It Works

**How This Circuit Is Tuned.** The signal picked up by the aerial flows through the primary of the tuning transformer and induces a current in the transformer secondary. The electrons surging in the secondary are tuned by the variable condenser to select the frequency desired by the operator.

**Action of the Grid Circuit and Plate Current.** The radio-frequency surges from the tuning circuit on the control grid of the type 24A tube cause the plate current to flow in radio-frequency pulses. The plate-current wave shape is the same as the wave shape of the radio-frequency surges on the grid of the tube, but is much stronger.

The radio-frequency plate-current surges flow in the primary of the coupling transformer. These surges induce a radio-frequency alternating current in the secondary of the radio-frequency coupling transformer which is connected to the next radio-frequency stage or to the detector stage.

These surges are still at radio frequency but are amplified by the screen-grid tube and by the voltage step-up of the coupling transformer.

**Inductive Resistors Cause Squeals or Hums.**    If you use an inductive resistor in the cathode lead, your set may hum or it may squeal.    An inductive resistor is made of resistance wire wound on an insulating rod.    The wire forms a small coil.    If the coil is of a size that has a resonant frequency of oscillation at or near 60 cycles, an oscillating current will build up in the resistor and will cause a variation in the grid bias that you hear as a 60-cycle hum.

If the resistor is wound so the resonant frequency is higher, a squeal may result.    The only remedy for this condition is to replace the resistor with a noninductive carbon resistor.

### Questions

**1.** Compare the wave shape of the current on the grid with the wave shape of the current in the plate circuit.

**2.** Is the current on the grid an alternating current or a pulsating direct current?

**3.** Is the current in the plate circuit an alternating current or a pulsating direct current?

**4.** Is the current in the secondary of the coupling transformer an alternating current or a pulsating direct current?

**5.** Compare the amplitude of the current in the secondary of the coupling transformer with that of the current on the grid of the tube.

**6.** Explain how an inductive resistor in the cathode lead can cause your set to squeal or hum.

## Volume Control—How to Control the Amplification or Gain

For receiving distant stations as well as for bringing in other weak signals, several stages of radio-frequency amplification are valuable.    Some stations are farther from the receiver than others, and some stations have more power than others.    If the set is made sensitive enough to receive

the distant stations well, some programs will be loud enough to be unpleasant. A method of controlling the volume is very desirable. Two volume-control circuits are shown
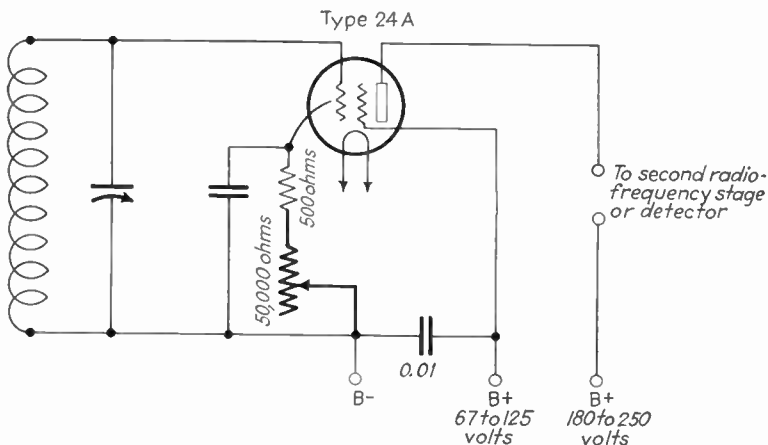


FIG. 233.   Volume-control circuit in radio-frequency stage.
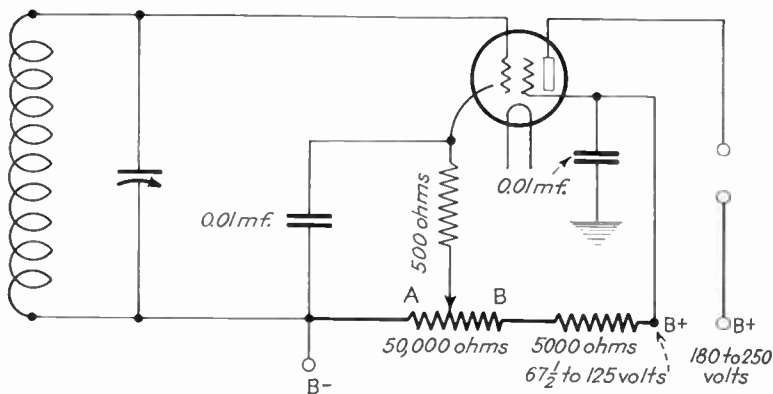


FIG. 234.   Volume-control circuit in radio-frequency stage.

here in Fig. 233 and Fig. 234. The control in Fig. 234 is smoother in operation.

**How to Wire the Circuit.** Connect a 50,000- to 100,000-ohm variable resistor in series with the cathode resistor as shown in Fig. 234.

**How to Operate the Set.** Turn the set on. Set the contact arm of the volume control at point *A* (see Fig. 234). Here none of the resistance is in the circuit, and you will receive the loudest signals. When you wish to cut down the volume of signals, turn the arm toward point *B* until you find the point where you get the desired volume.

**How It Works.** The bias on the type 24A radio-frequency tube in this circuit is correct for normal operation when the contact arm of the resistor is at point *A*. A negative bias of 3 volts is on the grid at this position. As the contact arm on the volume control is turned toward point *B*, the resistance in this circuit is increased. This increases the voltage drop across the resistor and increases the negative bias on the control grid, gradually bringing the tube toward cutoff. If the resistor is large enough, you can move the contact arm to point *B* and entirely stop any signals. Here the tube is biased entirely to cutoff.

### Question

1. Explain how making the grid more negative will decrease the volume of music.

## How to Couple Radio-frequency Stages to Other Circuits Using the Type 24A Screen-grid Tube

**Inductive Coupling between Radio-frequency Stages.** The circuit boards we have built for the radio-frequency stage may be coupled together by connecting the output of the first radio-frequency stage and the aerial-ground posts of the second radio-frequency stage. The circuit of this combination is shown in Fig. 235. This is inductive coupling between stages. The aerial coil and the grid coil act as a radio-frequency coupling coil here, as they do when used for the coupling coil between the aerial circuit and the grid circuit.

**Inductive Coupling between the Radio-frequency Amplifier and Detector Board.** When the radio-frequency amplifier is coupled directly to a detector, it may be coupled inductively by connecting the output of the plate circuit
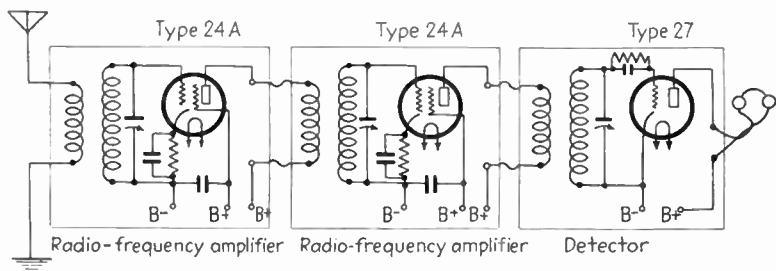


Fig. 235.   Inductive coupling between radio-frequency amplifier stages.
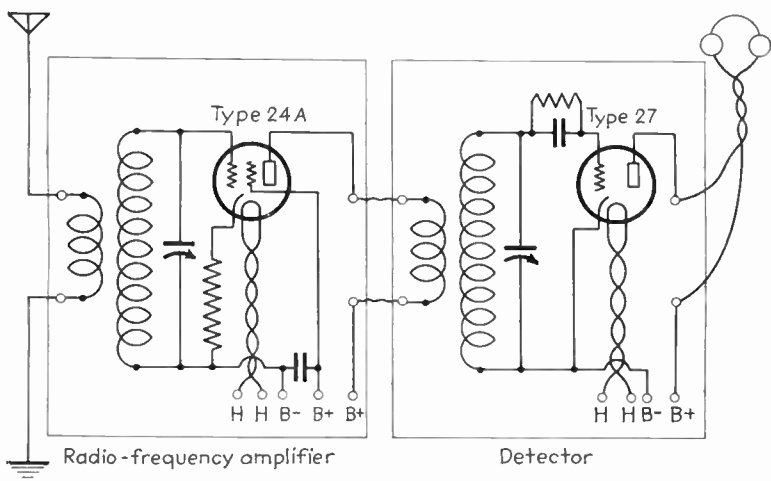


Fig. 236.   Coupling between alternating-current detector set, type 27 tube, and amplifier, type 24A tube.

of the radio-frequency stage to the aerial coil of the detector set. This circuit is shown in Fig. 236. The plate current flowing through the aerial coil of the detector set must not get into the grid coil.

## 10. THE ALTERNATING-CURRENT DETECTOR SET USING THE TYPE 24A TUBE

### How to Build and Wire the Set

**New Parts Needed.** A 25,000- to 100,000-ohm variable resistor—the resistor may be wire-wound, carbon, or other type—for controlling regeneration.

A $\frac{1}{2}$- to 1-microfarad by-pass condenser—for by-passing the radio-frequency surges from the screen grid to the cathode.
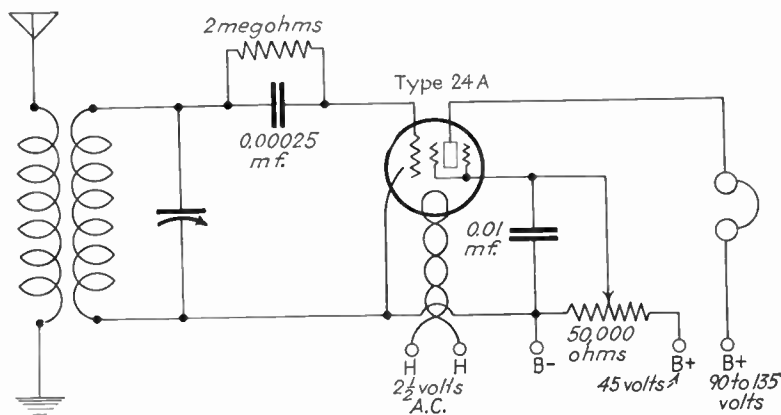


FIG. 237.   Detector circuit with type 24A tube.

**Circuit Changes.** A new B positive connection is added to supply the screen-grid voltage (see Fig. 237).

The screen-grid connection is made to the base terminal that was used for the control grid on the type 27 tube.

The control grid on the type 24A tube is connected to the metal cap on top of the tube.

**Coupling.** Impedance or resistance coupling must be used between the detector and the amplifier tubes.

**Wiring Changes.** Make connection to the control grid by a flexible wire between the grid condenser and the clip.

Connect the center terminal of the variable resistor to the screen-grid post on the tube socket.

Connect the ends of the resistor to the B negative and the B positive 45-volt terminal. Connect the by-pass condenser between the screen terminal on the tube socket and the cathode or the B negative lead. Connect the by-pass condenser as close to the socket terminal as possible.

### How to Operate the Type 24A Detector Set

There is little difference in the operation of the type 24A set and the type 27 set. You now have a sensitivity control in the variable resistor.

This control also governs the volume of the signals.

You will find this tube to be very much more sensitive than the type 27 tube, and you may expect to hear many new stations. The volume will be much better than before.

Connect 45 volts to the B positive screen terminal.

Turn the variable resistor about half in.

Tune the set with the variable tuning condenser. When the desired station is tuned in, move the variable resistor until the best volume and the clearest reception is had.

Use a .00025-microfarad grid condenser and a 2-megohm grid leak for receiving broadcast stations.

**Other Tubes That May Be used in This Circuit.** *The Type 35 Tube.* This tube can be used in the same circuit with no change. It is a variable-*mu* tube which is more stable than the 24A and is more sensitive.

*The Type 36 and the Type 39/44.* Both tubes are more sensitive than the type 24A and have higher amplification. Both tubes must have the heater voltage increased to 6 volts.

### How It Works

Sensitivity is controlled by the potentiometer in this screen-grid circuit. When you move the arm of the poten-

CHECKING UP
Even the smallest part must be tested in order to give a set its maximum efficiency.

tiometer, you increase or decrease the positive voltage on
the screen.   As there is more positive pull from the B
battery, the electrons rush to the plate faster, and more
current flows in the plate circuit.   This makes louder
signals in the phones.

### Question

1. Explain how changing the voltage on the screen grid will affect
the volume of signals.

## Coupling between Screen-grid Detector Tube and the Audio Amplifier

**Impedance Coupling.**   Impedance  coupling  is  used
between a screen-grid detector tube and an audio amplifier
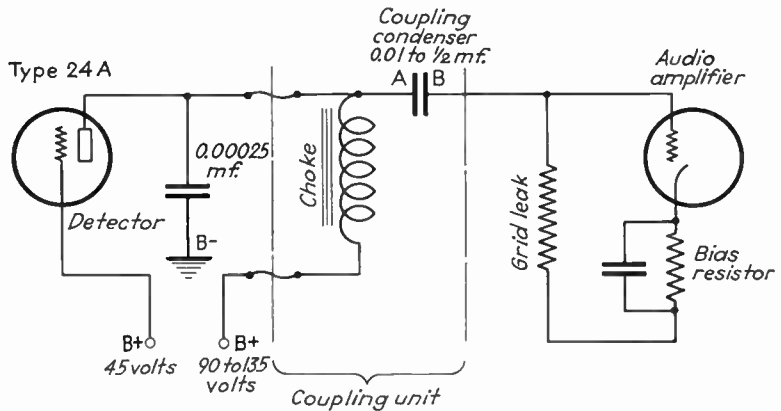


Fig. 238.    Impedance coupling between screen-grid detector and audio-amplifier
circuits.

because the impedance of the choke coil acts as a load that
is nearly the same as the plate resistance of the screen-grid
tube.   Transformer coupling is not satisfactory, since the
transformer primary impedance is too low.   Transformer
coupling produces distorted signals and low volume.

An impedance-coupled set will produce loud signals, but the quality of the music it produces will be only fair. This circuit is popular with amateurs because it will bring in code quite efficiently, producing loud signals from weak stations.

**How to Build and Wire the Circuit.** Connect a 30- to 200-henry audio choke coil in the detector plate circuit (see Fig. 238). You may substitute an audio transformer for the choke (see Fig. 239). A transformer is not as efficient as a choke. The coupling condenser may be of any capacity between .01 and $\frac{1}{2}$ microfarad.

**The Action of the Choke.** When the grid of the type 24A is positive, it causes electrons to surge to the plate. This surge tries to reach



FIG. 239. Audio transformer used as a choke.

the positive terminal of the B battery, but the back pressure of the choke coil holds up the surge of current and causes the electrons to pile up on both the coupling condenser and by-pass condenser.

At the first of the surge only a few electrons can get through the choke. As the surge grows in strength, the back pressure of the choke becomes less and more electrons get through. When the back pressure is gone, the electrons "whiz" through.

When the electrons of this surge have reached the B battery, the choke tries to pull more electrons.

The alternating-current resistance to the flow of current through the choke is never steady. It is very high at the first of the surge and very low at the end of the surge.

**The Coupling Condenser.**    The coupling condenser stops
the flow of direct current and keeps the high plate voltage
off the grid of the amplifier tube.

Surges of electrons on side *A* drive electrons from side *B*
to the amplifier-tube grid (see Fig. 238).    The size of the
coupling condenser is selected to allow all audio-frequency
surges to get to the grid of the audio-amplifier tube.

The electrons on the by-pass condenser drive electrons
from the other plate and into the ground.    The rapid radio-
frequency surges of the plate current can continue without
distortion since the by-pass condenser returns the surges to
the ground.    If the surges were forced to go through the
choke, they would be slowed up so much that the radio-
frequency wave shape would be different from the wave on
the grid and the signals would be distorted.

### 11. THE SUPERHETERODYNE RECEIVER

The ultimate desire of the designer is to develop a receiver
which is so sensitive that it will pick up extremely faint
signals.    This set must also be able to tune very sharply,
yet not so sharply that it will spoil the quality of the signals
it receives.    It should be simple to tune and should be able
to produce signals of good volume.    The superheterodyne
has these qualities.

**The Superheterodyne Receiver Introduces a New Prin-
ciple.**    Amplification of the superheterodyne is unusually
good because it amplifies at one fixed frequency.    This
makes it possible to develop an amplifying circuit of higher
efficiency than the usual audio- and radio-frequency circuits,
which must operate fairly well on many frequencies but not
perfectly on any one frequency.    The audio- and radio-
frequency amplifiers we have studied had to amplify fre-
quencies ranging from 500 kilocycles to 1500 kilocycles.

**We Must Build Two New Units.**    A new unit, called the
intermediate-frequency amplifier unit, is connected into the
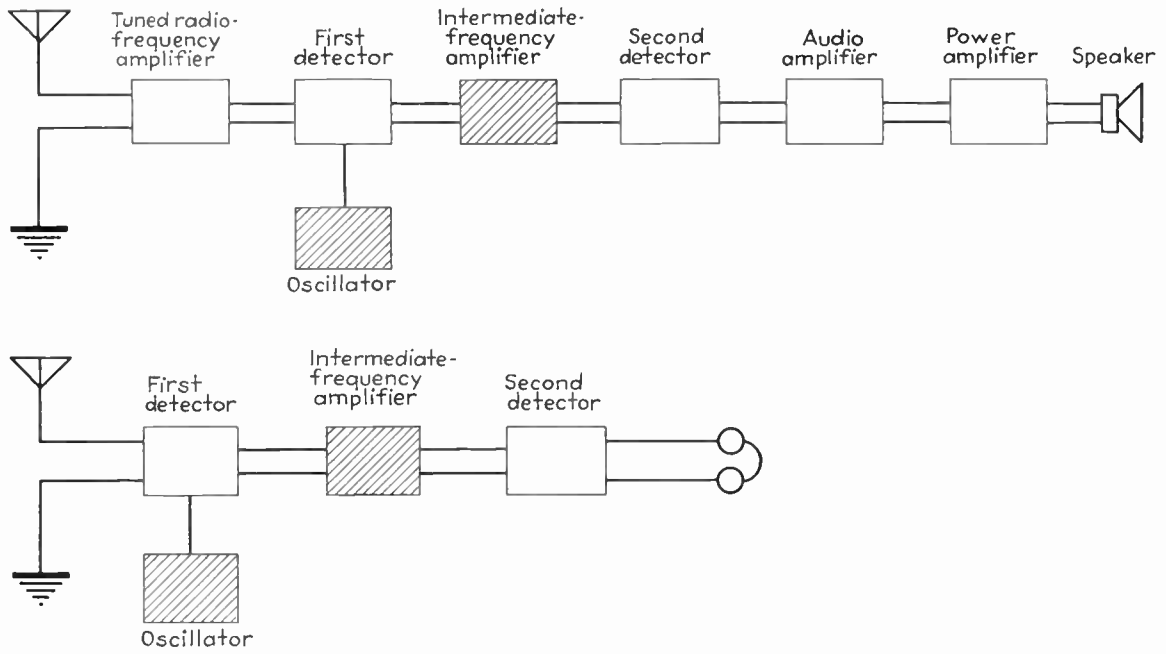
Fig. 240. Superheterodyne units. Units introduced into the set for the first time are the intermediate-frequency amplifier and the oscillator. These are shaded in this figure.

set. This unit tunes all signals at one fixed frequency of 465 kilocycles. The intermediate-frequency transformers are set at 465 kilocycles because this frequency is free from interference. Frequencies as low as 150 kilocycles could be used if it were not for interference. The efficiency of this circuit is due to the use of highly efficient coupling transformers in the intermediate-frequency amplifying stages.

Another new unit, called the oscillator, "leads" incoming signals into the intermediate-frequency unit. The intermediate-frequency units amplify at a low radio frequency where amplification is more efficient than at high radio frequencies. The effect of the use of the more efficient amplifying circuit is to bring in stations that would not otherwise be amplified enough to be heard.

We shall assemble a superheterodyne receiver by combining several of our standard alternating-current circuits with the new intermediate-frequency amplification unit and the new oscillator unit to form a superheterodyne circuit (see Fig. 240).

The high sensitivity of the superheterodyne receiver is obtained by using beat-note tuning. The fine selectivity of this receiver makes it popular for world-wide short-wave reception of broadcast programs. The superheterodyne is widely used by amateurs where selectivity is of utmost importance on account of the many amateur transmitting stations which are grouped into very narrow operating bands.

### How to Build and Wire the Set

It will be necessary to build only two boards for this set, the intermediate-frequency amplifier unit and a second unit for the oscillator. See Fig. 241 for the circuits.

Connect the wire shown in the circuit diagram (Fig. 241) that runs from the plate of the oscillator tube to a point
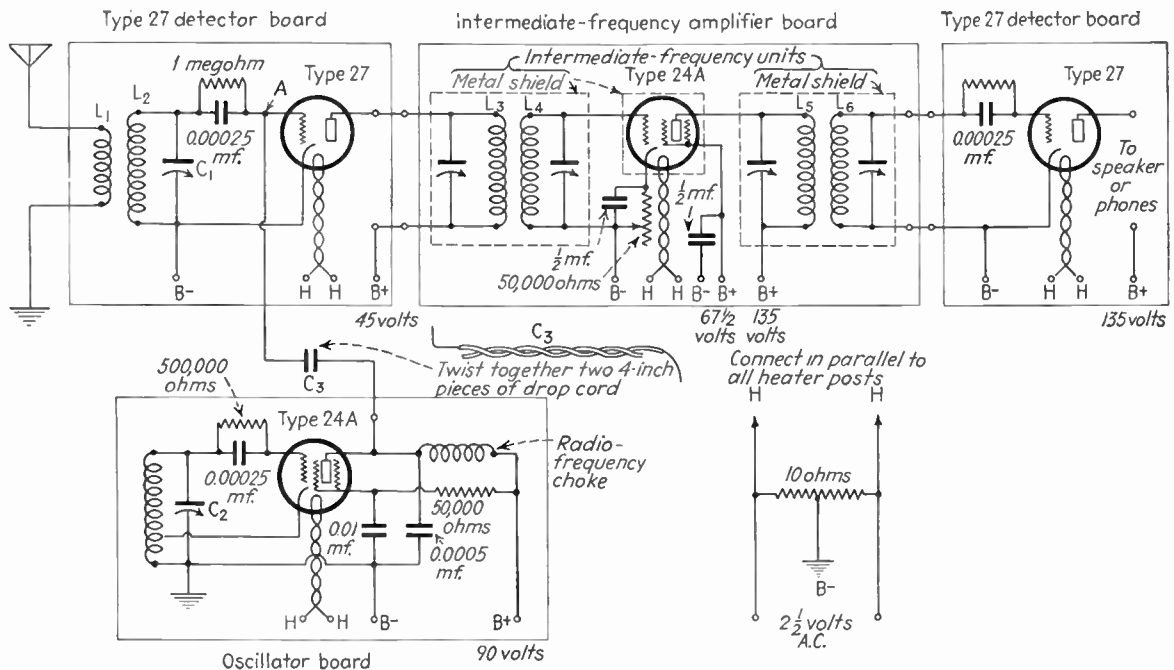
FIG. 241. Superheterodyne circuit.

Type 27 detector board

1 megohm

$L_2$

$L_1$

A

Type 27

0.00025 mf.

$C_1$

B−  H  H  B+

45 volts

intermediate-frequency amplifier board

Intermediate-frequency units

Metal shield

Type 24A

Metal shield

$L_3$  $L_4$

$L_5$  $L_6$

$\frac{1}{2}$ mf.

$\frac{1}{2}$ mf.

50,000 ohms

B−  H  H  B−  B+

67$\frac{1}{2}$ volts

B+

135 volts

Type 27 detector board

Type 27

0.00025 mf.

To speaker or phones

B−  H  H  B+

135 volts

500,000 ohms

$C_3$

Twist together two 4-inch pieces of drop cord

Type 24A

0.00025 mf.

$C_2$

0.01 mf.

Radio-frequency choke

00000

50,000 ohms

0.0005 mf.

H  H  B−  B+

90 volts

Oscillator board

Connect in parallel to all heater posts

H  H

10 ohms

B−

2$\frac{1}{2}$ volts A.C.

ALTERNATING-CURRENT TUBES

365

marked $A$ on the first detector board. Make the coupling
condenser $C_3$ by twisting together two 4-inch lengths of
drop cord.
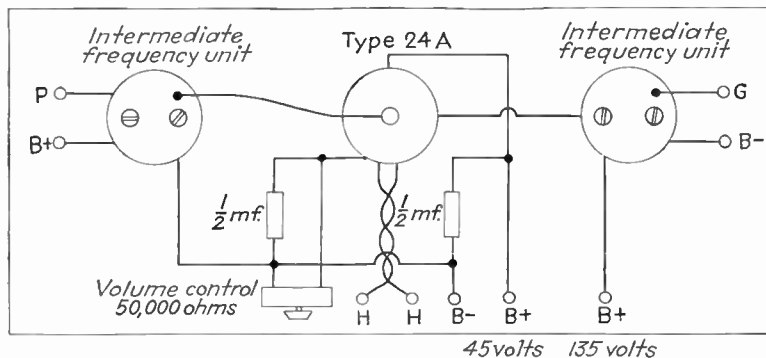


FIG. 242.   Intermediate-frequency amplifier unit.
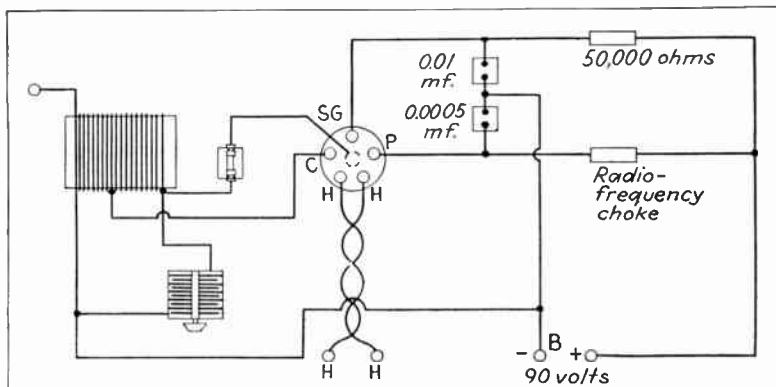


FIG. 243.   Oscillator unit.

**Position of the Parts.** Mount each new unit of the
superheterodyne on a small board. Place the parts as
shown in Fig. 242 and Fig. 243. Since the intermediate-
frequency transformers are well shielded, it is unnecessary
to use any special wiring arrangement on this board. Ground
the shields.

Place the 23-plate variable tuning condenser at the front
of the oscillator board in a convenient position for tuning
(see Fig. 243).   Place the oscillator coil a distance equal to
its diameter from the condenser or the tube.   Place the
gain-control resistor near
the front of the board for
ease in tuning.

**How to Wind the Os-
cillator Coil.**  Wind 60
turns of size 22 wire on a
3-inch tube for the oscil-
lator coil.   This coil is
the same size as the grid
coil of the radio-fre-
quency board.   Solder a
wire to the coil, about
one-third the distance
from the ground end of



Fig. 244.   Oscillator coil.

the coil, for the cathode tap (see Fig. 244).
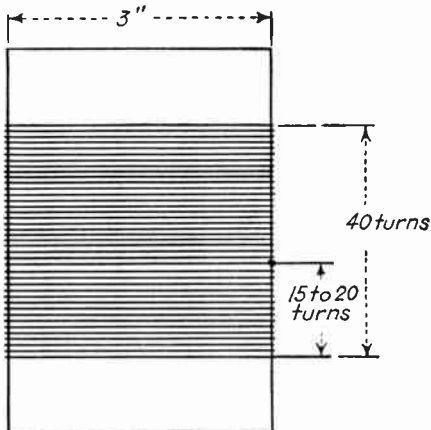
**General Information.**  Use heavy wire for the filament
heater supply.   Keep the wire as short as possible.   The
detector in this case will be a type 27 detector using grid
leak and condenser.

## How to Line Up the Set

**Adjust the Intermediate-frequency Tuning Unit.**  *How
to Line Up the Intermediate-frequency Unit.*  Each inter-
mediate-frequency amplifying unit must be accurately
tuned to the same frequency so the set will operate most
efficiently.   Each intermediate-frequency unit contains a
small radio-frequency transformer tuned with small vari-
able condensers, called trimmer condensers (see Fig. 245).
A small midget condenser or compression-type trimmer
condenser is connected across each radio-frequency coil

(see Fig. 246). An aluminum shield can fits over the unit.

Make a $\frac{1}{4}$-inch round dowel stick or bakelite rod 6 inches long with one end sharpened to the shape of a screwdriver
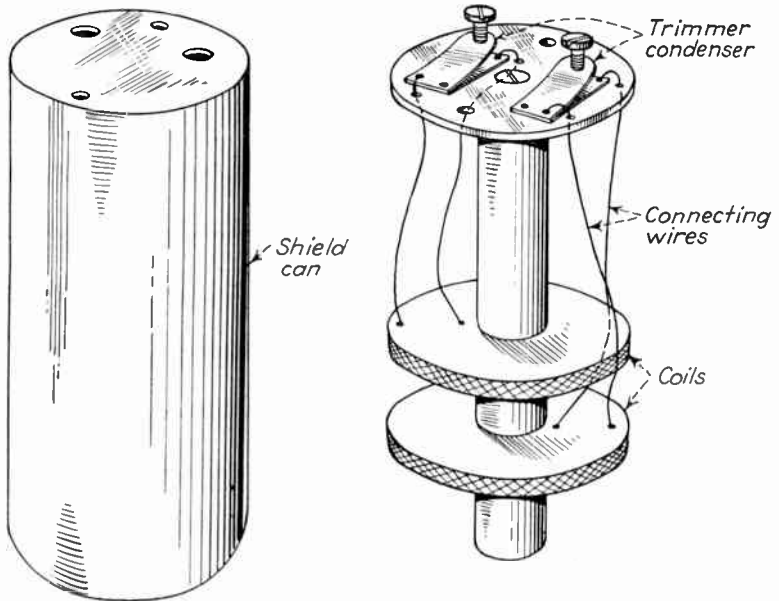


FIG. 245.    Intermediate-frequency unit removed from shield can to show coils and trimmer tuning condensers.

for an adjusting tool (see Fig. 247). The small screw heads on the top of the intermediate-frequency cans are the adjustments for the trimmer condensers.

*Step* 1.    Turn the power into the set.

*Step* 2.    Tune in a fairly loud station. Tune the condenser on the oscillator board and the condenser on the first detector board *at the same time*. Adjust the volume control so that signals from the station are faint but clear. It is easier to notice when a weak signal increases in strength than when a strong signal increases.

*Step* 3. Tune the second intermediate-frequency secondary to the station. You can tell when the condenser is set correctly by twisting the setting of the trimmer condenser back and forth past the loudest point of the signal,
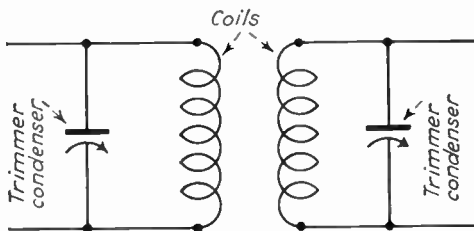


Fig. 246. Wiring of the intermediate-frequency unit.

decreasing the swing each time until you have the condenser set exactly on the loudest signal.

**Caution!** If you unscrew these adjustments too far, the screw will slip out of the nut of the adjustable plate of the trimmer condenser. Then you will have to take the shield cans off the intermediate-frequency unit to fit the screw back in place.



Fig. 247. Bakelite rod screwdriver used to adjust trimmer condensers.

*Step* 4. Now tune the first intermediate-frequency secondary to the loudest signal in the same way.

*Step* 5. Adjust the primary trimmers for the loudest signal. You will find the adjustment of the secondaries to be much finer than for the primaries.

*Step* 6. Repeat the whole process to make a final adjustment. The set now should be in proper operating condition.

### How to Operate the Set

*Step* 1. Turn on the set. Set the volume control full on.

*Step* 2. Adjust the oscillator condenser and the first detector condenser to find a station.

*Step* 3. Correct the tuning condenser setting for the best signal strength. After you have tuned in the desired station, set the volume control $R_1$ on the intermediate-frequency board (see Fig. 241 and Fig. 242). No other tuning adjustments are made in this receiver. The intermediate-frequency adjustments remain fixed when once adjusted.

## How It Works

**Beat Notes in Sound.** When two piano wires, tuned to exactly the same pitch, are set in vibration, you can hear one tone. But if you stretch one of the wires more tightly, its note will be higher in pitch than before. Now you will hear not only the tone produced by the first wire and the tone produced by the second wire, but you will also hear a third tone. The third tone is a slow, throbbing sound. It is called the beat note. When the two wires are vibrating at exactly the same rate, they are in resonance; no beat note is produced. This is called zero beat.

Let us say that the first wire has been tuned to a frequency of 256 cycles. This is the frequency of middle C on the piano. If the second wire is tighter than first one so that it produces a note of 300 cycles, which is a little higher than middle C, the third tone we shall hear is a low tone of 44 cycles or the difference between the vibrating frequency of each of the strings ($300 - 256 = 44$). It sounds like a slow "m-m-M-m-m-m-m-M-m-m-m" swelling in loudness at regular intervals.

**You Can Control the Pitch of the Beat Note.** If you tighten either wire its tone rises. The beat note changes. You can thus change the rates of vibration until the beat note sounds higher or until it can no longer be heard.

**Beat Notes in a Radio Circuit.** The action of the two strings in producing a beat note is similar to the action of a radio circuit in which there are two oscillations, each of a different frequency. The familiar whistle you hear when tuning a regenerative receiver (with the set in oscillation) is a beat note. It is caused by the carrier wave (to which you are tuning), "beating" with the oscillation produced by your set, to form what is commonly called the carrier whistle. This whistle is not the carrier; the carrier wave is a radio-frequency oscillation far above hearing.

The beat note which you hear is equal to the difference between the carrier frequency and the frequency at which your set is oscillating. You cannot hear either of the original radio frequencies. If we have two radio frequencies, a carrier frequency of 100,000 cycles and a receiver-oscillation frequency of 101,000 cycles, surging in a circuit, we can hear neither of the two frequencies since both are far above the hearable frequency. But the beat note produced by these two frequencies should be at 1000 cycles a second (101,000 cycles − 100,000 cycles = 1000 cycles). We can hear a frequency of 1000 cycles.

We also could produce a beat frequency of 1000 cycles by using two other radio frequencies, one of 100,000 and another of 99,000 cycles. Here the difference between the two frequencies again would be 1000 cycles and would produce a beat note of the same pitch as the beat note we just heard.

**You Can Control the Pitch of the Beat Note.** Just as with beat notes in sound, you can change the pitch of the beat note in your receiver. One of the frequencies comes over the air to your set. You cannot change this frequency. The other frequency is generated in your own set. In the superheterodyne receiver the second frequency is generated by the oscillator, which you can control.

You can tune the beat oscillator to get a beat note of any frequency you want.

**How the Oscillator Sets the Beat Note.** When a 1000-kilocycle signal from a broadcasting station is received in the aerial, you tune the oscillator of the superheterodyne receiver to a frequency of 1465 kilocycles. These two frequencies are now on the grid of the first detector tube. Every so often these two frequencies blend and produce a big surge of current (beat note) so one frequency is produced in the plate circuit. These big surges are the beat note, but they still are at a radio frequency (465 kilocycles). We could also tune our oscillator to 535 kilocycles and get a beat note of 465 kilocycles (1000 kilocycles − 535 kilocycles = 465 kilocycles).

**The Intermediate-frequency Stages Amplify Only a Narrow Frequency Band.** The intermediate frequency transformers can be tuned by the small trimmer condensers to a narrow band of frequencies near 465,000 cycles (465 kilocycles). When you adjust the trimmer to line up the set, you tune each coil and condenser to the same frequency near 465 kilocycles. This is the frequency of the station which you are using as a line-up frequency. If you had a special oscillator, you would line up the set at exactly 465 kilocycles. This means that it would only allow a signal to pass through the intermediate-frequency coils and tubes that has a frequency of 465 kilocycles and would reject or kill any other frequencies. The intermediate-frequency stages are simply radio-frequency stages with fixed tuning.

Suppose a station operating on 1500 kilocycles is picked up by the radio-frequency part of the set. We then tune the oscillator to 1965 kilocycles to get a 465-kilocycle beat note. This beat note feeds through the radio-frequency intermediate-frequency amplifiers, to a second detector.

If the station frequency is 700 kilocycles, you tune the oscillator to 1165 kilocycles. Again the beat note is at 465 kilocycles and will pass on through the intermediate-frequency amplifier.

The oscillator is tuned to each station so the radio-frequency beat note between the two will be at 465 kilocycles. The oscillator is built to tune to a frequency above the incoming signal frequency, for this permits the use of smaller coils and condensers in the set.

**Sharpness of Intermediate-frequency Tuning.** If the intermediate-frequency stages were built so they would tune with extreme sharpness, they would cut off so many of the high notes of music that you would not enjoy listening to the set. Therefore they are designed to operate best at 465 kilocycles but to work well for 5000 cycles on either side of this frequency. So they actually operate well over a band of frequencies from 460,000 cycles to 470,000 cycles. This set will receive the frequencies the average broadcasting station sends out. High-fidelity broadcasting stations operate over a 20-kilocycle band.

Amateur superheterodyne receivers, which are designed to receive code, tune very much sharper than for programs.

**The Detector and Audio Amplifier.** This tube acts as the ordinary detector tube. It makes the radio-frequency pulsations which have been amplified by the radio-frequency stages into the audio-frequency pulses which can be heard in the phones. If you desire, you can add power audio stages to increase the volume of the signal. The operation of these circuits has been described earlier in this chapter.

### Questions

1. Try striking various keys on a piano to listen for the beat notes. Strike keys close together and keys farther apart to hear the difference in pitch of the beat notes.

**2.** Can you hear the carrier wave from a radio broadcasting station?

**3.** How can you find the frequency of the beat note produced by the two radio-frequency waves?

**4.** Suppose your set were receiving a station with a frequency of 900,000 cycles. At what two frequencies could you set your beat oscillator in order to produce a beat note of 465,000 cycles?

**5.** If you are receiving from a station with a frequency of 1,000,000 cycles, what frequencies are applied to the grid of the first detector tube? Would there be one, two, or three frequencies in the plate circuit of the first detector tube?

**6.** If you are receiving from a station with a frequency of 120,000 cycles, is it better to tune the beat oscillator to a frequency above 120,000 cycles or below that frequency in order to get a beat note of 465,000 cycles? Give reasons for your answer.

**7.** Explain why it is usually more satisfactory to have sets for receiving code tune more sharply than sets for receiving music?

## How to Combine Sets Used in This Chapter into Practical Sets

**Set 1.** *Type 27 Detector.* This is a simple outfit, easy to operate, and one which is ideal for beginners to experiment with. This set is shown in Fig. 209.

**Set 2.** *Type 27 Detector–Type 27 Audio Amplifier.* With this set you can get louder signals.

**Set 3.** *Type 27 Detector–Type 27 Audio Amplifier–Type 45 Power Audio Amplifier–Speaker.* The power audio amplifier makes possible the use of a speaker. This set gives good quality signals but will not receive over much distance.

**Set 4.** *Type 27 Detector–Type 47 Power Audio Amplifier–Speaker.* The type 47 power amplifier replaces both the type 27 and the type 45 amplifiers. You will get good volume, but the quality is much poorer than when you use the type 45 tube.

**Set 5.** *Type 24A Detector–Type 47 Power Audio Amplifier–Speaker.* When you replace the type 27 detector with

a type 24A detector, you will have a much more sensitive set which will receive over greater distances than the other sets.

Set 6.   *Type 24A Radio-frequency Amplifier–Type 24A Detector–Audio Amplifier* (either the audio arrangement of set 3 or of set 4) *and Speaker*.   The radio-frequency amplifier makes the set very much more sensitive so it will receive over great distance.

# CHAPTER IX

## SHORT-WAVE SETS

**The Early Use of Short Waves.**   The history of radio shows a constant change in the wave lengths we have been using for sending and receiving purposes.   The first stations were constructed with very long aerials which operated on wave lengths as long as 20,000 meters.   It was believed for many years that the long wave lengths were best for long-distance communication.

Amateurs were first given the wave lengths below 200 meters.   It was thought that these short wave lengths (waves of higher frequency) were useless commercially, and the attitude was to "give the boys something to play with" that would be of no use to the commercial companies or the military or naval services.   But the amateurs began to build up an enviable record by sending messages over long distances on the short waves at times when the commercial and even the government services could not get through with their longer wave lengths and higher-power apparatus.

**The Short-wave Bands Come into Use.**   Investigation soon showed that stations using the higher frequencies and shorter wave lengths were able to operate over long distances on quite low power.   The development of vacuum-tube transmitting equipment further assisted the development of the short waves, and today it is common to find many services, government and commercial and ama-.teur, in the short-wave bands.

376

The amateurs now use several different bands of frequencies whose wave lengths are 160 meters, 80 meters, 40 meters, 20 meters and 10 meters. Wave lengths shorter than 10 meters were, until recently, believed to be useless. Chapter XIII takes up a set for receiving these ultrashort waves. Even the 10-meter band was considered doubtful. Sets operating on 10 meters were cranky and hard to get in operation.

But 20 meters and 10 meters proved to be capable of carrying signals over unheard-of distances. At one time the 160-meter and the 80-meter bands were occupied by beginners and a few phone stations. These bands seemingly did not operate well over long distance. But the 40-meter band seemed to be an all-around good band for distance both day and night. Later, the 20-meter band was found to be a marvelous daylight band for distance, or "DX" operation.

**Principles of Short-wave Sets.** The short-wave receiver is different from the long-wave receiver only in the size of the coils used in the tuning circuits and the size of the tuning condensers. The short-wave sets use the same circuit that we used in the direct-current and alternating-current receivers. Short-wave receivers used for continuous-wave telegraphy use oscillating regenerative detector circuits so the broken carrier wave formed by the key at the transmitting station may be made hearable in the receiver. Code cannot be heard on the simple nonoscillating detector. Refinements in the tuning system are needed because the amateur bands and other short-wave bands are narrow and require quite sharp tuning.

**Short-wave Plug-in Coils.** Since the amateur bands are separated and are narrow, it is not convenient to wind a coil which will cover all of the bands. Instead, small coils are wound on forms which are fitted with prongs as on a

tube base, so a coil which will tune over a narrow band of frequencies may be connected into the tuning circuit and may be easily exchanged for a coil of a different size. In this way the same set will operate on many frequencies. The same tuning condenser is used throughout. Vernier tuning is accomplished by using small condensers parallel to the main tuning condenser and by using a slow-motion dial. A favorite circuit for beginners is a detector-amplifier circuit which later may be improved by the addition of a stage of tuned radio-frequency amplification.

This circuit is improved further by thorough shielding to form a quite satisfactory communication-type receiver. This circuit is used at the present time by many amateurs for distance operation both on code and amateur telephone work.

Aerials used for short-wave receivers are described in Chapter XII. A favorite aerial for these receivers is the doublet type. Many amateurs who have sufficient space have a separate doublet for each band on which they expect to operate.

### Contents of This Chapter

### 1. THE ONE-TUBE DIRECT-CURRENT DETECTOR SET

**The Six-prong Coil Circuit.** In this set we shall use the three-coil circuit with condenser-controlled regeneration. We shall use a six-prong plug-in coil form on which to wind

the aerial coil, the grid coil, and the plate coil. This makes the circuit simple to study and to handle.

This circuit is useful later when we connect a tuned radio-frequency amplifier to the detector circuit.

**The Circuit.** This is the familiar one-tube detector circuit studied in Chapter V. But in this chapter it is adapted to use as a short-wave receiver.

**The Coil and Condenser.** In place of the large coil and condenser we shall use a midget tuning condenser or a cut-down broadcast condenser. The coil will be half the diameter of the broadcast coil and will have less wire. Otherwise the circuit and its handling is the same as for a broadcast detector set.

## How to Build and Wire the Set

**Parts Needed.** The new parts for this set will be a six-prong wafer socket to be used as the base for the plug-in coil; a 23-plate midget tuning condenser; a .0001-microfarad grid condenser and a 2-megohm grid leak. We shall use the same tube, tube socket, rheostat, by-pass condenser, and radio-frequency choke coil used in the long-wave sets.

**Variable Condensers.** The 17- to 23-plate midget variable condenser called for in this set has a capacity of about 150 micromicrofarads. Condensers of this capacity manufactured by different companies have a different number of plates. The stator plates of some midget condensers can be removed to change capacity.

The regeneration-control condenser must be somewhat larger than the tuning condenser for the best results.

**Grid Condenser and Leak.** Use a grid condenser of .0001-microfarad capacity. This size is most efficient on short waves, but a condenser of .00025 microfarad or .0005 microfarad will work. The .0001-microfarad condenser will bring distant or faint stations in more loudly. Try

several grid leaks in the set.　Use the one that brings in
the signals loudest.

**The Radio-frequency Choke and Body Capacity.**　The
receiving set will work with no radio-frequency choke, but
the tuning of the set will be affected when your hands are
near the phone cords.　This is caused by the radio-fre-
quency component in the cord.　The radio-frequency choke
stops the radio-frequency surges in the phone cords and
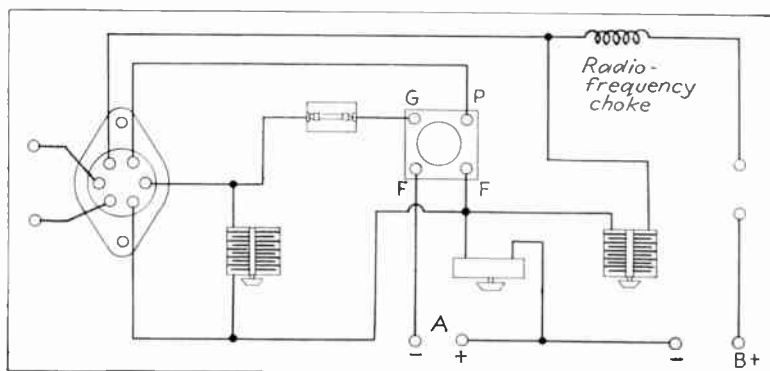


Fig. 248.　Short-wave detector set using direct-current tube.

forces them to by-pass through the regeneration-control
condenser to the cathode.

When the hand touches or moves away from tuning dials,
the capacity of the body changes the tuning.　The body
acts as a series condenser.　Connect the rotary plates of
the tuning condenser to ground (B negative), where the
radio-frequency voltages are lowest and less effect is noticed
from hand capacity.

**How to Wire the Set.**　Wire as shown in the wiring
diagram in Fig. 249 and board layout in Fig. 248.　Connect
the grid-return wire to the A positive wire.　Motorboating
and poor regulation sometimes occur when the grid wire is
connected to the A negative wire.

**Wiring Cautions.** Wire the short wave sets carefully. Sets operating on the higher frequencies are more sensitive to noise and to poor connections than are the long-wave sets.
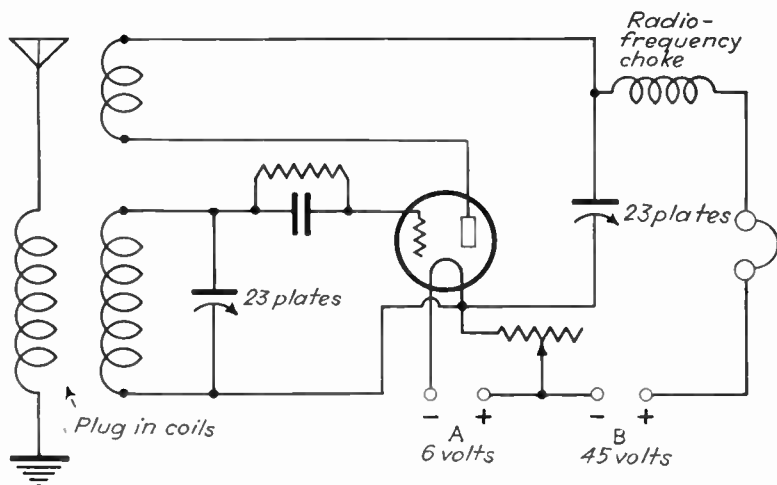


Fig. 249. Circuit of direct-current short-wave detector set.

Solder all joints. Mount all parts solidly so no vibration of any parts occurs in ordinary handling and tuning.

### Questions

**1.** Compare the size of the regeneration condenser with the tuning condenser in short-wave sets.

**2.** Compare the size of the grid condenser in short-wave sets with this condenser in broadcast sets.

**3.** Why is there body capacity in short-wave sets which use no radio-frequency choke?

### 2. THE CONSTRUCTION OF SHORT-WAVE PLUG-IN COILS

Coils for the short-wave bands with wave lengths below 200 meters (frequencies above 1750 kilocycles) are smaller than coils used for the long-wave sets. The tube on which the short-wave coil is wound is smaller than the coil for the broadcast sets.

We shall build four coils so their tuning ranges overlap. The tuning range will start at about 1500 kilocycles and range up to 15,000 kilocycles. We shall show construction and wiring for coils using five- and six-prong tube bases and tube sockets.
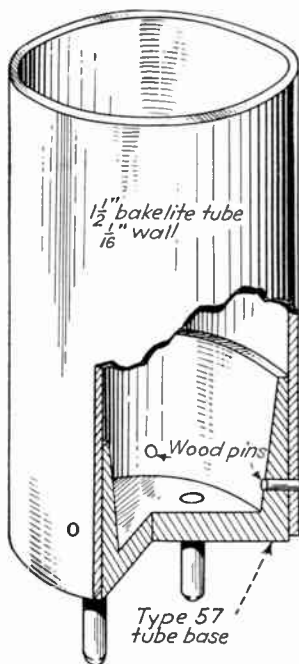


FIG. 250. Cutaway view showing how coil form is fastened to tube base.

### How to Build and Wind a Set of Plug-in Coils for a Six-prong Base

**Make the Coil Forms.** Purchase a 10-inch length of $1\frac{1}{2}$-inch (outside diameter) bakelite tubing with $\frac{1}{16}$-inch wall at a metal supply house. Tubing of this size will just fit over the standard four- and five-prong tube bases. It may be possible to find tubing of the correct size that was used for a coil form in an old set. Larger tubing may be used, but the number of turns must be cut down if the same size of wire is used.

Saw the tubing into four pieces each $2\frac{3}{8}$ inches long. Use a fine blade in the hacksaw and turn the tube while sawing to prevent chipping. The saw chips the edges of the tube where it leaves the cut. Smooth the ends of the tube with a coarse file. Finish by rubbing on a piece of sandpaper laid flat on the workbench.

**Fasten the Coil Form to a Tube Base.** Slip the bakelite tube over the tube base (see Fig. 250).

Mark the position of four holes about $\frac{3}{8}$ inch from the lower edges of the bakelite tubing with a sharp point.

Drill $\frac{1}{8}$-inch holes at the marks through both the bakelite tubing and the tube base.

Drive four hardwood pins into the holes and cut them off flush with the surface of the tubing. These pins will hold the tube base firmly in position in the tubing. Metal pins lower the efficiency of the coil somewhat.

**How to Arrange the Coils.** The grid coil is placed at the top of the coil form as far as possible from the metal parts of the base. The effect of metal near the grid coil is very noticeable at high frequencies. The efficiency of the plug-in coil with the grid coil at the lower end of the form is much less than when the grid coil is wound at the top of the form. The station volume is less, and the tuning is not as sharp.

The position of the plate and the aerial coils has less effect on the operation of the set than does the position of the grid coil.

**Wind the Grid Coil.** Make a small hole in the tub-



Grid coil

Plate coil

Aerial coil

Bottom of base coil

Plate

Top of socket

Aerial
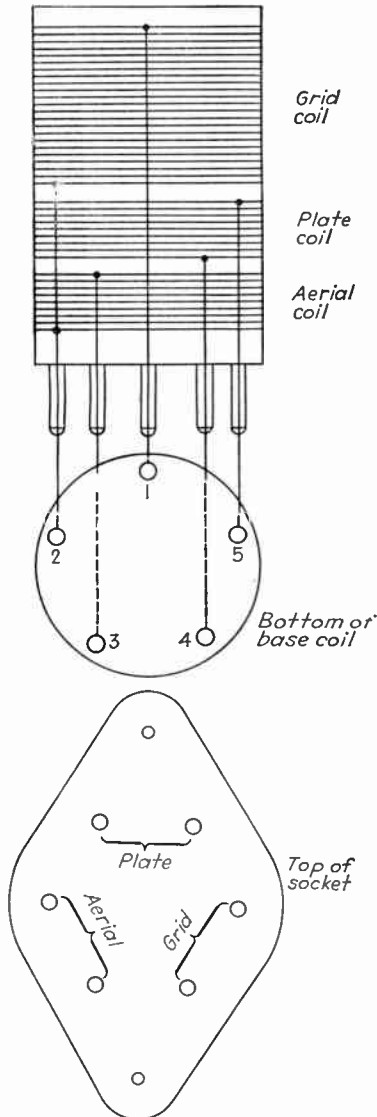
Grid

Fig. 251.    Coil-to-base connections and socket connections.

ing with a dental drill about $\frac{3}{16}$ inch from the upper edge of the coil and fasten the wire at the end of the grid coil by passing it through the hole. Make this hole opposite the prong to which the grid end of the coil is to be soldered (see Fig. 251).

Slip the end of the wire through the hole in the tubing, run it down through the hollow prong, and bend it back over the end of the prong to hold it while you are winding the coil. Fasten the other end of the wire in a vise or around a nail to keep the wire tight while winding. Wind on the number of turns shown in the coil winding table for the grid coil (page 386). Keep the wire tight while winding. Count the turns by slipping a screw-driver blade over the coil lightly. You can hear a light tap as the blade drops from wire to wire.

When the proper number of turns is wound on, cut off about 6 inches more wire than the turns have required. Hold the end of the winding in place. Mark the position of the end of the grid coil in line with the prong shown in Fig. 251, and drill a hole. Slip the wire through the hole and pull tight, run through the base prong and bend over to hold in place as before.

Small-sized wire on the grid coils is not desirable, as the radio-frequency currents flowing in this circuit are very weak, and wire resistance should be kept as low as possible so the current can build up at resonance.

**Wind the Plate and Aerial Coils.** Now drill a hole to start the plate-coil winding. Space the plate coil about $\frac{1}{8}$ inch away from the grid coil. See Fig. 251 for the position of the hole.

The plate coil feeds back energy from the plate circuit to the grid circuit so the set will oscillate. Use size 28 or 30 wire on the plate coil to bunch the field around the plate coil.

Wind the aerial coil. Space it about $\frac{1}{8}$ inch from the grid coil.

**Fasten the Coils in Place.** When all of the coils have been wound, scrape the wire ends sticking through the base prongs and fasten them with a drop of solder.

Paint the coils with nail polish, clear lacquer, or collodion to hold the winding in place so that the wire will not loosen as the coils are handled when they are plugged in and out of the socket.

**The 20-meter Coil.** The turns of the 20-meter coil are spaced the diameter of the wire to keep down distributed capacity. This is done by winding two wires of the same size side by side. When the winding is finished, one wire is removed and the winding fastened in place with collodion or nail polish.

The insulation on spaced windings may be silk, cotton, or enamel, since the spacing kills the capacity effect between wires or reduces it until it is too small to consider. The wires may be bare.

Use size 18 or 20 wire for the 20-meter coil.

### Questions

1. Describe the most efficient method for fastening the bakelite tubing onto the tube base.

2. Why is the grid coil placed at the top of the tube?

3. What is the disadvantage of using small-size wire for the grid coil?

4. Explain how to " space wind " a 20-meter coil.

5. Why is spaced winding necessary?

6. What is the objection to using enamel wire on close-wound short-wave coils?

## Coil-winding Turns

**The Grid Coil.** The number of turns on this grid coil controls the range over which the set will tune when shunted with a midget condenser. Wind on too many

turns at first, then cut off turns until the desired tuning range is covered (see Fig. 251).

**The Plate Coil.** The number of turns on this coil controls the feedback and the regeneration. Wind on too many turns. Then cut off a turn at a time until the set goes into oscillation with the condenser or the variable resistor at about the center of the dial.

**The Aerial Coil.** The number of turns on this coil is not critical. Wind on enough turns to give a good transfer of energy to the grid and plate coils. Try adding to the number of turns to see if the signals will be louder. Too many turns will cause broader tuning and may cause dead spots where the set will not oscillate.

Space the coils about $\frac{1}{8}$ inch apart. If there is too much coupling between coils, increase the space to about $\frac{1}{4}$ inch.

The connection of each coil to the base prongs is made in such a way that crossing is avoided in the set wiring.

COIL WINDING TABLE

| Wave-length Range, Meters | Grid Coil, Turns | Plate Coil, Turns | Aerial Coil, Turns | Wire Size for Grid Coil |
|---|---|---|---|---|
| 160 | 70 | 20 | 10 | #28 double silk cover |
| 80 | 35–40 | 10 | 6–8 | #22 double silk cover |
| 40 | 18 | 6 | 4–6 | #22 double silk cover |
| 20 | 5 | 5 | 5 | #18 enameled cover |

### Questions

**1.** The range over which the set will tune is controlled by the number of turns on which coil?

**2.** The feedback and the regeneration are controlled by the number of turns on which coil?

## How to Wind a Set of Plug-in Coils on a Five-prong Base

**Coil Arrangement.** Wind the grid coil on the upper part of the tube so it will be as far from the metal prongs as possible. Wind the plate coil below the grid coil. You will

notice that the connection to the grid is made at the top of the coil as for the six-prong base coil (see Fig. 252).

**Use of the Five-prong Base Coil.** This coil is widely used by amateurs and is very popular. In the two-tube short-wave set the aerial coil is grounded to the same prong to which the ground of the grid coil is connected. One disadvantage in using this type of coil is that transformer coupling cannot be used between the radio-frequency stage and the detector stage. Impedance coupling must be used instead.

**Coil Winding Turns.** Use the same number of turns for each coil as was used for the six-prong coil form.

### Questions

1. When five-prong coils are used, to which base prong is the aerial coil grounded?

2. What type of coupling must be used on sets which have five-prong coil bases?

## How to Adjust the Number of Turns on Plug-in Coils

**The Effect of Different Sizes of Wire.** We find the



Grid coil

Plate coil

Aerial coil

Bottom of coil base

Aerial
3 ○            ○ 4

Ground        Plate        Top of socket
2 ○            Grid        ○ 5

1 ○
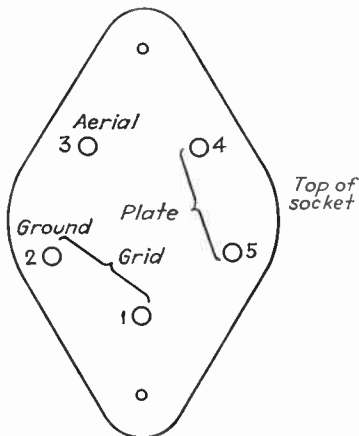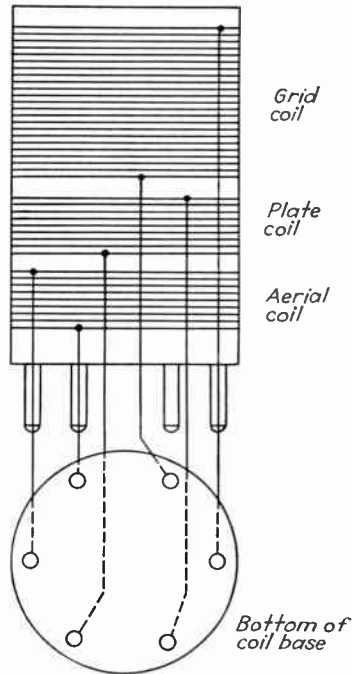
Fig. 252. Plug-in coil and socket, five-prong.

number of turns for a coil by winding on too many turns. Then we cut off turns till the set works well. If the wire size given in the table is used, little adjusting will be necessary. Perhaps the set will not oscillate or it will squall.

If smaller wire is used, wind on the number of turns called for. The effect of using smaller wire will be the same as if too many turns were on the coils. Turns can then be cut off to balance the coils.

If the wire is too large, wind on two extra turns for every ten turns called for in the coil-winding instructions. As the wire gets farther from the correct size, add more turns.

**The First Set of Coils.** It is a good idea to wind test coils with scrap wire. The first coils will then be an experiment, and you will not feel particular about their appearance and you will not be reluctant to add or cut off turns.

Fasten the ends of a short piece of wire with a drop of solder. After the first coil is wound and balanced, a better looking coil can be wound on the same form.

**Adjust the Plate Coil First.** The set must oscillate to receive code and to locate the short-wave stations, especially the distant ones.

**B Voltage.** Use the correct B voltage for the tube to be used in this set. If the B voltage is too high the set will squeal and will be hard to adjust for sensitivity. It will go into oscillation too easily.

If too many turns are wound on the plate coil, the set will oscillate too strongly and may squeal or "pull over" into oscillation. This is shown by either a bad audio squall or howl or by too loud a pop in the phones when the grid wires are touched.

Cut off turns, one turn at a time, until the set oscillates gently with the condenser or resistor set half in. Too large a grid leak will cause oscillation to start with a loud bang instead of with a soft thud.

**Too Few Turns.** When not enough turns are wound on the coil, the set will not oscillate. Oscillation will not start even when the condenser or resistor is turned full in or when the B voltage is increased. The remedy is to add about twice as many turns of wire as you think you will need so that there will be extra turns to cut off. Wind the extra turns on top of the coil if necessary.

**Now Adjust the Grid Coil.** The number of turns on the grid coil determines the width of the frequency band over which the set will tune. The size of the tuning condenser is fixed so the number of turns on the grid coil determines the frequency band to which the set will tune when the coil is plugged in.

Wind more turns on the grid coil if you want the coil to reach higher wave lengths. Take off turns if it tunes too high.

It will be found that changes in the number of grid coil turns have some effect on regeneration. Adjust the number of turns on the plate coil after changing the grid coil if necessary.

**Adjust the Aerial Coil.** The aerial coil must have turns enough to induce currents in the grid and plate coils that will operate the set. Too few turns will not supply enough energy to the set to hear the signals in the phones. The set will not be sensitive. Weak and distant signals will not be heard.

But too many turns on the aerial coil make the coupling so close that tuning is broad, and it is hard to separate stations with the tuning condenser. The set will go out of oscillation at different places on the dial. When this happens, either remove turns from the aerial coil or space the coil farther from the grid coil to loosen the coupling. The aerial coil is the least sensitive of the three coils to adjust.

**The 20-meter Coil.** The 20-meter coil is the most critical to adjust. At the higher frequencies feedback is greater. The 20-meter coil often goes out of oscillation at one or more places on the condenser dial. This is caused when the aerial is in resonance with the grid coil. The aerial circuit then draws enough energy from the set to stop oscillation.

Oscillation can be started again by increasing the plate voltage or by adding to the turns on the plate coil. Change in plate voltage is not desirable. The plate voltage should be the same for all coils. If adding to the turns does start oscillation but also starts howling, some other method must be found to keep the set oscillating.

The aerial may be shortened or lengthened a few feet. When the length is right, the set will oscillate again over the whole condenser range. A small variable condenser in series with the aerial has the same affect but adds another adjustment which is not desirable. Change the number of turns on the aerial coil.

Sometimes a radio-frequency choke in the plate circuit between the phones and the plate coil will stop the trouble. Wind 200 turns of size 36 wire scatter fashion on a $\frac{1}{2}$-inch dowel 2 inches long for the choke. Keep the winding not over 1 inch long.

### Questions

**1.** If you are using smaller wire than is listed in the table, will it be necessary to wind on more or fewer turns than are called for?

**2.** How is the operation of a set affected when not enough turns are wound on the plate coil?

**3.** Is the frequency band over which a set will tune controlled by the condenser or by the number of turns on the grid coil?

**4.** Explain why sets on the 20-meter band will often go out of oscillation at certain places on the condenser dial.

**5.** Make a list of methods for correcting faulty oscillation on short-wave sets.

## 3. THE DIRECT-CURRENT DETECTOR SET WITH PANEL ADDED

The addition of the metal panel has several advantages over the breadboard layout. The set can be made somewhat more compact. This does away with much connecting wire and makes the set a bit more efficient. Shorter wires in the tuning circuits increase set efficiency. The smaller set takes less table room, if used for code practice, and leaves space for paper and other equipment.

The metal panel shields the set parts and makes tuning steadier. There is no hand capacity.

In this set we shall combine a breadboard circuit layout with a metal panel or shield. Here we shall take up the slight changes in wiring and set arrangement needed to adapt the circuit to use with the panel.

This set is wired so it still follows the appearance of the circuit diagram (Fig. 249). The metal panel supports the three controls used in the short-wave set. The panel also acts as a shield to prevent body capacity from interfering with tuning.

### How to Build and Wire the Set

**Baseboard.** Mount the set on a baseboard.

**Panel.** Screw a metal panel to the front of the set base. Make the panel of brass, galvanized iron, or aluminum. The metal should be between $\frac{1}{16}$ and $\frac{1}{8}$ inch thick and 6 inches high. Make the panel as long as your breadboard. The iron may be thin because it is fairly rigid; the brass and aluminum should be thicker because of softness and a greater tendency to bend.

Bore three holes through the panel $2\frac{1}{2}$ inches above the baseboard, one for the tuning condenser, another for the rheostat, and the last for either the volume-control condenser or variable resistor. The size of the hole depends

on the size of the mounting screws on the condenser or the rheostat.
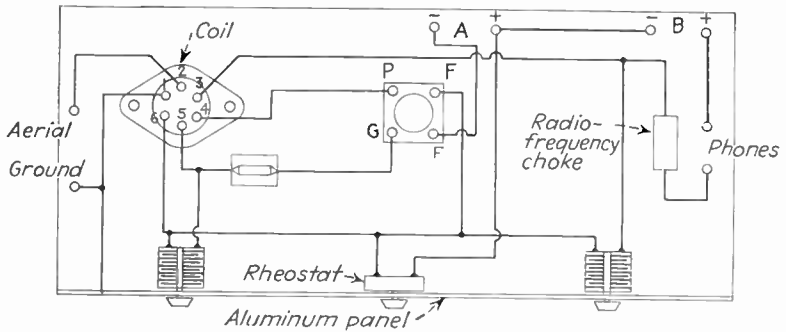


FIG. 253.   Detector set with panel.
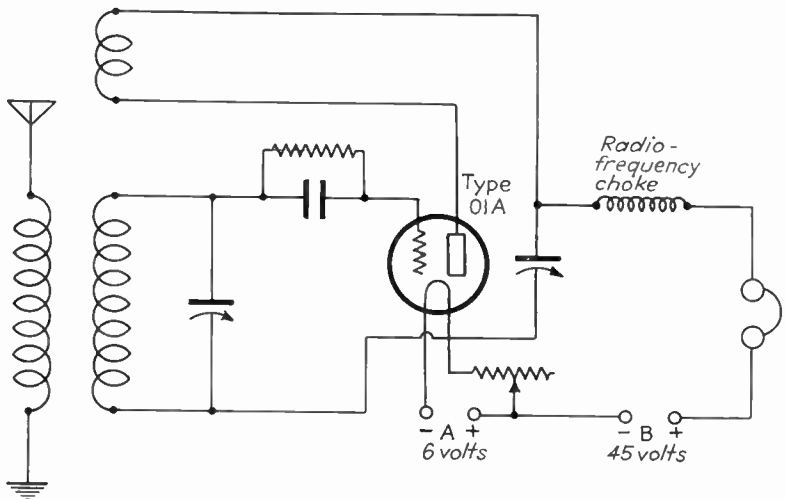


FIG. 254.   Circuit of detector set.

**The Position of the Parts.**   Place the parts as shown in Fig. 253.   Use either a .00025-microfarad grid condenser or a .0001-microfarad condenser and a 2-megohm grid leak.

**How to Wire the Set.**   Wire the set as shown in Fig. 254.   The use of the panel makes it necessary to put the

battery connections at the rear of the board. This makes minor changes in the circuit.

## How to Operate the Set

The operation of this set was described in Chapter V.

## How It Works

The explanation of this circuit is the same as for the corresponding direct-current receivers in Chapter V.

### Question

**1.** Compare the advantages and disadvantages of resistance-controlled regeneration with those of condenser-controlled regeneration.

## Circuit with Regeneration Control by a Variable Resistor

A resistance regeneration control detunes the set less than did a condenser control. But a poor resistor is apt to be more noisy in operation and will break into oscillation more easily. The set is not as stable in operation as is a condenser-controlled set. This set is a simple one to build and to operate (see Fig. 255 and Fig. 256).

### 4. THE ELECTRON-COUPLED REGENERATIVE RECEIVER

A useful development in regenerative circuits is one using a portion of the grid coil for feedback in place of using a plate coil. This circuit is used with a screen-grid tube or a cathode-type tube.

Examine the circuit shown in Fig. 257. This circuit shows that the cathode is connected to a point near the ground end of the coil. The regeneration is controlled by the amount of B voltage on the screen grid of the tube. The benefit of using this type of circuit is that it is a stable oscillator, being much better in this respect than any we have used. This is of great advantage when using a set

for receiving code signals. This circuit is often used for monitors and in frequency meters for testing transmitters.
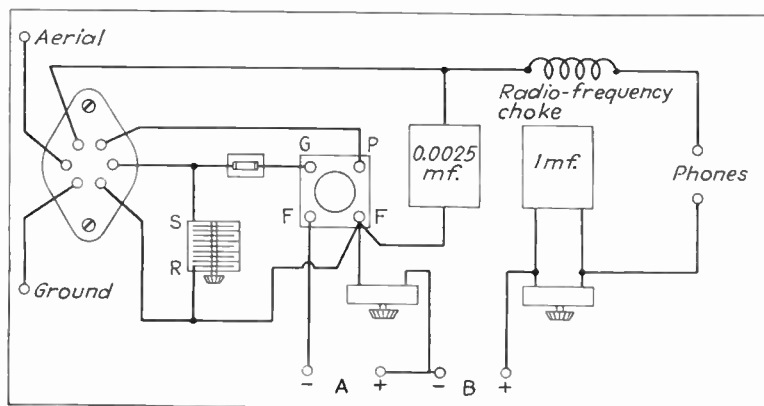


FIG. 255. Detector set with resistance regeneration control.
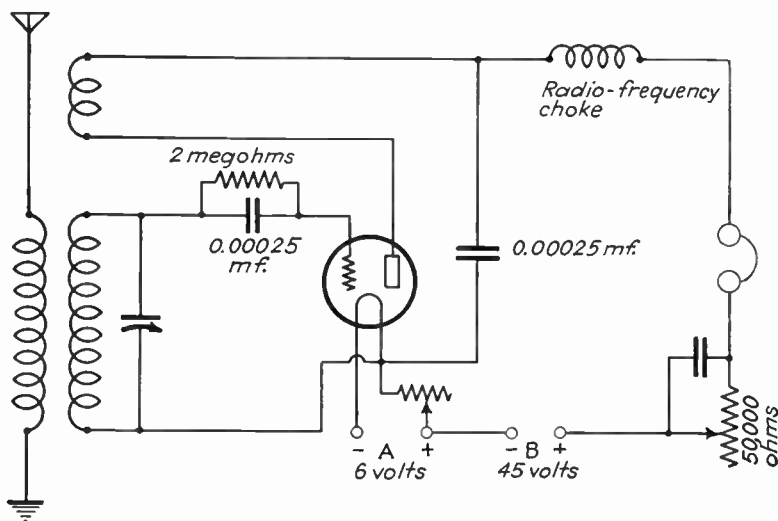


FIG. 256. Resistance regeneration control circuit.

## How to Build and Wire the Set

See Fig. 258 for the board layout.

**The Coil.** Wind the coils on five-prong forms. You will need an aerial coil and a grid coil. Use the same
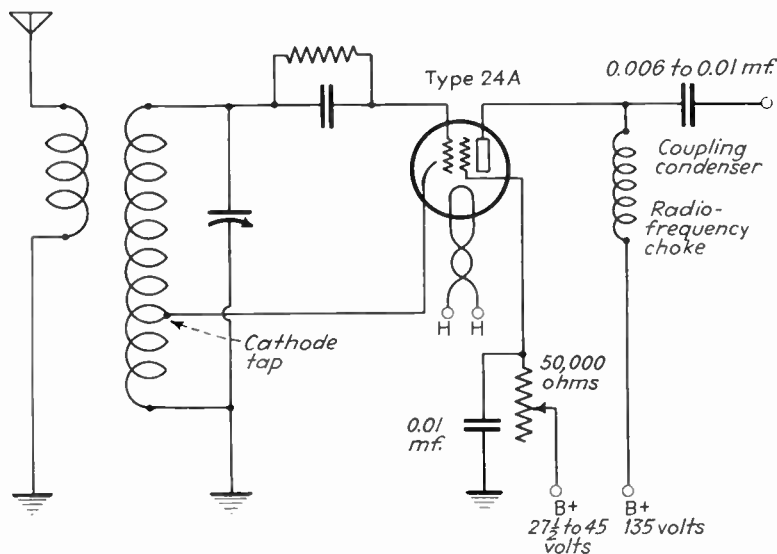


FIG. 257. Electron-coupled regenerative detector circuit.
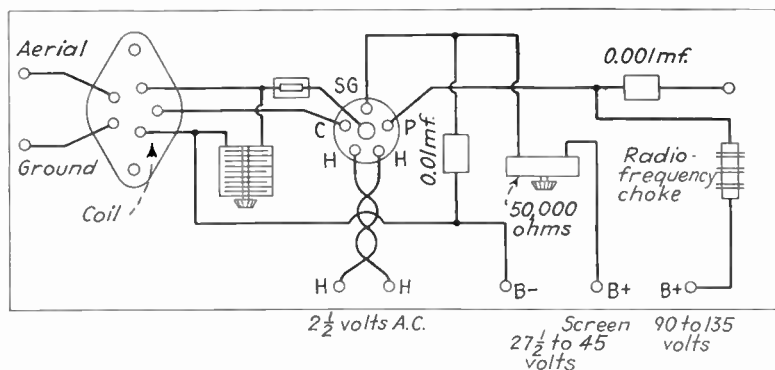


FIG. 258. Electron-coupled regenerative receiver.

number of turns for these coils as for the other plug-in coils. Connect a wire about an eighth of the number of turns from the ground end of the grid coil (see Fig. 259). This

is the cathode tap.    Drill a hole through the form at this
point.    Run the cathode wire to one prong of the tube base.
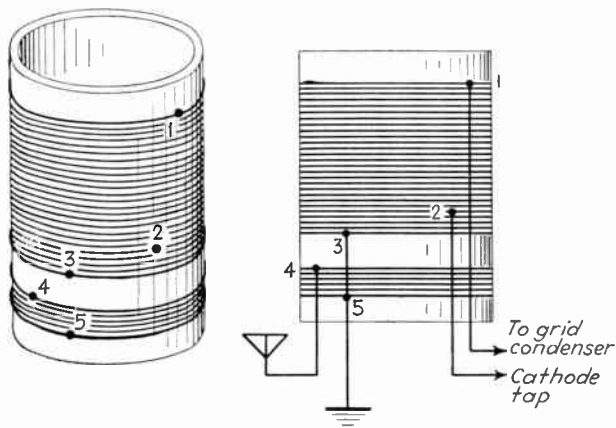


FIG. 259.    Connections of five-prong coil for electron-coupled set.
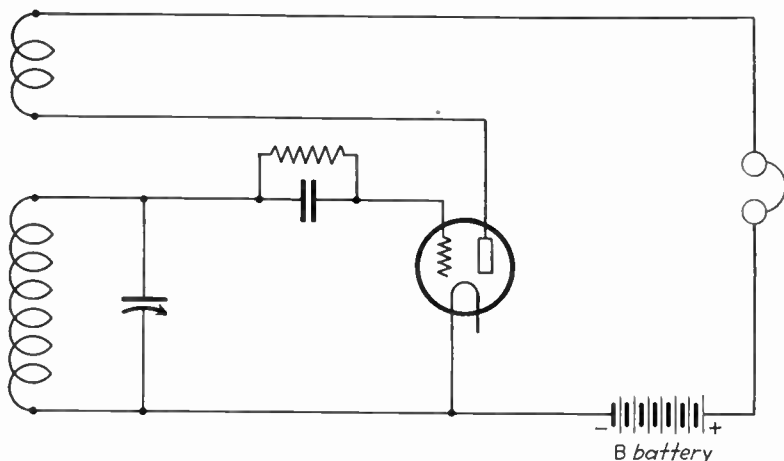


FIG. 260.    Regenerative detector circuit.    The A-battery wiring is omitted for
greater simplicity.

**The Circuit.**    When you use a screen-grid tube, you must
couple to the amplifier through either a resistance or an

impedance coupling circuit. Regeneration is controlled by the screen-grid resistor.

## How to Operate It

This set is operated in the same manner as are other short-wave receivers. You will find that it is easy to adjust
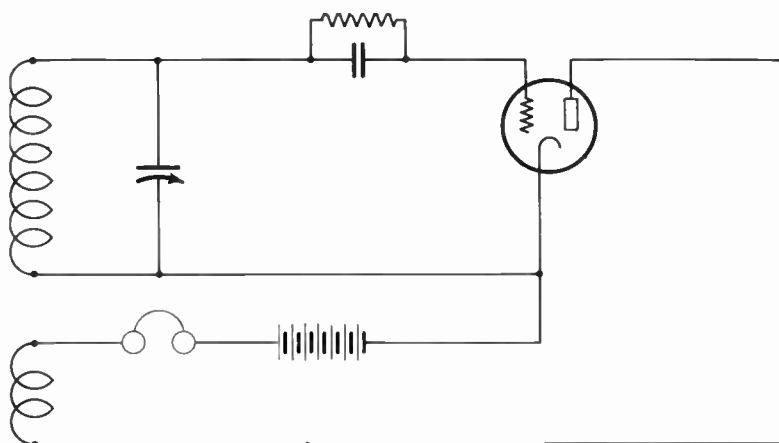


Fig. 261. Regenerative circuit, with B wiring redrawn.

close to the oscillation point and that once adjusted it will not break into oscillation easily.

## How It Works

We can understand the operation of this circuit by comparing it to the familiar regenerative circuit we have studied in Chapters V and VIII. This circuit is shown in Fig. 260. Energy in this circuit is fed from the plate circuit back to the grid circuit by means of a plate coil.

Let us redraw this circuit into a new form. In Fig. 261 we show the plate coil and its connecting wires drawn below the grid coil instead of above as it was in Fig. 260.

To simplify this circuit, we shall move the position of the B battery to the wire between the plate and the plate

coil. This leaves two wires $M$ and $N$ in Fig. 262 which are connected together at $X$. The circuit will operate just as well if this connection is made between the coils.
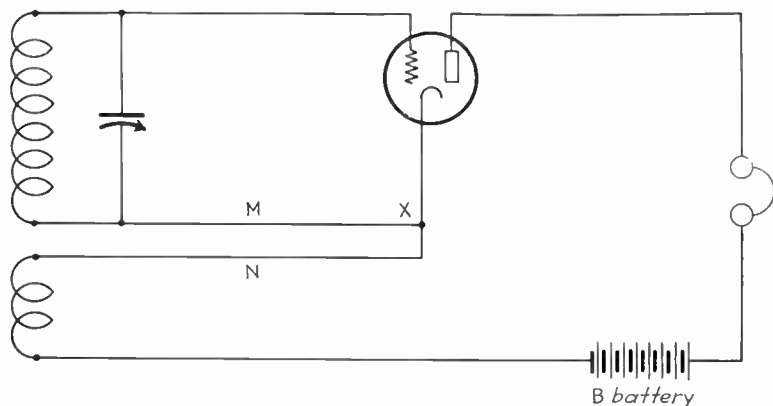


Fig. 262. Regenerative circuit, with B battery moved to new position in circuit.
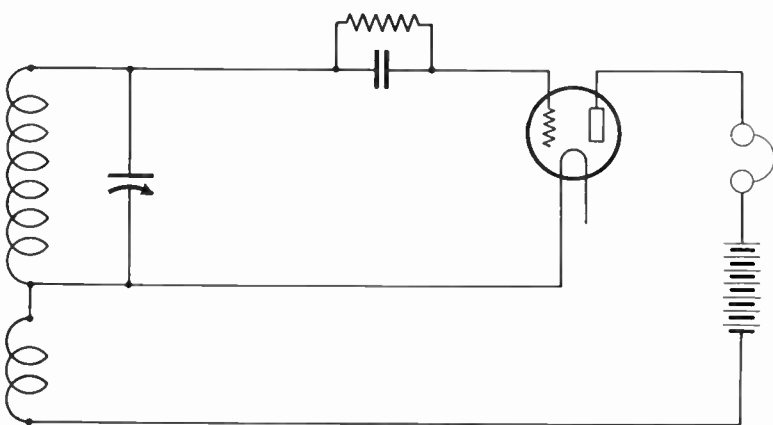


Fig. 263. Regenerative circuit, plate coil connected to grid coil.

We can now draw one coil instead of two (see Fig. 263). Instead of connecting the tuning condenser across the grid part of the coil, we shall connect it across the whole coil. This set, shown in Fig. 264, operates the same as did the

original regenerative circuit (see Fig. 260). The plate part of the coil feeds back energy to the grid part of the coil as before.

### 5. A TWO-TUBE SHORT-WAVE RECEIVER

The two-tube set shown here is a breadboard unit with a metal panel. It is a combined detector and audio amplifier used to familiarize you with a more compact set and the wiring problems that come from close spacing of parts.

This set is so easy to build and wire that it is a favorite with many radio amateurs and experimenters as a set to
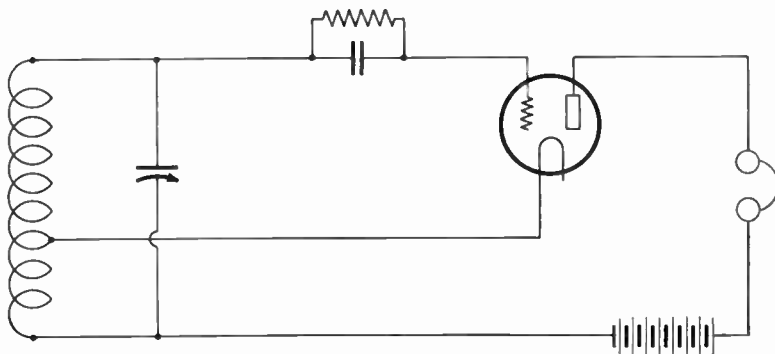


FIG. 264. Electron-coupled circuit is the regenerative circuit, with tuning condenser across entire coil.

use for learning the Morse code by listening to commercial stations that send out press and news items.

After you build a set, you will find that you need a week or two to become familiar with its peculiarities of operation so you can get the most out of it.

This set is sensitive enough to receive stations at a good distance, yet it is not so sensitive that its tuning is critical and hard to learn.

### How to Build and Wire the Set

**Tubes.** Use the type 27 tubes in both the detector and audio-amplifier circuits.

**Board Layout.**  Set the parts on the board as shown in the board layout in Fig. 265.  The detector tube socket will be at the left near the plug-in coil.  The grid leads must be as short as possible.  The coil must be at least $1\frac{1}{2}$ inches from the tube or the condenser on the panel.
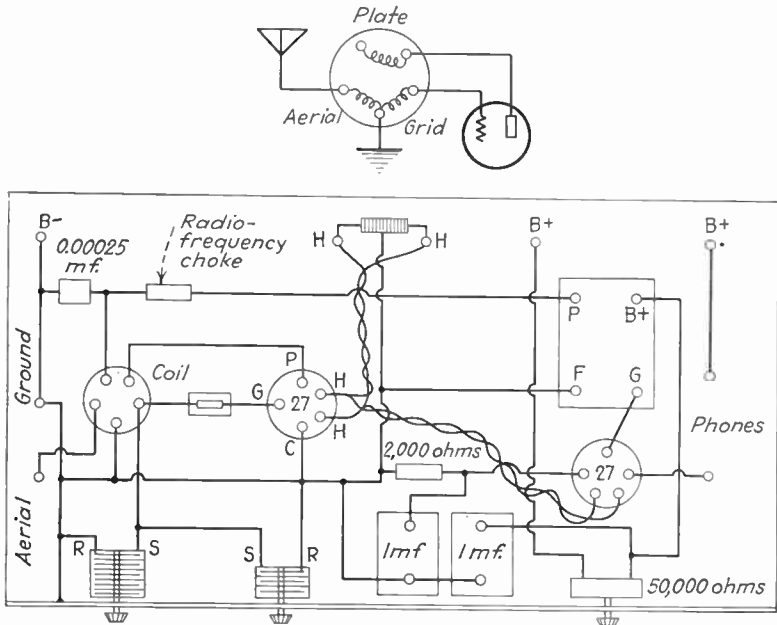


Fig. 265.   Two-tube short-wave set.   The connections to the plug-in coil are shown above.

Any convenient arrangement may be used for the parts of the audio amplifier.

**New Parts.**  *Coils.*  Wind one or more plug-in coils to cover the frequency bands on which you wish to receive. Wind each coil on a five-prong form.

*Condenser.*  Use a 23-plate midget condenser for rough tuning and a 3- to 7-plate midget for fine or "band-spread" tuning.

*Grid Condenser and Leak.* Use a .0001-microfarad grid condenser with a 2-megohm grid leak for a short-wave set.

*Other Parts.* The other apparatus is the same as that used for detector and amplifier circuits.

**The Tuning Circuit.** Follow the circuit diagram in **Fig. 266** carefully. Note the wires from the grid coil to the
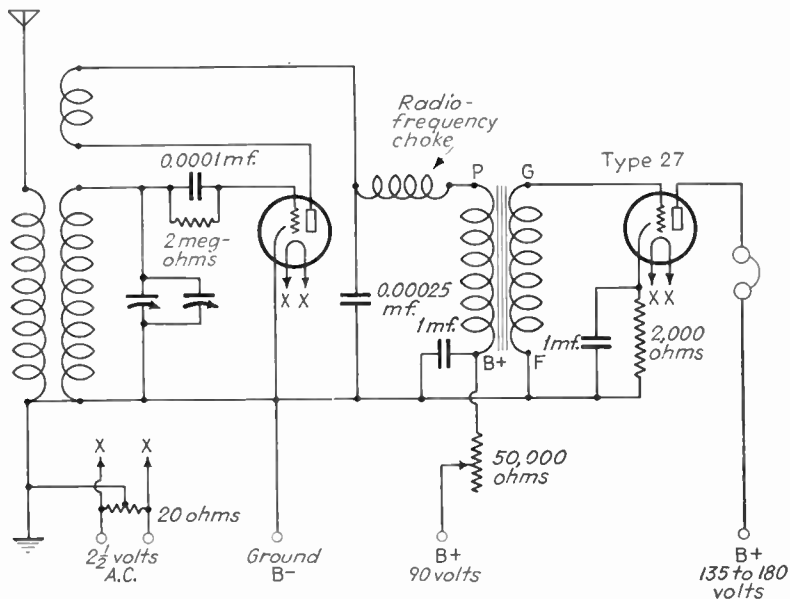


FIG. 266. Circuit for two-tube short-wave set.

grid condenser and grid leak, then to the grid of the type 27 detector tube; make these as short as possible both for efficient operation and to prevent feedback from plate wires. Keep wires from the grid coil to the tuning condensers as short as possible. Use a vernier dial for fine tuning on the 3- to 5-plate midget tuning condenser.

Keep the plate leads short and as far as possible from the grid leads. If it is possible to run the plate leads at an

angle to the grid leads, there will be less chance of induction from the plate leads to the grid wiring.

Run a wire from the B negative or ground connection to the panel. Generally the variable condenser mounting to the rotor plates grounds the set.

## How to Operate the Set

See How to Operate the Set in part 4 of Chapter V.

Tune with the receiver adjusted so it is oscillating.

The two tuning condensers connected in parallel are new. Tune first with the large condenser to the approximate setting for the station you wish to receive. You will soon learn where to set this dial for any group of stations. You can mark these positions easily.

Tune accurately to the station with the vernier dial attached to the small condenser, without changing the setting of the large condenser.

Turn back the regeneration control until the set just goes out of oscillation. You will hear the stations best here.

## Why It Works

See the explanation of Why It Works in part 4 of Chapter V.

**The Band-spread Condenser.** The capacity of the 3- to 5-plate condenser connected in shunt across the 23-plate midget tuning condenser adds to the capacity of the larger condenser. The two condensers then tune to a lower frequency.

Tuning with the small condenser makes a small change in the total capacity of the two condensers and so permits us to tune very closely. The effect is the same as if the stations on the band to which we are tuning were "spread" apart. We can now hear stations that we would otherwise be unable to tune in.

The vernier or slow-motion dial gears down the motion of the knob so the condenser plates can be moved distances much less than is possible by turning an ordinary dial with the fingers.

## 6. SUGGESTIONS FOR BREADBOARD CIRCUIT ARRANGEMENTS

Here are several circuit combinations using the circuits we have just studied as applied to short-wave sets mounted breadboard panel style. It is worth while to build several sets arranged in this fashion to become accustomed to using these circuits before attempting to put the same circuit on a metal chassis.

**Set 1.** *Direct-current Detector Set—Type 01A or Type 30 Tube.* This is a direct-current one-tube detector circuit, using a coil mounted on a six-prong tube socket. Use either resistance or condenser regeneration control.

**Set 2.** *Direct-current Detector Set—Type 01A or Type 30 Tube.* This set is the same as set 1, but it uses the five-prong coil socket in place of the six-prong socket. If you wish to use a radio-frequency amplifier with this set, it is desirable that the six-prong socket be used instead of the five-prong.

**Set 3.** *Direct-current Detector and Audio Amplifier on One Board—Two Type 01A or Two Type 30 Tubes.* This set is a combination of the two circuits mounted on the same board, which makes a nice set for the beginner to use while practicing code and learning the answers for amateur radio license questions. This set works quite well. It is easy to build and to get in operation. It is not so sensitive that it is hard for the beginner to handle.

**Set 4.** *Alternating-current Detector—Audio Amplifier Set.* This set is similar to set 3, but the type 27 tube is used in place of the type 01A or type 30 tube.

**Set 5.** *Screen-grid Detector Circuit.* The screen-grid tube is used in the detector set with the standard circuit using a six-prong coil socket.

**Set 6.** *Audio Amplifier Added to the Screen-grid Detector.* In this set we use a screen-grid detector with a type 27 audio amplifier. This is a very sensitive set which may be used for communication work and is efficient and inexpensive.

### 7. THE ALTERNATING-CURRENT SHORT-WAVE COMMUNICATION-TYPE RECEIVER

## How to Build and Wire the Set

**The Breadboard Arrangement.** Lay out the parts on the board, as shown in Fig. 267. This circuit and the parts
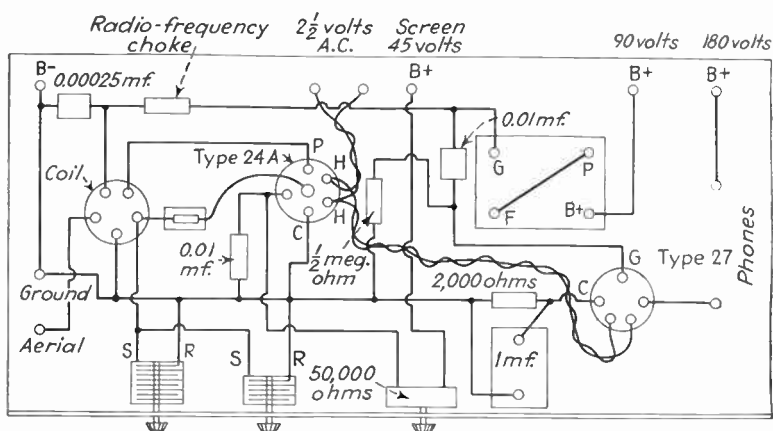


FIG. 267. Communication receiver.

layout is the same as for the set using two type 27 tubes. A tube shield is placed over the screen-grid detector tube in this set. Use a type 24A detector and a type 27 amplifier tube.

**How to Wire It.**    Run the grid wire either from the coil socket or directly from the top of the coil form (see Fig. 268).    While this latter arrangement keeps the grid wires short, yet a connection must be made to both ends of the grid-condenser–grid-leak unit.    One end runs to the tube cap, and the other end runs to the coil.

One other change is the wire lead for the screen-grid connection.

**Grid Condenser and Leak.**    Use a .0001-microfarad grid condenser and a 2-megohm grid leak.    The .0001-microfarad condenser makes the set more sensitive for distant and weak stations.

## How to Operate It

Turn on the heater current.    Use the plate voltage shown in Fig. 268.

This tube is so sensitive that the circuit must be carefully wired and adjusted to prevent feedback, squealing, and dead spots where the set will not oscillate in tuning.    You will also find it necessary to get the screen voltage and the plate voltage correct in order to get the best efficiency out of this set.    A direct-current voltmeter should be used to test the plate voltages.

The operation of the tuning controls and the adjustment for oscillation have been explained in Chapter VIII.

### Question

1. Describe the characteristics of this set in comparison with the other sets which did not use a screen-grid tube.

### 8. THE TUNED RADIO-FREQUENCY RECEIVER

The famous tuned radio-frequency set so greatly favored by amateurs for a communication receiver is a simple and most efficient circuit for short-wave sets.    This set will be made up of one stage of tuned radio-frequency amplifi-
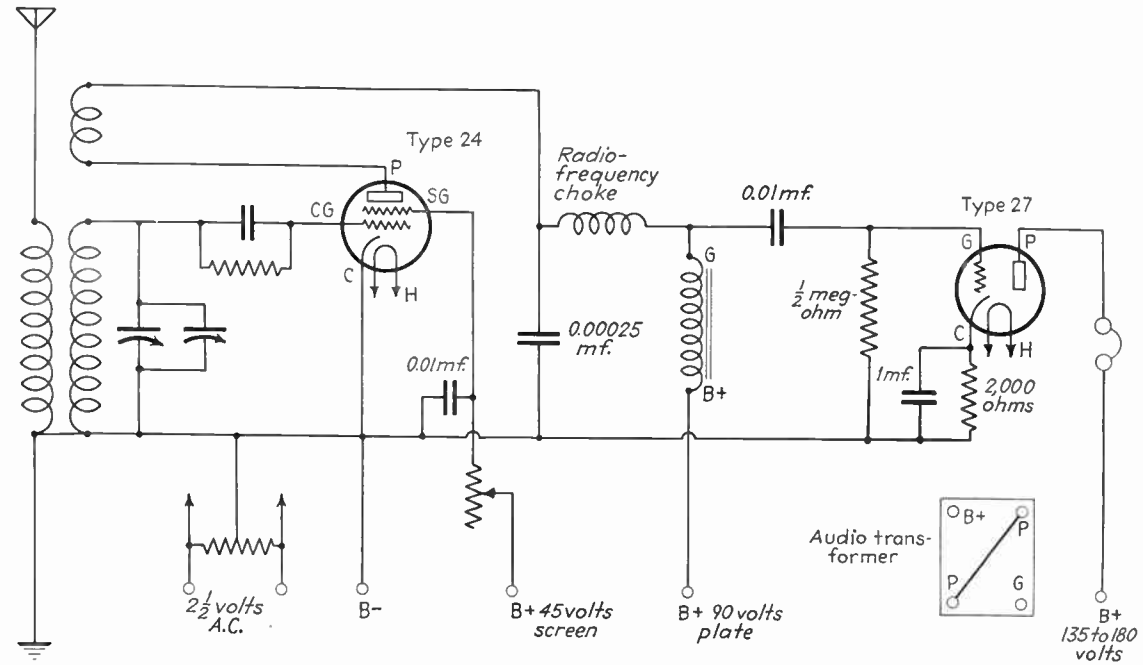
FIG. 268. Communication receiver circuit.

cation, a detector, and one stage of audio amplification, using two type 24 tubes.

Tuned radio-frequency amplification stages are used to build up the strength of very weak signals before they reach the detector. This extends the range of the receiver greatly, bringing in signals that could not be heard at all with a detector set. For this reason a stage of radio-frequency amplification is popular on amateur short-wave receivers where distant reception is a chief object.

The addition of a radio-frequency stage to an amateur set greatly sharpens the tuning and makes the set more selective. A tuned radio-frequency receiver using three tubes—a radio-frequency amplifier, a screen-grid detector, and an audio amplifier—is very popular with amateur radio operators where sensitivity and selectivity are important. With these operators, volume is not important since most of their reception is with earphones.

This set may be used not only for receiving amateur signals but also may be adapted, by use of the proper-sized coils, for a midget broadcast receiving set by adding a power amplifier tube and a dynamic speaker. We shall first build this set on a breadboard. Later it may be rebuilt into a completely shielded metal chassis if a more efficient set is desired.

While the set given here is not the last word in efficiency, it is one with which you can experiment handily. It is efficient enough for long-distance amateur telegraph and telephone use, yet it is inexpensive and easy to tune. It uses parts in its construction which can later be used for a highly efficient set.

**Baseboard.** We shall mount the set on a wooden baseboard. After we have worked with the set enough to become thoroughly familiar with its operation and its hookup, we shall redesign it and place the parts on a metal

subpanel and use additional shielding for the tubes and coils.   We then place the wiring under the subpanel.

**Band Spread.**   We shall want some form of band-spreading device for finer tuning.   Band spreading is obtained by a number of methods; a common method is

FIGHTING CRIME BY MEANS OF RADIO
The modern short-wave radio is used in many cities as a means of communication between headquarters and squad cars.

the use of a 3- to 5-plate midget condenser wired in parallel with the main tuning condenser.   By using a vernier dial on this condenser, the tuning is made still finer.    The main tuning condenser is set approximately to the frequency desired, and the band-spread condenser is used for the fine tuning.

This set is no longer the type of experimental set with which we have been working so far in this book. Many of the sets we have used have operated well over considerable distance and have produced signals of quite good quality. One reason for the efficiency of these sets has been their simplicity. The parts were separated far enough so as to avoid feedback from coupling between stray radio-frequency fields or magnetic fields. None of these sets have been built for beauty or appearance.

We are ready now to make up a set which is compact and efficient and which will receive over greater distances and will be easier to tune.

**Shielding.** Use a metal panel and arrange the set so that it may be shielded. The set will work quite well with individual shields over the radio-frequency tube and the detector tube.

With the parts of this set laid out as shown in the board layouts, the radio-frequency coil is placed at a considerable distance from the detector coil. This is done to prevent feedback and poor tuning. By covering both the detector tube and the radio-frequency tube with tube shields, this is eliminated. Each tube shield must be grounded to the B negative wire. A plate shield may instead be set up between the detector circuit and radio-frequency circuit. This plate must be grounded.

The coils and tubes of one stage must be shielded from the coils and tubes of the next stage to prevent feedback, which will cause squealing, dead spots in the tuning, possible hum, and other annoying difficulties in operation. Condensers need shields only on sets that have much amplification.

A good type of shield is made of sheet iron, steel, or copper, plated with chromium. The iron shields out any magnetic effect between stages set up by audio frequencies,

and the copper plating shields out all high-frequency currents which travel on the surface of the metal.

A copper or an aluminum shield is good for radio-frequency shielding but is poor for audio-frequency shielding. Tinned iron is better for audio-frequency shielding than copper.

The power transformer, even when shielded, must be kept as far away from the audio frequency stages as possible to keep out 60-cycle hum. There is little feedback from the power transformer into the radio-frequency circuits.

**Individual Shielding and Box Shielding.** Aluminum or copper shields which fit over each tube are available on the market. A coil shield-can must be about twice the diameter of the coil and at least an inch or more from the ends of the coil. If the metal shield is too close to the coil, it absorbs energy from the magnetic field of the coil and cuts down on the strength of the signals. Individual shields probably are better than box shields and are easier to install.

It is important in shielding to separate the side walls of the metal box shields used between stages, because a single wall between stages will have some coupling effect. It is better to make two separate metal boxes with about $\frac{1}{4}$ inch of space between them, one box for each stage.

**Experimental Shielding.** Place a metal plate between stages or set a tomato can over parts of each stage to test shielding. Each shield must be connected to the B negative or ground lead. Try shielding a set which squeals badly and is hard to set close to the regeneration point. Metal panels used for shields against body capacity must be grounded.

**The Panels.** The panel should be heavy and rigid enough to support tuning condensers, resistor, and other controls. Suitable materials for the panel are galvanized iron or aluminum. Any of these materials will shield out

body capacity when grounded to the B negative or to the ground. Copper and aluminum must be between $\frac{1}{16}$ inch and $\frac{1}{8}$ inch thick, depending on the size of the panel. Brass or iron sheets $\frac{1}{16}$ inch thick are stiff enough to support the apparatus mounted on them. All of the shields, if used on the breadboard set, must be connected together and grounded.
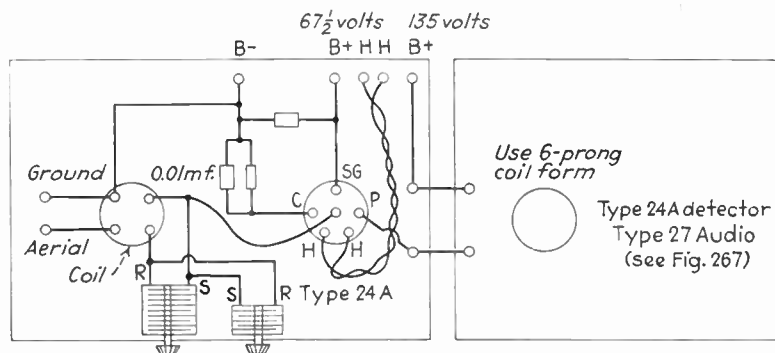


FIG. 269. Tuned radio-frequency amplifier stage added to short-wave receiver.

### Questions

1. To what must the tube shields be grounded?

2. Is the band-spread condenser connected in series or in parallel with the main tuning condenser?

3. List the parts of one stage which must be shielded from certain parts of the next stage.

4. Is a copper or an aluminum shield better for radio-frequency shielding? Which metal is best for audio-frequency shielding?

5. Is iron better than copper for audio- or for radio-frequency shielding?

6. Why must the side walls of metal box shields be separated between stages?

## How to Build and Wire the Set

**The Panel.** Use a sheet of $\frac{1}{16}$-inch aluminum, 7 inches high and 12 inches long. Aluminum is pleasing in appearance, easy to drill and cut, and not too expensive.

Arrange the parts and study out the position of the wiring before mounting the parts on the panel (see Fig. 269). The kind of parts you use will determine the position of the mounting holes.

Another arrangement is to put the radio-frequency amplifier on one board and the detector and the audio amplifier on another board. In this way you use two smaller pieces of aluminum.

**Drill the Panel.** Drill three $\frac{1}{8}$-inch holes near the lower edge of the panel for brass round-head wood screws to be used for fastening the panel to the edge of the wood base.

The kind of dials you expect to use determines the position of the mounting holes on the panel. Use a small knob and pointer for the band-set condenser. Use a vernier or slow motion dial for the band-spread condenser. Place this dial in the center of the panel.

Mount an on-and-off switch on the panel for the B voltage.

**Position of the Parts.** Place the parts as shown in the board layout (see Fig. 269).

Place the band-set condenser at the left of the panel. Place the coil back of the band-set condenser so the tuning circuit leads will be as short and direct as possible.

Place the detector socket near the coil socket so the grid lead will be short.

**How to Wire It.** Wire this set by connecting the wires from part to part as directly as possible (see Fig. 270). The wires all are to be as short as is practical. In this set you will no longer be able to follow the appearance of the circuit diagram.

### How to Operate It

The operation of this set is no different from that of other regenerative circuits we have studied.
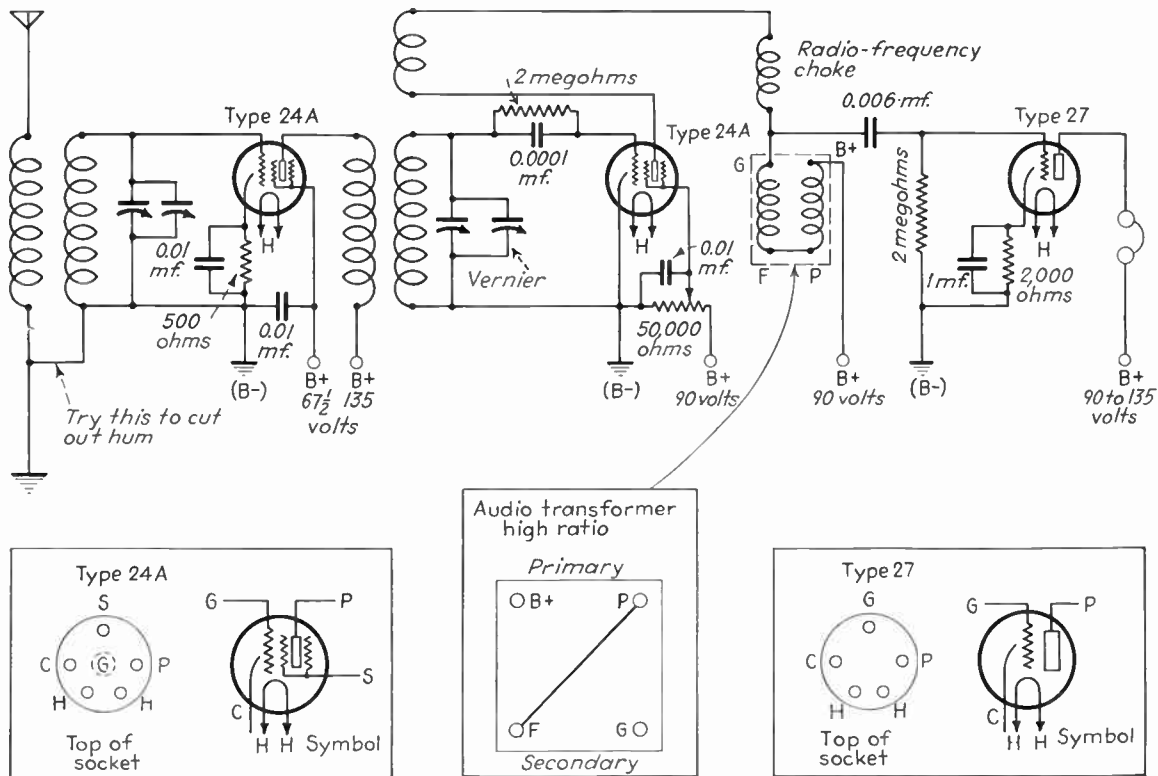
FIG. 270. Tuned radio-frequency short-wave receiver circuit.

## 9. A TUNED RADIO-FREQUENCY RECEIVER WITH METAL CHASSIS AND PANEL

### How to Build the Panel and Chassis

**The Front Panel.** Make the panel of a sheet of aluminum or sheet iron. The panel must be rigid. An aluminum panel should be about $\frac{1}{8}$ inch thick. Iron, which is more rigid, may be about $\frac{1}{16}$ inch thick.
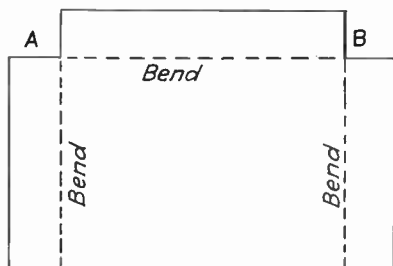


Fig. 271.   Sheet metal cut for chassis.

**The Chassis or Base.** The chassis is made of lighter material. Use aluminum $\frac{1}{16}$ inch thick or iron thick enough to form a rigid base. The chassis is an open box. Mark the size of the sheet metal as shown in Fig. 271.
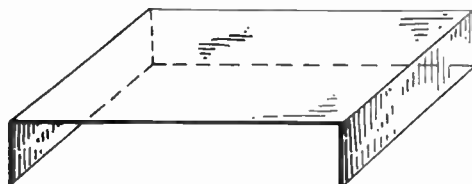


FIG. 272.   Chassis ready for drilling.

Make the lines $2\frac{1}{2}$ inches from the edges of the metal. This is the depth of the chassis. Cut out corners $A$ and $B$ and bend on the dotted lines to form the chassis as shown in Fig. 272.

Cut, bend, and drill several angles for fastening the panel to the chassis (see Fig. 273). Cut holes $1\frac{1}{2}$ inches in diameter through the chassis for the



FIG.   273.   Angles   for fastening.

sockets. These holes may be cut by a specially prepared punch and die or with a circle cutter which is held in a brace.

Both the punch set and the circle cutter are expensive. You may scratch a circle for the hole, then drill closely spaced $\frac{1}{2}$-inch holes just inside the circle. Cut through the metal between the holes with a small cold chisel. Smooth up the hole with a half-round file. Cut burrs off the aluminum with a dull knife. Drill $\frac{1}{4}$-inch diameter holes for wires which must run through the chassis. Mount the wafer socket for the tubes under the chassis by means of two small machine screws.

Only the plug-in coils, the tubes, and the tuning condensers are placed on top of the chassis. In this way the leads which carry radio frequencies are shielded from the tubes and from the coils. The audio transformer is placed below the chassis if there is room for it.

Any part in the circuit which is to be grounded is soldered to soldering lugs bolted to the chassis.

Fasten the panel to the chassis with angles held in place by brass machine screws $\frac{1}{2}$-inch long. Drill the panel and the angles for the screws.

Shield each tube with a metal tube shield. Can shields for the coils must be at least 3 inches in diameter.

Wire the set with "push-back" wire. This wire furnishes good insulation and is very convenient to use.

Some constructors build the power supply in the same set. You may do this by allowing room on the chassis for the power transformer. Mount the filter parts under the chassis. Select a well-shielded transformer for this set. Cut a hole in the chassis for the connection lugs.

Complete details for constructing this type of set are given in the many excellent publications and handbooks on radio construction and operation. Such information is beyond the scope of this text.

### Question

1. Why are such parts as the plug-in coils and tuning condensers placed above the chassis?

# CHAPTER X

## OSCILLATORS AND TRANSMITTERS

In this chapter we shall study the different vacuum-tube circuits used as power oscillator circuits. We have already studied receiving sets which can be made to oscillate. In this chapter we shall study methods of developing powerful oscillations in power oscillator circuits.

**Power Oscillator Circuits.** We shall study and operate several commonly used oscillator circuits. Some of these circuits are the Hartley oscillator, the tuned-plate–tuned-grid oscillator, and the crystal oscillator. We shall work with these circuits until we become familiar with their operating peculiarities and the methods of adjusting them for efficient operation. We shall learn to test and adjust the frequency at which the oscillator operates and shall learn to develop and use simple testing equipment.

**Uses for Power Oscillators.** We shall study the oscillator circuit in use as part of a radio telephone or radio telegraph transmitter. We shall examine the use of the amplifying advantage of a tube in a power amplifier circuit. Here we shall take up not only Class A amplifiers but also Class B and Class C. We shall also study methods of keying and adjustments of transmitters for efficient operation.

### Contents of This Chapter

### 1. THE HARTLEY OSCILLATOR

## How to Build and Wire the Set

**Arrangement of Parts.** Place a 23-plate variable condenser (.00025 microfarad capacity) at the left of the board (see Fig. 274). This should be a low-loss type receiving condenser with good insulation. The plates must be well spaced to prevent sparking between plates. This is necessary since high voltages are built up in the tank circuit.

See the instructions on How to Wind Oscillator Tank-circuit Coils in this chapter.

Use a .00025-microfarad grid condenser and a 50,000-ohm 5-watt grid leak.

The radio-frequency choke is either a $\frac{1}{2}$-inch dowel about 3 inches long on which is wound 2 inches of enameled wire (No. 30 to No. 34), or a receiver-type choke.

**How to Wire the Set.** The tuning circuit, which consists of the variable condenser and the coil, is called the tank circuit (see Fig. 275). The heaviest currents in the oscillator flow in the tank circuit. The wiring must be heavy and direct.

*The Tank Circuit.* Connect the ends of the tank coil to the tank tuning condenser with wires as short and direct as possible. Use wire of the same size as that used on the

coil.    The rest of the circuit should be connected with
fairly heavy wire running as directly as possible from point
to point (see Fig. 275).    Attach the clip to the center of
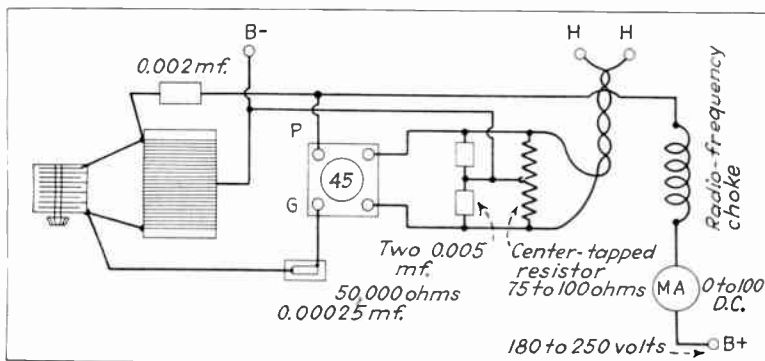


FIG. 274.    Hartley oscillator.
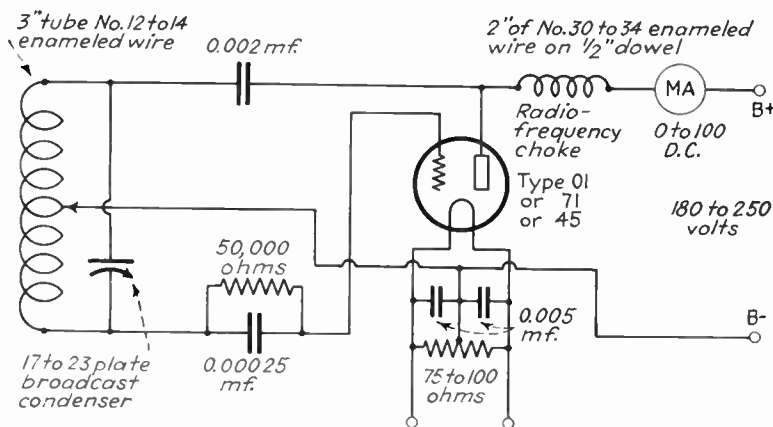


FIG. 275.    Hartley oscillator circuit.

the resistor connected to the B negative.    This clip is moved
along the coil to change the grid-excitation setting.

*B Supply Connections.*    The wiring diagram shows the
B supply connected in shunt across the heater and plate.

The B supply may also be connected in series. This is shown in Fig. 278.

Connect a direct-current 0–100 milliammeter in the B positive wire. Use a 0–300 milliammeter if the voltage is over 250.

Connect a switch in the B negative lead if there is no switch on the power supply. This switch should not cut
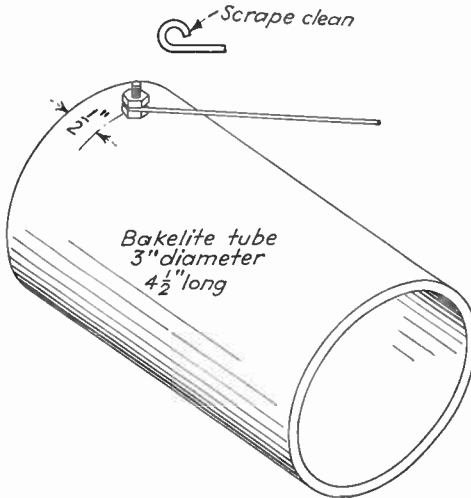


FIG. 276. Coil-winding details.

off the heater or filament voltage. It is used to shut off B power while making adjustments to the set.

Connect two .005-microfarad filament by-pass condensers and the .002-microfarad high-voltage mica blocking condenser, as shown in Fig. 275.

*Tubes to Use.* Any of the tubes we have used can be used in the oscillator circuit. The type 45 tube is the best tube to experiment with. It is stable and a strong oscillator.

**How to Wind the Oscillator Tank-circuit Coils.** *The Coil Form.* Use bakelite tube of 3-inch diameter for the coil form. Drill a hole for a small machine screw $\frac{1}{2}$ inch

from one end of the tube. Fasten the screw in place with a nut.

*The Wire.* Use size 14 enameled or bare copper wire. Wind on 35 turns. This coil will tune in the 160-meter amateur band when shunted with a .00025 microfarad variable condenser.

*How to Wind the Coil.* Scrape the insulation off the end of the wire for about an inch. Make a loop in the end of the wire (see Fig. 276). Slip this loop over the machine screw and fasten in place with a nut.

Unreel about 30 feet of wire and fasten the end to some solid object.
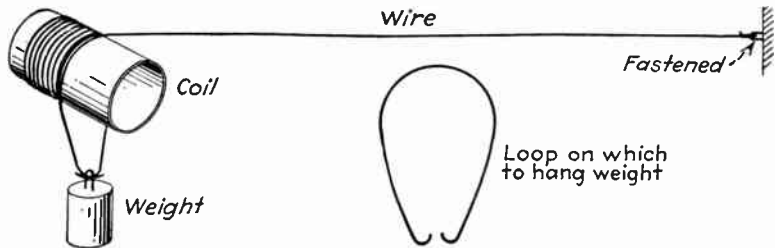


FIG. 277. Coil-winding detail; how to space turns when winding coil.

Make a loop of wire of the same size as that used in the coil (see Fig. 277). Hang the loop over the coil form with a weight hooked in the loop.

Pull the wire tight and wind the coil by rolling the tube toward you. Keep the loop of wire between the turns. This keeps the turns spaced evenly. Keep the wire tight or it will slip, and you will have to start over.

*How to Fasten the End of the Wire.* Drill a second hole at the end of the winding and place a machine screw as at the other end of the coil.

If you are working alone, make a trial winding to find the location of this hole. If you have assistance, hold the wire tight while your helper drills the hole and fastens the machine screw in place.

Now scrape the wire and make a turn around the machine screw. Keep the wire tight to prevent the coil from slipping until the wire is fastened in place with the nut. Now cut off the surplus wire.

Solder the ends of the wire to the machine screws.

Paint the whole coil with collodion or clear lacquer to fasten the wire in place. Nail polish can also be used.

Scrape the insulation off each wire for $\frac{1}{2}$ inch for the length of the coil to make connections to the wires.
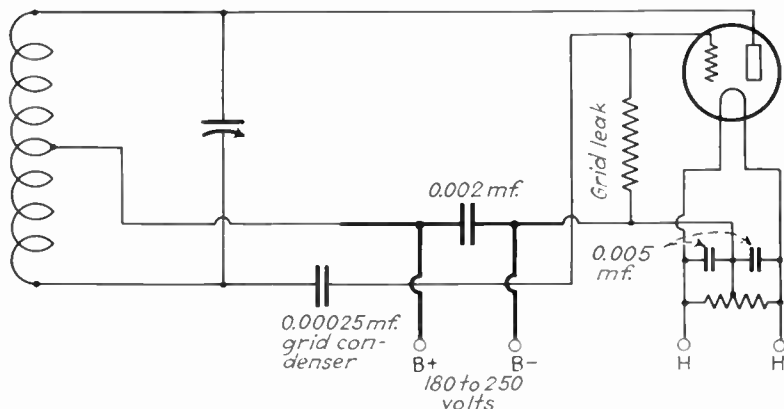


FIG. 278.   Hartley oscillator circuit using series feed.

**Series and Parallel B Power Connection.** *Series Feed.* When series feed (see Fig. 278) is used, the voltage of the power supply is connected to the tank circuit, and there is danger of shocks when changing the adjustment of the excitation tap. You need no radio-frequency choke in the plate lead when series feed is used. Use series feed for frequencies above 1500 kilocycles. It is so difficult to get a choke to operate well at high frequencies that series feed should be used.

*Parallel Feed.* Parallel feed (see Fig. 279) used with the Hartley circuit is safe to handle. There is no plate voltage on the tank circuit.

Much power can be lost in an improperly built or selected choke.   A receiver-type choke may be used in the low-power transmitter.   A poor choke will lose all of the radio-frequency power generated in the oscillator.
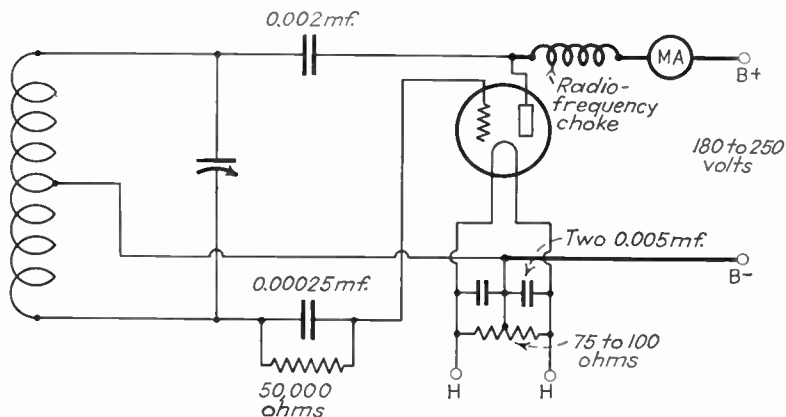


FIG. 279.   Hartley oscillator using parallel or shunt feed.

### Questions

**1.** What type of feed should be used for frequencies above 1500 kilocycles?   Give the reason for your answer.

**2.** Which is the safer type of feed to use?

**3.** What is the disadvantage of a poor choke in the parallel-feed sets?

## How to Operate the Oscillator

**Turn the Set On.**  Turn on the heater current before turning on the B voltage.   Check the heater voltage at the tube terminals.   Incorrect voltage on the heater fila-ment overloads the tube and shortens its life.

**Turn On the Plate Voltage.**  This circuit will oscillate with from 90 volts up to 250 volts on the plate.   If you use too high plate voltage, the electrons are pulled off the filament too rapidly and the life of the tube is shortened.

You can see small sparks on the filament when this occurs. The remedy is to reduce the B voltage until sparking stops.

A lamp and loop may be used to see if the set is oscillating.

**Tuning.** Tune with the condenser. Set the frequency by monitor or frequency meter. This is explained in part 3 of this chapter.

**Shocks.** Shocks received on the low-powered oscillators and transmitters using under 250 volts on the plate are strong enough to be unpleasant.

In the Hartley circuit using shunt feed no direct-current shocks will be gotten on the tank circuit. The direct current is kept out of this circuit by the plate-blocking condenser. Shocks from the direct-current circuit are more severe.

**Adjust Grid Excitation.** *Step* 1. Set the clip at the center of the tank coil. Be sure the B voltage is off.

*Step* 2. Turn on the B voltage. Read the milliammeter. The current may be as high as 50 milliamperes. Now, set the tank condenser near the center of the dial. The frequency of the oscillator is changed by adjusting the tank condenser. The set will oscillate over all of the condenser range.

*Step* 3. Adjust for the lowest possible reading (about 10 milliamperes) on the milliammeter by moving the position of the clip. The position of the clip controls grid excitation by changing the feedback from the plate part of the coil to the grid part of the coil.

Move the clip toward the plate end of the coil for more excitation and toward the grid end for less excitation. This setting is different for each tube.

The size of the grid leak also affects the excitation. Try different sizes of grid leak to get the proper grid excitation.

When the clip is too near the grid end of the coil, the set will stop oscillating since there is not enough grid excitation.

The plate current goes up when the set stops oscillating. Watch the milliammeter. The tube will heat and may burn out if it stops oscillating.

**How to Check for Oscillation.** Touch the grid leak. The tube will stop oscillating and draw much power. This method should be used only on low-power sets.

Touch the tank coil or condenser plates with a pencil. The size of the spark shows the strength of the radio-frequency flowing in the tank circuit.

A small neon tube will glow when touched to any of the tank-circuit wires if the set is oscillating.

### Questions

1. When the clip is moved toward the plate end of the coil, is the grid excitation increased or is it decreased?

2. What happens to the plate current when the set stops oscillating?

3. Describe several methods for testing to see whether the set is in oscillation.

4. State where serious shocks may be encountered on this set.

**Tuning with a Load.** *Step* 1. Place the dummy antenna (described in part 2 of this chapter) near the oscillator tank coil.

Watch the lamp indicator on the dummy aerial. The dummy aerial circuit absorbs the energy from the tank circuit that would be absorbed by an aerial and its coupling coil when the oscillator is used as a transmitter. The dummy antenna is the "load" into which the oscillator is operating. Current induced in the pickup coil by the tank coil is used to light the lamp. The lamp is the actual load on the oscillator. Here the current is changed to heat.

The lamp should burn brightly as the pickup coil is brought nearer to the tank coil. The reading of the milli-

ammeter should increase rapidly.    This indicates that more plate current is being used to drive the tank circuit. Energy is being drawn from the tank coil by the dummy aerial load.

*Step* 2.    Adjust the "load" coupling.    If the set stops oscillating before the lamp burns brightly, either the coupling is too close or there is too little grid excitation.

Loosen the coupling by moving the pickup coil away from the tank coil.

Increase the grid excitation by moving the filament clip toward the plate end of the tank coil.    This causes more current to flow in the grid part of the coil and increases excitation.    The lamp should now burn more brightly. The lamp will go out when the set stops oscillating.    Set the coupling so the plate current doubles.

**Method of Tuning to a Certain Frequency.**    *Step* 1. Tune with no load on the circuit.    Set an absorption wave-meter (see part 3 of this chapter) to the desired frequency. Place the meter pickup coil near the oscillator.    Tune the tank condenser so the meter lamp or indicator shows a maximum glow.    Remove the meter.

Do not set the meter too close to the tank coil or the lamp will burn out.

*Step* 2.    Couple the load to the circuit.    Now, couple the dummy antenna to the tank coil for a load and tune the loaded circuit for the desired output.    If you want 10 watts output from the oscillator, use a 10-watt lamp in the dummy aerial.    It will burn at full brilliance when the oscillator is delivering 10 watts to the dummy aerial.

*Step* 3.    Recheck the frequency.    Bring the absorption wavemeter near the load and retune.    See if the added dummy antenna load has changed the frequency of the oscillator.    If the frequency has changed, readjust the tank condenser without taking away the load.    Now adjust the

load for maximum output.   This process of adjusting the tank condenser and the load is continued until the desired output is obtained at the frequency at which the set is to work.

### Question

1. Explain several ways to adjust the set so that it will oscillate while under a heavy load.

## Power of a Hartley Transmitter

**Measure the Power Input.**   *Step* 1.   Couple a load to the tank coil.
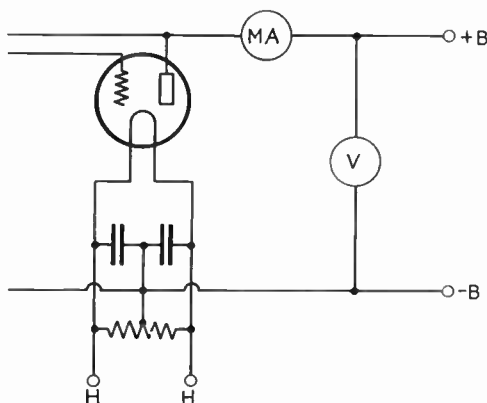


Fig. 280.   Connection of meters to measure power input to oscillator.

*Step* 2.   Measure the plate voltage with a high-resistance voltmeter.   See Fig. 280 for its connection in the circuit.

*Step* 3.   Measure the current in the plate circuit with a milliammeter.

voltage $\times$ current in milliamperes $=$ milliwatts input

Divide the product (in milliwatts) by 1000 to get the watts input.

Example:

500 volts $\times$ 30 milliamperes current =
$$15,000 \text{ milliwatts of power}$$
$$15,000 \div 1000 = 15 \text{ watts input}$$

### Questions

**1.** What is the power input in a Hartley circuit operated on 300 volts and a plate current of 20 milliamperes?

**2.** When connected as shown in Fig. 280, does the milliammeter measure the current taken by the voltmeter?

## How the Hartley Oscillator Works

**Electrons Surge Through the Tube.** When the filament is lighted, a space charge immediately builds up around the
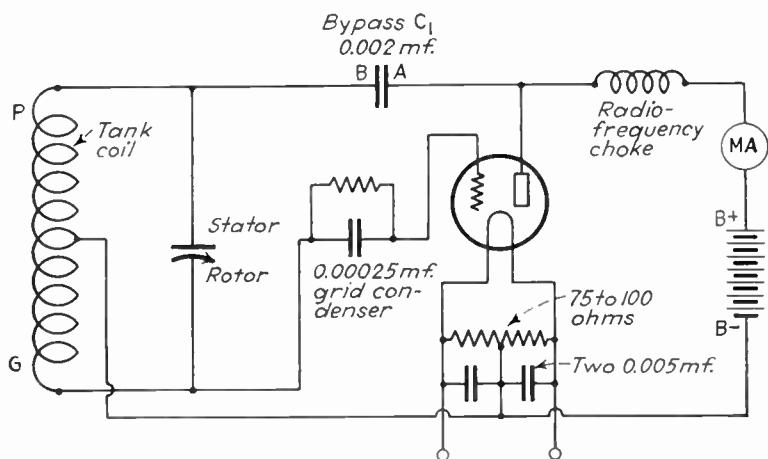


FIG. 281. Hartley oscillator, operation.

filament in the tube (see Fig. 281). Now, when you turn the B battery on, the electrons are pulled to the plate out of the space charge, and a current flows through the tube. The electrons surge through the tube and the plate circuit on their way to the B battery.

**The Radio-frequency Choke Coil Stops the Surge.**   The surge is forced over to the by-pass condenser $C_1$ by the back pressure or choking effect of the radio-frequency choke.   The electrons flow on side $A$ of the condenser and drive electrons off side $B$.

The electrons from side $B$ flow to the tank condenser and fill the stator plates.   The electrons then overflow and start through the plate part of the tank coil (marked $P$). When this surge starts, it induces a current in the grid part of the tank coil (marked $G$).   This current in the $G$ part of the coil flows in the opposite direction to the current which induced it or toward the center tap.

The induced current in the grid part of the coil draws the electrons off the grid of the tube, acting through the grid condenser.   As the grid becomes positive by losing electrons, it adds to the pull of the plate and more electrons stream through the tube until the limit of the ability of the tube to increase the current flow from filament to plate is reached.

Now the stator plates of the tank condenser are highly charged with electrons.   As the first surge through the tube begins to slow up, the electrons on the stator plates begin to rush out through the tank coil and into the rotor plates of the tank condenser.   The flow of current from the condenser comes at the peak of the current flow through the tank coil.   When a steady current is flowing, no electron flow is induced in the grid part of the coil to oppose the current flowing in the plate part of the coil.   The flow of a current in a coil must be increasing or decreasing to make induction possible.

The electrons fill the rotor plates of the tank condenser and then rush on to the grid condenser, where they force electrons to the grid of the tube.   As electrons collect on the grid, they repel the electrons in the space charge and

finally stop the flow through the tube. This completes one half of the surge.

As the current flow through the tube stops, the pressure of electrons on the rotor plates of the tank condenser forces a surge back through the tank coil to the stator plates of the tank condenser. No current is flowing from the plate of the tube to oppose the return of the electrons through the coil. The grid is kept negative by the grid condenser
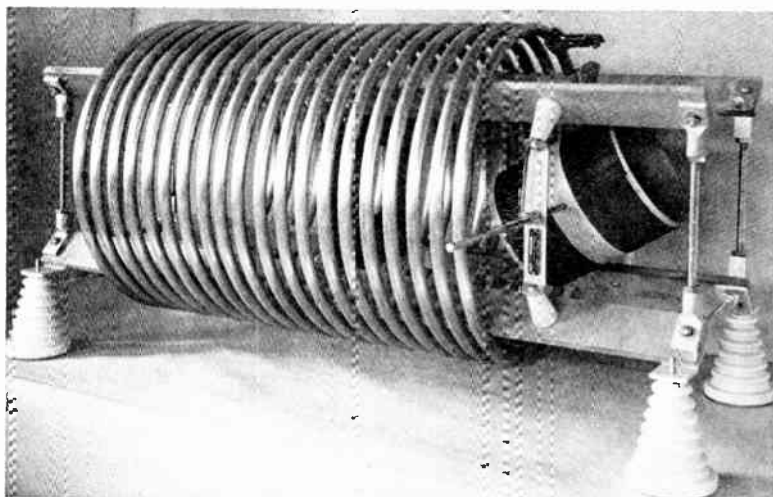


*Courtesy E. F. Johnson Co.*
HIGH-POWER INDUCTOR WITH COUPLING COIL FOR FEEDBACK

and the grid leak long enough for this surge to be completed. The sizes of the condenser and the grid leak are selected to fit the frequency at which the oscillator will work.

As the current surge through the tank coil from the rotor to the stator begins to die out, the magnetic field built up around the tank coil by the first surge tries to keep the current flowing. This pull draws electrons from the grid, making it positive. The current flow through the tube,

which was stopped by the negative grid, now begins again. The pull of the positive grid helps the pull of the plate and another surge begins.

**Grid Excitation.**    The grid-return wire is connected near the center of the tank coil.    When moved toward the grid end of this coil, less voltage is induced in this part of the coil and the grid is not made so strongly positive.    The set oscillates with less power.    The position of the grid return thus controls the grid excitation.

This whole process occurs at lightning speed. The Hartley oscillator circuit is capable of oscillating both at the comparatively low frequencies used on the broadcast bands and also at the extremely high frequencies, hundreds of millions of cycles a second, of the ultrahigh frequencies used in the 10-, 5-, and $2\frac{1}{2}$-meter sets.

### Questions

**1.** Explain why the $A$ side of the by-pass condenser is filled with electrons when a surge flows onto the plate of the tube.

**2.** When a surge starts down through the plate part of the tank coil, will the grid end of the grid coil force electrons onto the grid or draw electrons away from it?

**3.** Will this increase or decrease the flow of the plate current?

**4.** When the impedance or back pressure of the tank coil is overcome, where do the electrons go which were on the stator plate of the tuning condenser?

**5.** What effect will this flow have upon the grid?

**6.** What holds the grid negative long enough to keep the plate current shut off while the condenser rotor plates unload back through the tank coil?

**7.** What effect will the tank coil have upon the grid when the current upward through the tank coil suddenly decreases?

### 2. CONSTRUCTION OF A DUMMY ANTENNA

Use the dummy antenna in place of the regular aerial while you are experimenting with oscillators or trans-

mitters, and do not want to send out radio waves. The
dummy aerial is a coil-and-condenser tuning circuit. A
lamp is used as a resistance to absorb the electrical energy
picked up by the coil from the oscillator tank circuit (see
Fig. 282).
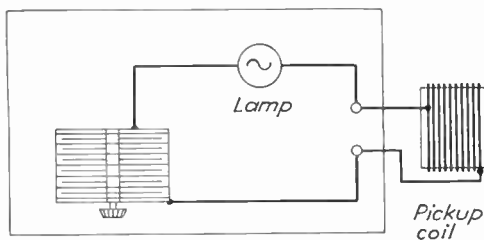


Fig. 282.   Dummy antenna.

### How to Build and Wire It

**The Coil.** Wind eight turns of size 14, 16, or 18 bare or
enameled wire on a 3-inch tube. The number of turns
should be about half that of the tank coil.

**The Condenser.** Use a 23-plate receiving condenser
similar to the one used for the tank-circuit condenser.

**The Lamp Indicator.** Wire a
lamp socket in series with the coil
(see Fig. 283).

### How to Operate It

Screw a lamp in the socket large
enough to absorb the energy deliv-
ered by the oscillator.
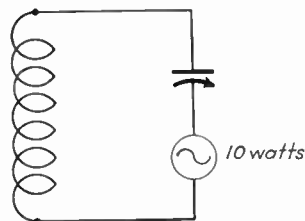


Fig. 283.   Dummy antenna
circuit.

Set the pickup coil near the
oscillator tank coil. Tune the dummy aerial condenser
until the lamp glows brightest. At this point the plate
milliammeter should show an increase in the plate current.

Connect the 10-watt lamp to the 110-volt circuit to see
the full brilliance of the lamp before using it in the dummy

circuit. The glow of the lamp shows the amount of current the dummy antenna draws from the oscillator.

**Power Output.** The power output of the oscillator is 50% of its input power. The power output is the energy in watts delivered to the aerial by the oscillator. The power input is found by multiplying the oscillator plate voltage by the plate current.

When 500 volts is used on the oscillator plate and the plate current is 40 milliamperes:

500 volts $\times$ 40 milliamperes $=$ 20,000 milliwatts

20,000 milliwatts $\div$ 1000 $=$ 20 watts input to the oscillator

output $= \frac{1}{2}$ input

$\frac{1}{2} \times$ 20 watts $=$ 10 watts delivered to the dummy aerial

Screw a 10-watt lamp in the socket. Tune the set and compare the glow of the lamp in the dummy to the glow of another 10-watt lamp connected to the lighting circuit. The output of the oscillator can be judged by the glow of the lamp in the dummy aerial.

### 3. THE ABSORPTION-TYPE FREQUENCY METER

## How to Build the Meter

Make a base of wood 4 inches wide and 6 inches long. Screw a piece of bakelite 6 inches square to the edge of the wood (see Fig. 284).

**The Condenser.** Mount a .00025 microfarad broadcast variable condenser on the bakelite panel. Mount a socket for a flashlight lamp near the binding post so the wiring can be short and direct.

Use a well-made variable condenser of the same size as the one in the oscillator. The ordinary sized condensers are used for the broadcast bands. Use an 11- to 13-plate midget condenser for the short-wave bands.

**The Coil.** Bore holes in the bakelite coil form so that
two pieces of size 14 bare copper supporting wire can be
bent through the holes (see Fig. 284). These wires are
used to keep the coil and meter wiring the same length at
all times. If these lengths are changed, the calibration
curve for the meter will be incorrect.
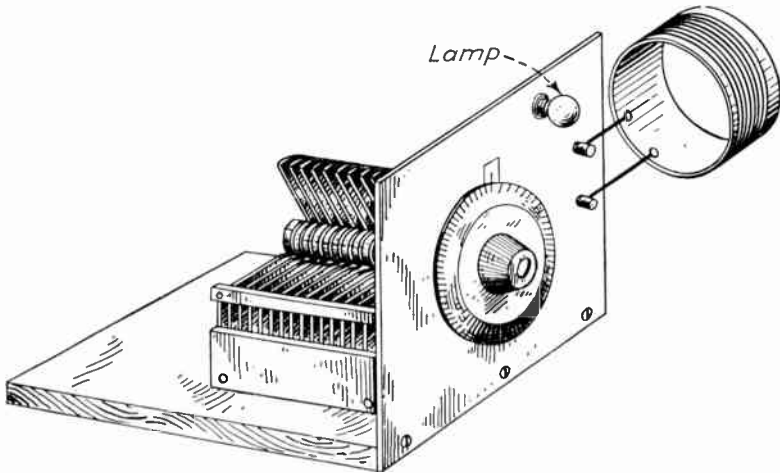


Fig. 284. Absorption-type frequency meter.

For the broadcast band, make a coil of eight turns of
size 22 double cotton-covered wire on a form 3 inches in
diameter. Make a coil for each band on which you expect
to test frequencies.

## How to Operate the Meter

The absorption-type frequency meter is a tank tuning
circuit to which is attached a light, or detector, and phones
to show when the circuit is in resonance with the frequency
we are trying to measure (see Fig. 285). The flashlight
lamp is used to indicate resonance by the strength of the
glow. Sometimes a crystal detector and a pair of phones

are used. The loudness of the sound in the phones indicates resonance.

The absorption-type meter is not highly accurate. Its accuracy is from 20 to 30 kilocycles. It is used as a rough check to show on which band the transmitter is tuned. Use a monitor and a receiver for more accurate measurements. Since it responds only to the fundamental frequency, the absorption-type meter is valuable for setting the frequency of the transmitter to a definite frequency band. A monitor will respond to harmonics.
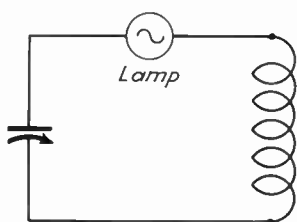
### How to Calibrate the Meter

Tune the receiving set to a station on or near the 160-meter band. Adjust the receiver so that it is oscillating. You can find the frequency on which each station operates in a call book.

Now set the frequency-meter coil close to the detector coil but not close enough to stop oscillation. Tune the meter condenser to resonance with the receiver. At resonance the receiver will stop oscillation.
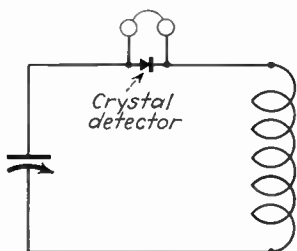
Fig. 285.   Absorption-type frequency meter, circuits.

For finer adjustment move the meter coil a few inches away from the detector coil and retune to the most accurate point of resonance. This is the exact resonance point.

The Calibration Curve. You can draw a calibration curve on squared cross-section paper. Draw two heavy lines, as shown in Fig. 286. Label the one line condenser setting and label the other frequency.

Start with the station to which your receiver is tuned. Make a dot which will be above the condenser setting for this station and opposite the frequency for this station (see Fig. 286).

You want several points on your cross-section paper representing the condenser setting and the frequency of
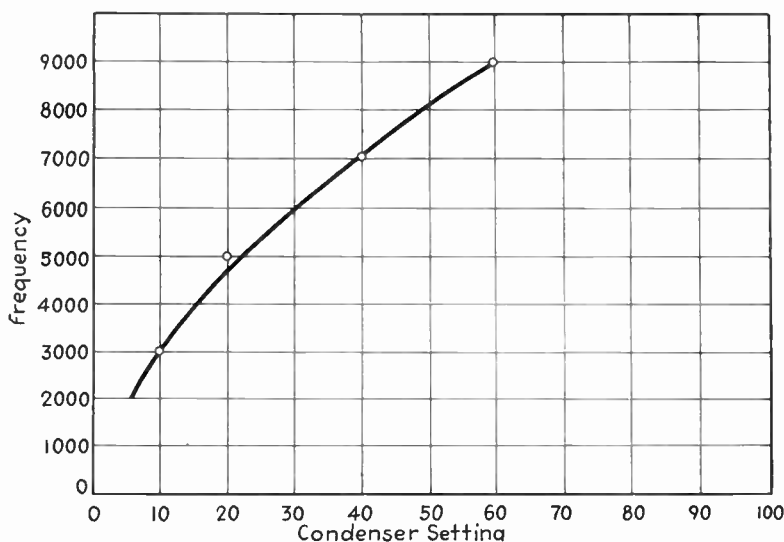


Fig. 286. Calibration curve.

different stations. Tune the receiver to several stations to get a number of points on the paper.

**Draw the Curve.** Sketch a light line through the points. This line may not hit each point exactly. But make the line a smooth curve with no sudden jogs or bends. After you have checked the points, draw in the curve as a heavy line.

*How to Use the Curve.* Set the meter condenser to some station whose frequency you want to know. Follow the line above this condenser setting to the curve, then go

straight across to the frequency base line (see Fig. 286).
Read the frequency on this line.

### Questions

**1.** Will an absorption-type meter respond to the harmonics produced
by an oscillator?

**2.** How can you tell when the meter is set at the same frequency as
the receiving set?

### 4. THE TUNED-PLATE–TUNED-GRID OSCILLATOR

This oscillator circuit is fundamentally different from the
Hartley oscillator.   In the tuned-plate–tuned-grid circuit,
energy is fed back between the grid and the plate of the
tube instead of through the coil.   A tank circuit is built
into both the grid circuit and the plate circuit.

The tuned-plate–tuned-grid circuit will tune over a
wider range of frequencies than will the TNT circuit
studied in part 5 of this chapter.

## How to Build and Wire the Set

**The Baseboard.**   Mount this oscillator on a larger base-
board.   A convenient size is $9\frac{1}{2}$ inches by 20 inches.   This
allows sufficient space so that the wiring will not be crowded.

**Arrangement of Parts.**   Mount the parts as shown in
Fig. 287.

**Coils.**   Both the grid and plate tank coils must be the
same size and both must be wound with the same size and
number of turns of wire.   See How to Wind Oscillator
Tank-circuit Coils, described in part 1 of this chapter.

**Condensers.**   The variable condensers in the tank cir-
cuits must have plates which are spaced far enough apart
to prevent sparking between plates.   Use a molded mica
condenser of high voltage rating for the grid condenser and
the blocking condenser.

**How to Wire the Set.** Wire the tank circuit, shown in heavy lines in Fig. 288, with heavy wire, for example size
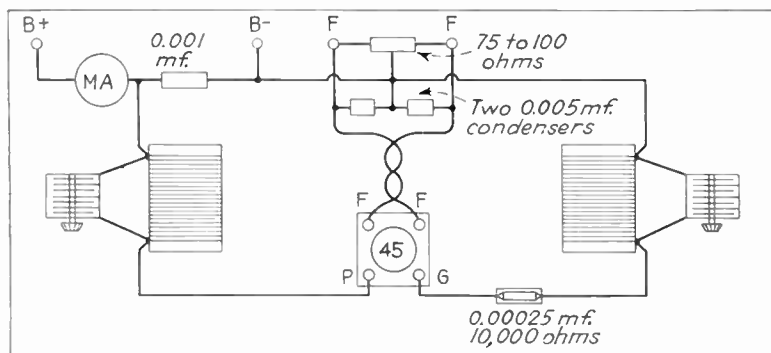


FIG. 287. Tuned-plate–tuned-grid oscillator.
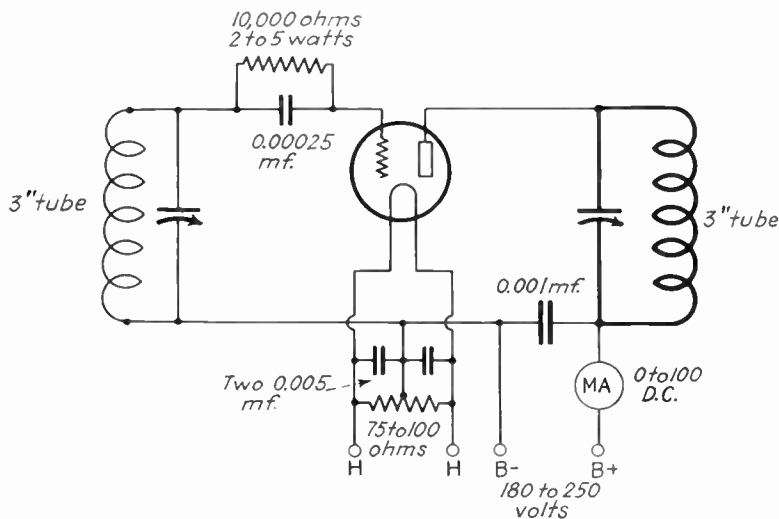


FIG. 288. Tuned-plate–tuned-grid oscillator circuit.

14. The other wiring of the set may be with pushback wire or other convenient wire, about size 18.

**Tubes to Use.** Any of the tubes suitable for the Hartley oscillator may be used with this oscillator. The type 45 or the type 26 make good oscillator tubes.

## How to Operate the Set

**Cautions!** You must have a milliammeter in the plate circuit while adjusting and using this set. An inexpensive meter may be used for an indicator of oscillation and for tuning.

The tube, the meter, and the rectifying tube will burn up if the set stops oscillating when coupled to a heavy load. Turn the set off if the plate of the tube becomes red hot or if the meter shows a sudden current increase.

Check the tuning of both the plate and grid circuits with an absorption-type wavemeter. If one circuit is tuned to 40 meters and the other to 80 meters, the set will not oscillate and the load on the tubes may be great enough to burn them out. The size of the grid coil must be correct or it will spoil the note of the oscillator when the oscillator is used as a transmitter. To find the correct size of the coil, either add or remove turns until the note is clear and free from an alternating-current hum.

*Step* 1. Turn on the heater current first. After the filament is heated up, you may turn on the B voltage. When the plate voltage is below 250 volts, both filament and plate power may be turned on together. But for higher plate voltages the B voltage may jump between the elements before the filament is hot and destroy the tube. In many circuits the plate current is very high before the set goes into oscillation.

*Step* 2. Turn the plate tank tuning condenser to the desired frequency setting. If the plate current is high, the circuit is not in oscillation. Swing the grid condenser until the meter dips. This indicates the circuit is oscillating.

*Step* 3. Adjust the grid tank condenser until the lowest plate current is shown by the plate milliammeter.

*Step* 4. Tune the plate tank condenser. Watch the meter and tune for the lowest plate current on the meter. If the set stops oscillating, the plate current will rise. Now give the grid condenser a final readjustment to provide enough excitation at the correct frequency. Check to see that the plate condenser is set at the correct frequency.

**How to Check for Oscillation.** This was explained in part 1 of this chapter.

**Couple a Load to the Oscillator.** *Step* 1. The load may be either an aerial, a dummy aerial, or an amplifier circuit. Bring the coupling coil of the load near the plate tank coil. The plate milliammeter will show a rise in current as the load draws power from the oscillator.

*Step* 2. Adjust the grid tuning condenser for the highest current reading.

*Step* 3. Readjust the tank coil slightly to reach the proper frequency. If the frequency is correct, no adjustment needs to be made and the set is tuned. Test the frequency with an absorption-type wavemeter.

## How It Works

**Turn On the Set.** When the filament is heated, it throws off electrons which form a space charge around the filament. When the B battery is turned on, it drains electrons off the plate, making the plate highly positive. Electrons surge from the space charge to the positive plate (see Fig. 289). This causes a current of electrons from the plate to surge through the tank coil to reach the B battery.

**The Tank Coil Opposes the Surge.** When the surge of electrons reaches the plate tank coil, the sudden rush of current causes a back pressure to develop in the coil which retards the free flow of electrons to the B battery. The
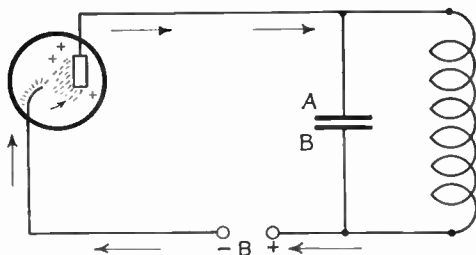
FIG. 289.   The first surge starts.
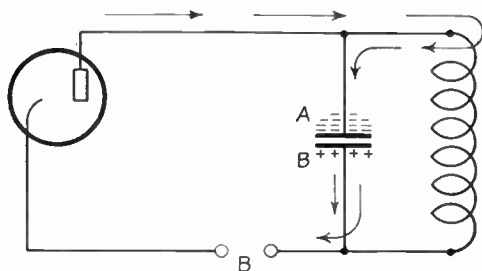


FIG. 290.   Tank coil opposes surge and charges the condenser.
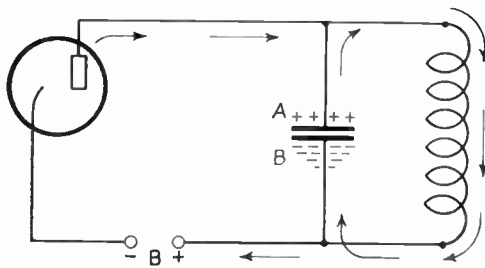


FIG. 291.   Surge breaks through tank coil.

electrons which cannot flow through the coil easily flow
instead into side *A* of the tank tuning condenser (see Fig.
290).   This makes side *A* negative and drives electrons off
side *B* to the B battery.

**The Surge Breaks through the
Tank Coil.**  When the pull of the B
battery overcomes the back pressure
of the tank coil, the first electron
surge flows through the tank coil.
The tank coil pull empties side *A* of
electrons and loads them on side *B*
(see Fig. 291).   Side *A* is now posi-
tive and side *B* negative.
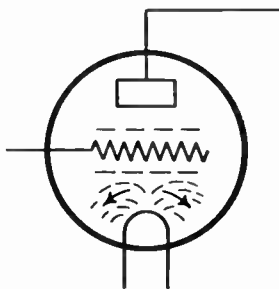


Fig. 292.   The grid now
becomes negative.

**Grid Shuts Off the Plate Current.**

When the electron surge has reached side *B*, side *A* and the
tube plate are very positive.   The plate and the grid of a
three-element tube have enough surface to act as a small
condenser.   The positive plate of the tube attracts electrons
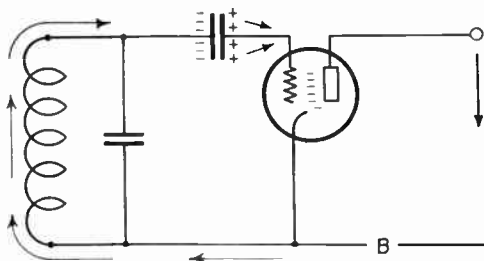


Fig. 293.   When the grid is negative, no electrons flow to the plate.

to the grid from the grid circuit (see Fig. 292).   The grid
now becomes negative.

During the second surge through the plate circuit, some
electrons flow through the grid circuit and reach the grid
condenser.   This drives more electrons to the grid (see
Fig. 293).   The grid becomes negative enough to shut off
the flow of electrons to the plate.

**The Surge Returns to Side *A*.**   When the grid is negative, no current can flow through the tube.   The grid leak holds the electrons trapped on the grid until the heavy load of electrons on side *B* can surge back to side *A*.   This makes *A* negative.   Some electrons surge to the tube plate and make it very negative.   This is the second surge (see Fig. 294).   The first and second surges are one cycle or one oscillation.

**The Grid Again Becomes Positive.**   By the time the surge has reached side *A*, the electrons on the grid have leaked off through the grid leak and the grid has become positive (see Fig. 295).   The grid is made more positive by the negative plate helping to push the electrons off of the grid.

**The Grid Tank Circuit Oscillates.**   When the negative plate drives electrons off the grid, electrons are driven to the grid tank condenser, side *C*, and surges start through the grid tank coil as in the plate tank coil (see Fig. 296).

The grid tank coil must be tuned to the same frequency as the plate tank coil so that the surges in the grid coil will occur in step with the kicks from the grid.

The grid tank circuit acts as a timing circuit.   Electron surges from the grid tank coil occur at the right time both to make the grid more positive when the negative plate makes the grid positive and to help the positive plate make the grid more negative at the proper time.

**The Third Surge Starts.**   The positive grid lets electrons surge to the plate again.   This third surge fills plate *A* and rushes through the tank coil.   This surging continues oscillating back and forth through the tank coil until a powerful radio-frequency oscillating current is surging through the tank circuit.

This surging is kept going by the pushes from the plate of the tube.
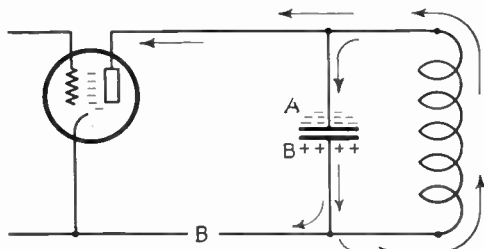
Fig. 294.   The second surge starts.
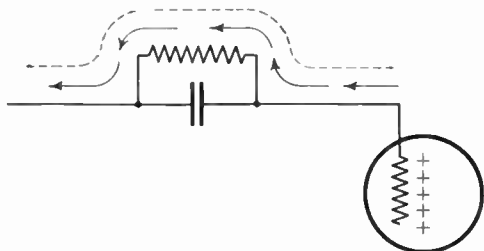


Fig. 295.   Electrons leak off the grid and make it positive.
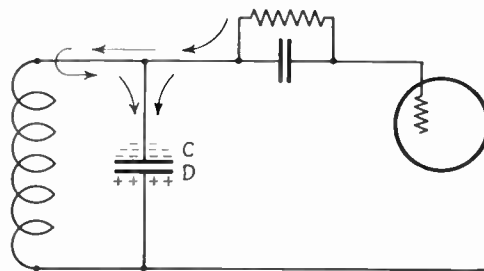


Fig. 296.   The grid tank circuit oscillates.

**The Purpose of the Grid Condenser and Leak.** The grid leak has enough resistance to hold a considerable quantity of electrons on the grid and on side $C$ of the grid condenser. This keeps the grid negative enough so that during most of the cycle of the grid tank oscillation no current flows in the plate tank circuit. This gives the surge time to return from side $B$ through the plate tank coil to side $A$. This surge is ready to start back through the tank coil just as the grid triggers the plate current and shoots another surge to the plate circuit. The grid then acts like an automatic on-and-off switch.

The plate current flows in jerks or spaced surges timed by the grid, giving the electron surges oscillating between side $A$ and side $B$ through the tank coil a boost or a kick at just the proper instant to build up continuous oscillations in the plate tank circuit.

**The Plate-current Meter Readings.** When the plate tank circuit is properly tuned, very little current flows through the tube because during part of each cycle this current is shut off by the negative grid. These timed plate-current surges build up a powerful tank-circuit oscillation.

But if the tank circuit is not properly tuned, the surges in the plate circuit and in the grid circuit will be out of step. The grid now does not become negative enough to shut off the plate current during part of each cycle, so much more plate current flows. The plate milliammeter reading goes up and the plate of the tube gets hot.

### Questions

1. When side $B$ of the tuning condenser in Fig. 291 is negative, what is the charge on the plate? What charge does the plate produce on the grid?

2. Is the grid positive or negative when the electrons flow from plate $B$ back to plate $A$, as in Fig. 294?

**3.** When plate *A* has a heavy negative charge, as in Fig. 290, what will be the charge on the plate? What charge does the plate produce on the grid? What effect will the grid now have upon the plate current?

**4.** Show the current flow in the grid circuit when side *B* of the condenser in the plate circuit is negative, as in Fig. 291.

**5.** Trace the current flow in the grid circuit when side *A* of the condenser in the plate circuit is negative.

**6.** What would be the effect on the operation of this set if the grid leak did not have enough resistance?

### 5. THE TNT OSCILLATOR

### How to Build and Wire the Set

**Baseboard.** Mount the parts for the TNT oscillator on a larger baseboard, as shown in Fig. 297.

**How to Wire the Set.** Wire the tank circuit with size 14 wire. Use size 14 or smaller wire for the connections. Wind the grid coil just like the plate tank coil. Use it in place of the grid coil and condenser. You will have to add turns or remove turns to adjust the coil to operate at the desired frequency. Wind one more turn on the grid coil than on the plate tank coil. For B power connections, series feed, as shown in Fig. 298, is more efficient than shunt feed.

### How to Operate the Set

The operation of the TNT oscillator is the same as for the tuned-plate–tuned-grid circuit. You must wind a separate grid coil for each frequency. Change the grid-coil and the tank-coil tuning to change frequency.

When a TNT self-excited oscillator is used as a transmitter the grid coil must be the right size or the note of the oscillator will sound bad.

### How It Works

This circuit operates the same as does the tuned-plate–tuned-grid oscillator. The size of the grid coil is changed until it tunes to the desired frequency.

## 6. THE OSCILLATING QUARTZ CRYSTAL

The self-excited oscillators that we have just studied have one serious defect when used as part of a transmitting set.
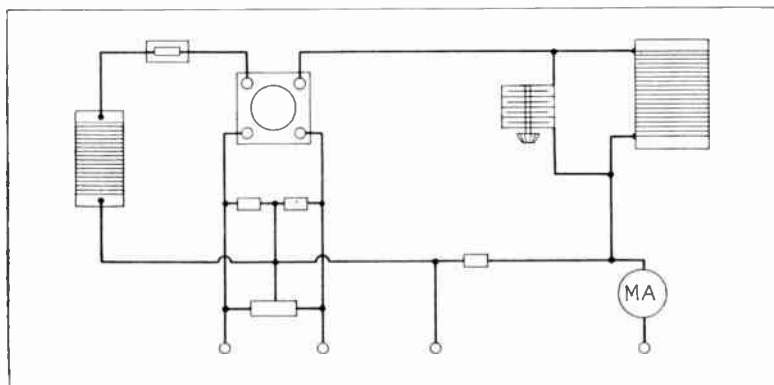


FIG. 297. TNT oscillator.
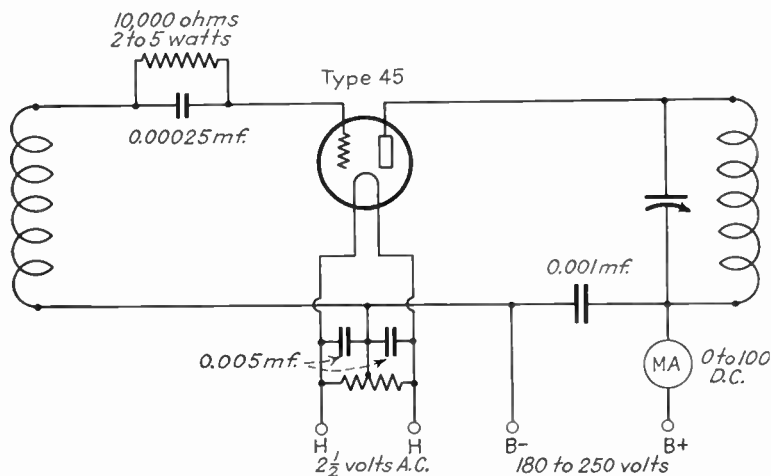


FIG. 298. TNT oscillator circuit, series feed.

The frequency at which the oscillator operates is not steady. The frequency of self-excited oscillators changes

when the plate voltage changes. It changes with the swinging of the aerial in the wind and with other conditions. These oscillators must be carefully adjusted to keep the frequency reasonably steady. The federal laws require that a transmitting set be built and operated so that it will send out only one frequency. This is done to prevent interference between sets operating on near-by frequencies. When the frequency of a transmitting station shifts and changes, it interferes with other stations and is hard to keep tuned in at a receiver.

A type of oscillator that would operate constantly on only one frequency was long needed. A method of frequency control was found in the properties of crystals of pure quartz.

### Question

**1.** Make a list of things which will cause the frequency of a transmitter to vary.

**Characteristics of Quartz Crystals.** Quartz crystals occur in nature in the form of six-sided crystals of different sizes that terminate in a pointed end (see Fig. 299). The faces of the crystal are flat and smooth, and the crystals are often transparent.

Quartz is a highly elastic but solid mate-



Fig. 299. One end of a quartz crystal.

rial. If put under pressure, the molecules of the quartz will be compressed very slightly and will tend to squeeze and flatten as would a rectangular piece of rubber if put under pressure. The thickness of the quartz may not change more than a fraction of a thousandth of an inch. When the pressure is removed, the quartz will spring back into shape and then

will continue past its original shape just as a steel spring will whip back and forth (oscillate) when it has been pulled back and released. The molecules of the quartz crystal will similarly continue to vibrate for a short time. The pressure which presses the quartz slab slightly out of shape produces a slight voltage drop or difference of electric pressure between the two surfaces of the quartz slab or plate. The harder the quartz slab is squeezed the higher the voltage drop between the two surfaces.

If two metal plates are placed against the two surfaces of the quartz plate and then connected to a battery, the difference in voltage between the two plates, which is an electric pressure, will squeeze the quartz slab and cause it to flatten slightly as if it were squeezed mechanically. When the voltage is shut off, the molecules of the crystal will spring back into shape and will continue to oscillate. This peculiar property of a slab of quartz crystal is called the piezoelectrical effect. Tourmaline crystals also are piezoelectric, but they are quite expensive. Quartz crystals are more practical.

**How the Quartz Crystals Are Prepared for Use in Radio Circuits.** Flat thin slabs are cut out of large quartz crystals with special cutting equipment. The blanks from which the finished radio "crystal" is made are cut with their edges parallel to the long edges of the original crystal (see Fig. 300). Blanks for use in radio circuits are cut in several different ways. In Fig. 300 are shown the positions of the X cut and the Y cut in the original crystal. The X cut is taken at right angles to two flat faces or sides of the crystal. The Y cut is taken so as to be cut between the two corners of the crystals.

The X cut is thicker than the Y cut. It is used for circuits where considerable power is to be developed. The thicker X cut is popular with experimenters because it is

less likely to be broken in handling and by use in experimental circuits.

**The Frequency of Vibration.**   Each crystal will vibrate at one fixed frequency.   The thickness of the crystal slab determines the frequency at which the crystal will oscillate. Thick crystals vibrate slower than do thin crystals.   The Y-cut crystal will vibrate at a different frequency than an X-cut crystal even if both are the same thickness.
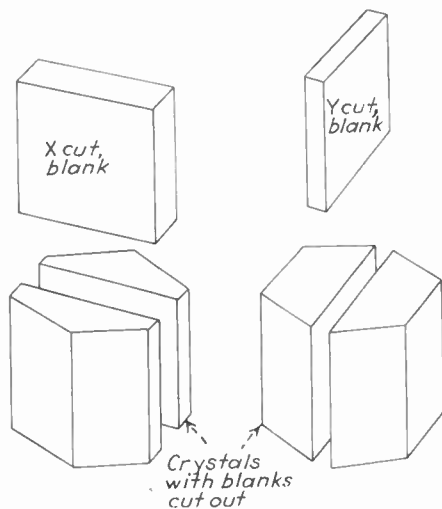


Fig. 300.   Crystal cuts.

A crystal which will oscillate at the rate of 1800 kilocycles (1,800,000 cycles) per second is about the size and thickness of a dime.

**How Finished Crystals Are Prepared.**   After the rough blank has been sawed out of the rock crystal, it must be ground perfectly flat.   A crystal which is not flat is not all the same thickness.   When set in vibration, each thickness will vibrate at its own frequency.   Such a crystal will either not vibrate at all or will break.   This ability of a

crystal to vibrate at only one frequency is the thing that
makes it valuable in the radio circuit.

**How the Crystal Is Connected in the Circuit.**    A finished
crystal blank is placed in a special holder.    There are
many types of holders on the markets.    Fundamentally a
holder consists of two metal plates placed on each side of
the crystal.    The plates are ground perfectly flat and
smooth.    They are made of a metal that does not corrode

easily, such as copper,
brass, bronze, silver,
German silver, or nickel.

A commonly used
crystal holder is one in
which the crystal rests
between two metal
plates in an enclosed
holder (see Fig. 301).
The upper plate is laid
loosely on the crystal.
Connection to the two
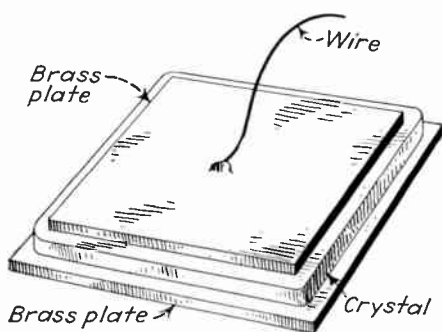


Fig. 301.   The crystal is placed loosely
between two metal plates.

metal plates is made by wires from each plate to a prong on
the crystal holder.    A cover keeps out dust and dirt particles
(see Fig. 302).    In some crystal holders the upper plate is
spaced away from the crystal.    Still other crystal holders
are arranged so this spacing may be adjusted to make small
changes in frequency at which the crystal will operate.

**How the Crystal Operates.**    The two plates between
which the crystal rests form a condenser with the crystal
as a dielectric.    When there is no current on the two plates,
there is no strain on the crystal.    But when one plate is
made positive and the other is made negative by a battery
or by a current, the two plates are of opposite polarity
and they attract each other.    This places the crystal under
an electrical strain or pressure and causes it to flatten out

slightly. When the battery is disconnected, the crystal springs back to its original shape and beyond it, oscillating after the current is off. The speed at which it vibrates depends both on its thickness and the way it was cut from the blank.

Now if we connect an alternating current across the metal plates that has the same frequency as the frequency at which the crystal vibrates, the crystal will oscillate as long
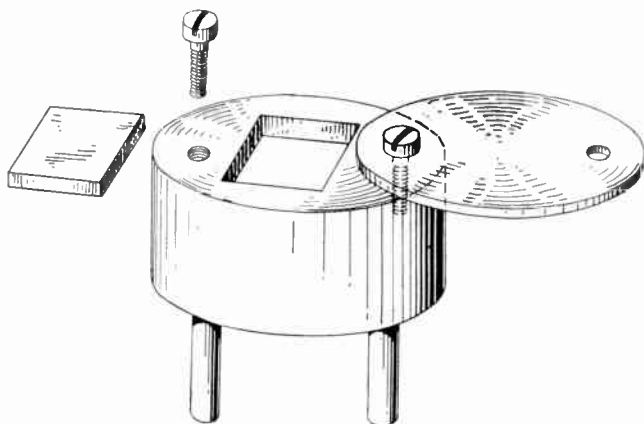


FIG. 302. Crystal holder.

as this alternating current flows. If the current alternates at any other frequency, the crystal will not oscillate. The rock crystal has practically no internal resistance to vibration at one frequency, but for any other frequency the internal resistance is extremely high.

**The Crystal Will Produce an Alternating Current.** If we apply a pressure to the crystal at regular intervals, it will produce an alternating current of the same frequency as the frequency of the pressure that we apply. But the pressure must be applied at the frequency for which the crystal is ground, or it will not oscillate.

**Heat Affects Frequency.** A crystal cut on a certain axis will oscillate at a higher frequency when the temperature is higher and at lower frequency when cool. Crystals used in broadcast sets are placed in crystal "ovens" in which the temperature is kept uniform by a thermostat. This prevents any slight frequency changes due to changes in operating-room temperature.

### Questions

1. Will a crystal oscillate if its sides are not parallel?

2. What effect does thickness have upon the rate of vibration of a crystal?

3. Will the crystal oscillate if the impressed alternating-current has a frequency different from the rate of vibration of the crystal?

4. What effect has temperature upon rate of vibration?

### 7. THE CRYSTAL OSCILLATOR CIRCUIT

## How to Build and Wire the Set

**Parts for the Set.** Screw two sockets to the baseboard, one for the crystal holder and one for the tube (see Fig. 303). Use a carbon resistor in the grid circuit. The tank coil and condenser in the plate circuit are the same as used in the Hartley circuit. Use a carbon resistor in the crystal oscillator circuits. This resistor must be noninductive. A purchased choke is more efficient than one you make. A poor choke lowers the power output of the oscillator. Connect a direct-current 0–100 milliammeter in the positive plate lead (see Fig. 304).

**Tubes Used in Oscillator Circuits.** The voltage produced by the crystal is weak. A type of oscillator tube must be used which will develop the greatest output from this weak grid voltage. The crystal operates best with high-*mu* power tubes. You may use either the type 45 tube or the type 47 tube. Both make good crystal-oscillator tubes. In both tubes small changes in grid voltage
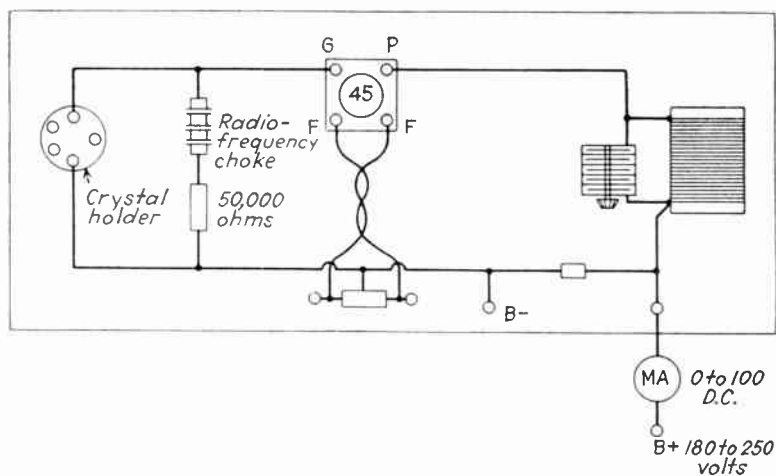
Fig. 303.    Crystal oscillator board.
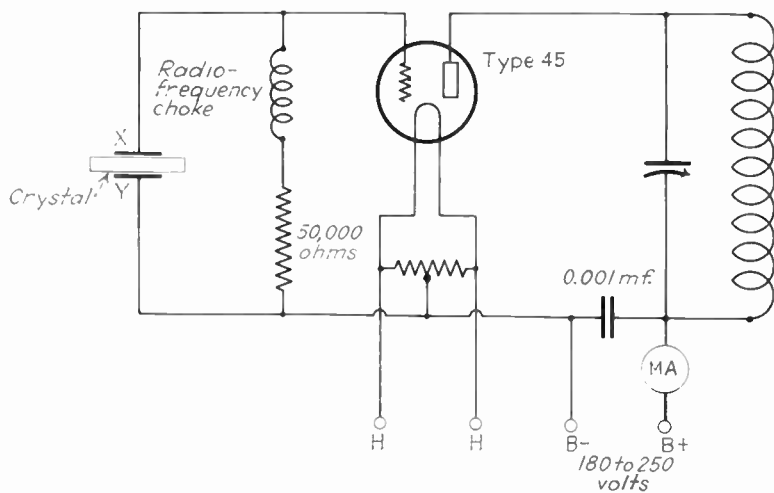


Fig. 304,    Crystal oscillator circuit,

cause large changes in plate current. The type 47 is pre-
ferred because it requires less grid current than does the
type 45 tube. You can get more power output with the
type 47 tube than with the type 45 tube. If too much grid
current flows, the crystal will heat and will break. The
crystal will heat more when the type 45 tube is used. It
requires more power from the crystal. Keep the grid cur-
rent below 70 milliamperes.

Type 47 (filament $2\frac{1}{2}$ volts alternating current), type 42
(filament 6.34 volts alternating or direct current), and type
2A5 (filament $2\frac{1}{2}$ volts alternating current) tubes are all
good oscillators. These are the same tubes made for
different filament voltages. The type 2A5 is a later type
of tube than the type 47.

### How to Operate It

*Step* 1.   Turn on the current to heat the tube filament.

*Step* 2.   Connect from 180 to 250 volts to the plate
terminals. Use not over 300 volts on the plate of the
oscillator. Turn on the B voltage after the filaments are
heated.

*Step* 3.   Test for oscillation by touching the tank circuit
with a pencil or with a neon tube. A spark will jump to
the pencil. The neon tube will glow if the set is oscillating.

*Step* 4.   Tune the tank circuit with the condenser to the
frequency of the crystal. This circuit will not oscillate
unless it is tuned to the same frequency as that of the
crystal. The plate current will drop sharply as the circuit
begins to oscillate. The plate current, before the set goes
into oscillation, is about 20 milliamperes with 300 volts on
the plate.

Turn off the plate voltage if the circuit does not oscillate.
No damage will be done to the crystal when the set runs
without oscillating.

The power output of a crystal oscillator is 85% of the input power. This is much higher power output than for the self-excited Hartley circuit where the output was only half the input power.
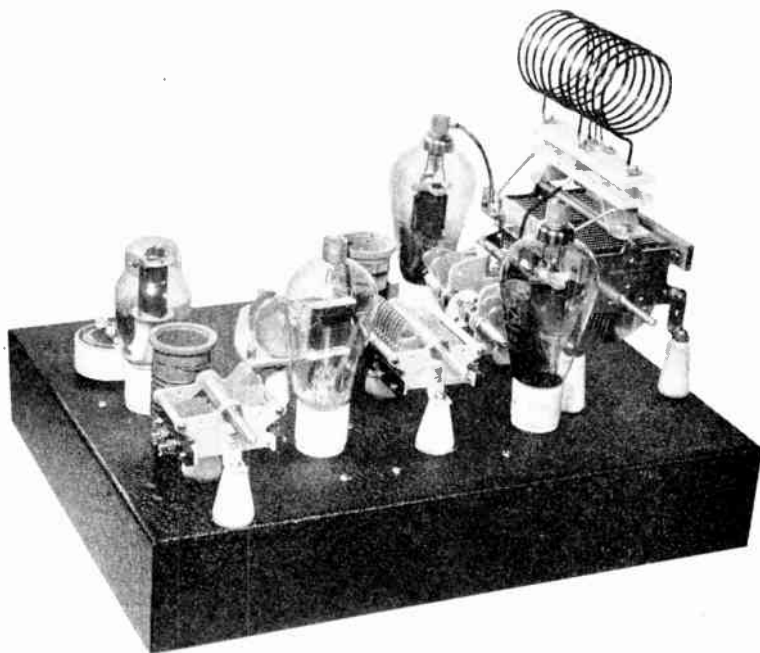
AN AMATEUR TRANSMITTER UNIT
This unit is complete from crystal to amplifier. No power unit is shown.

### Questions

**1.** Should high- or low-*mu* tubes be used with a crystal oscillator?
**2.** What is the disadvantage of using a high grid current on the crystal oscillator?

## How It Works

**Turn the Set On.** When the filament is heated, it throws off electrons. When the B battery is turned on, it makes

the plate highly positive. The positive plates draw elec-
trons from the space charge around the filament, and plate
current flows.

**The Plate Tank Circuit Oscillates.** When the surges of
electrons from the tube plate reach the tank coil, they
begin to oscillate through the tank circuit. See How It
Works in part 4 of this chapter for this explanation.

**Feedback Starts the Crystal Oscillating.** At the instant
the B battery makes the plate positive, the grid becomes
negative by condenser action (see Fig. 304). The highly
positive plate draws electrons to the grid from plate $X$ of
the crystal holder. This makes plate $X$ very positive.
The condenser action between plate $X$ and plate $Y$ of the
crystal holder causes electrons to be attracted to plate $Y$.

The unlike charges on $X$ and $Y$ cause the two plates to
be attracted together. The different charges on plates $X$
and $Y$ exert an electrical pressure or force on the crystal
which causes it to flatten out slightly.

**The Crystal Vibrates or Oscillates.** Once set into vibra-
tion, the crystal will continue to vibrate for some time but
at only one definite frequency. Current fed back through
the capacity of the tube from the plate tank circuit gives
the crystal these driving surges. These surges, coming at
regular intervals, though weak, can build up very strong
vibrations in the crystal, strong enough to shatter the
crystal.

As the crystal vibrates, it generates an alternating cur-
rent between plates $X$ and $Y$ much stronger than the weak
surges that generated it. This current is so powerful that
it takes control of the action of the grid.

**How the Crystal Controls Frequency.** The crystal will
oscillate at only one frequency. Electron surges generated
by the oscillation of the crystal reach the tube grid and
time the surges of plate current which keep the tank circuit

oscillating. If the tank circuit is tuned so that it oscillates at a frequency different from that of the crystal, the current fed back through the tube will reach the crystal out of time with the surges generated by the crystal. The two sets of surges oppose each other and will stop the crystal oscillating. The crystal, therefore, forces the circuit to oscillate at only one frequency.

**Purpose of the Radio-frequency Choke and Grid Leak.** When the grid becomes positive, it collects electrons from the filament. These electrons flow back to the filament through the radio-frequency choke and the grid leak. The grid-leak resistance keeps enough electrons on the grid to prevent plate current from flowing except at timed intervals. The grid is negative during most of the plate-current cycle. The radio-frequency choke prevents the rapid surges of alternating current generated by the oscillation of the crystal from shorting through the grid-leak resistor. Instead it forces the surges to flow on and off the grid.

### Questions

1. Compare the strength of the current produced by a crystal with the strength of the exciting current.

2. Where is the current produced that keeps the crystal in oscillation?

3. Explain what happens if the plate tank circuit is tuned to a frequency different from that of the crystal.

4. What is the purpose of the radio-frequency choke?

5. What is the purpose of the grid leak?

### 8. THE FREQUENCY-DOUBLER CIRCUIT

A crystal for the higher frequencies must be cut very thin. Such a crystal is easy to break if it is handled, and it is also easy to break if used in a circuit which is improperly operated. Crystals ground for the 80-meter and 160-meter bands are rugged and thick enough for ordinary experimental and operating use.

A transmitter can operate on the popular 40-meter band by using a thick, sturdy 80-meter crystal in place of the thin, easily broken, higher-frequency crystal in the oscillator circuit. This is done by feeding the output of the oscillator into an amplifier circuit which doubles the frequency of oscillation to 40 meters.

This 40-meter frequency can now be amplified just as could the 80-meter frequency.

As many stages of amplification can be added as the builder can afford.
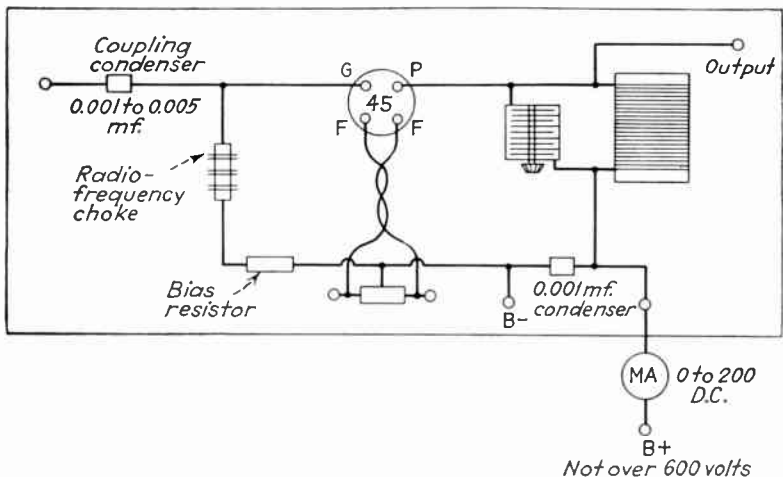


Fig. 305. Frequency doubler board.

### Question

1. What are some advantages to amateurs of using frequency-doubler circuits?

### How to Build and Wire the Set

Place the socket for the tube and the plate tank coil and condenser in the position shown in Fig. 305. Use high-voltage mica condensers for the coupling and the blocking condensers in the plate circuit. The coupling condenser

must stand the plate voltage of the preceding stage.   Its
voltage rating should be twice the plate voltage.

**Tube.**   Use a type 45 or a type 47 power tube.

**Bias.**   Use either a C battery or a 5000-ohm noninduc-
tive resistor connected to the grid through a radio-frequency
choke to get the proper bias.   The bias voltage must be
twice the voltage needed for cutoff.
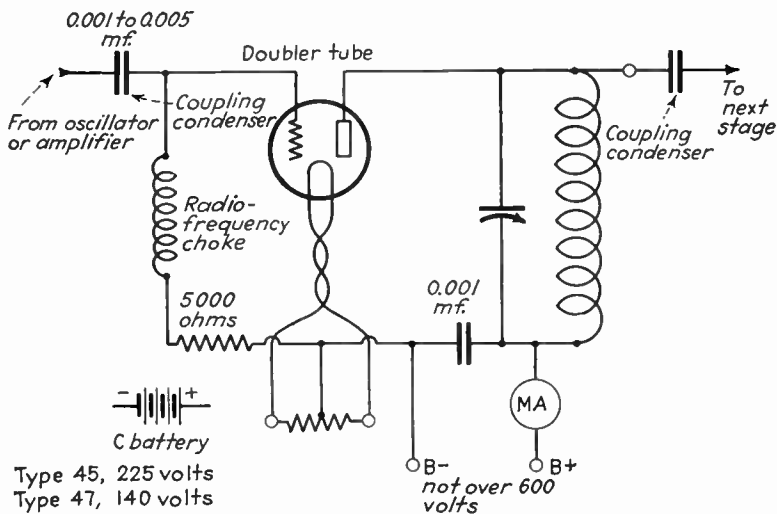


FIG. 306.   Frequency doubler circuit.

**Choke.**   Use a good radio-frequency choke in this circuit.
Hand-wound chokes are inefficient and much power is lost
through them.   A receiver-type choke can be used in sets
up to 50 watts input.

**Excitation.**   Excitation for the grid and doubler tube
comes from the oscillator stage, either through the small
.001- to .005-microfarad coupling condenser, as shown in
Fig. 305, or by means of a coupling coil.

**Plate-current Meter.**   Place a phone jack on the board
so a direct-current 0–200 milliammeter can be connected in

the circuit (see Fig. 305). One meter can be used for the whole set—the oscillator, the buffer, the doubler, and the final amplifier—by connecting a phone jack in the B positive plate lead on each stage. When the phone plug which is connected to the meter is out, the points on the jack close the circuit so the plate current can flow. But when the plug is pushed into the jack, the plate current for that stage flows through the meter.

### How to Operate It

*Step* 1. Turn on the oscillator and doubler filament-heating current.

*Step* 2. Turn on the B voltage after the filaments have had time to heat.

*Step* 3. Plug the meter into the plate-circuit jack on the oscillator. Adjust the tuning condenser until the crystal stage is in oscillation. Check the frequency with an absorption-type wavemeter.

*Step* 4. Tune the doubler circuit to twice the frequency (half the wave length) of the oscillator with an absorption type wavemeter. This meter is used because it will respond only to the fundamental frequency and will not respond to harmonics.

When tuned off frequency, the doubler will draw a heavy plate current. If the plate of the tube begins to get red, turn off the plate voltage until you find the reason for the heating.

You can tune the set so that it doubles twice, say from 80 meters to 20 meters, in the same stage. But if this is done, the output of the doubler is very low and its efficiency very poor. Therefore only simple doubling, as from 80 meters to 40 meters or from 40 meters to 20 meters, is done in each stage.

**The Bias Supply.** Use either a C battery or a noninductive resistor in the doubler circuit to set the grid bias of

the tube.   This must be 225 volts for a type 45 tube and
140 volts for the type 47 tube.

**Caution!**   The grid bias, when a resistor is used, is
caused by the current from the oscillator.   (The excitation
voltage to the doubler grid.)   If the oscillator is turned off,
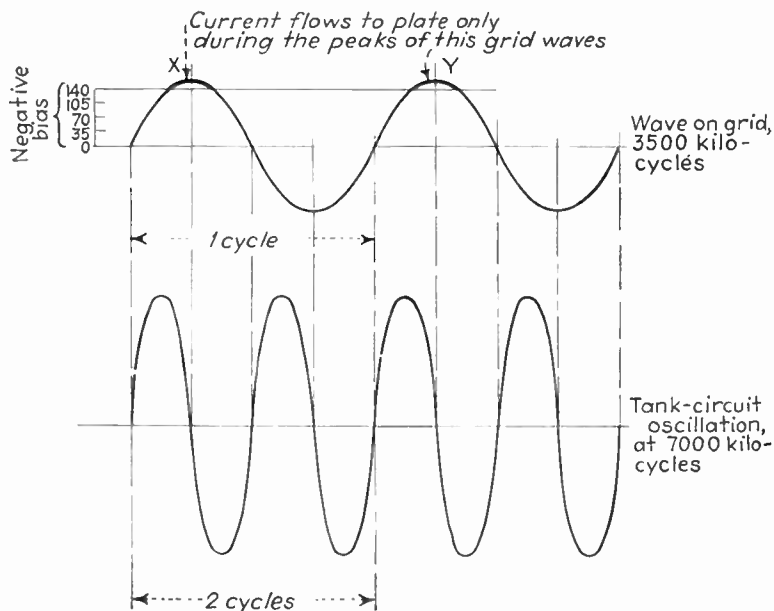


Fig. 307.   Wave picture showing how the frequency doubler works.

the grid will become positive enough to draw current and
the doubler tube will burn out.

For this reason the oscillator stage is not keyed.

## How It Works

**The Source of Excitation.**   The grid of the doubler tube
is excited by electron surges from the oscillator circuit
through the coupling condenser (see Fig. 306).   The
voltage applied to the grid of the tube is called the grid
excitation.

The wave-form picture in Fig. 307 shows the current
from the previous stage that is on the grid of the doubler
tube. (The grid of the doubler tube is biased to about
twice cutoff.) Current will only flow in the plate circuit
of the doubler tube when the surges from the previous stage
become positive enough to overcome the grid bias (see $X$
and $Y$, Fig. 307).

The doubler tank circuit is tuned to twice the frequency
of the oscillator. When current flows through the doubler
plate circuit, it starts a surge in the tank circuit (see Fig.
308). This current
surges through the tank
coil to side $B$ of the con-
denser, then returns
through the tank coil to
side $A$. It then coasts
back again through the
coil to $B$, then back to
$A$.

At the instant when
the surges from $A$ start
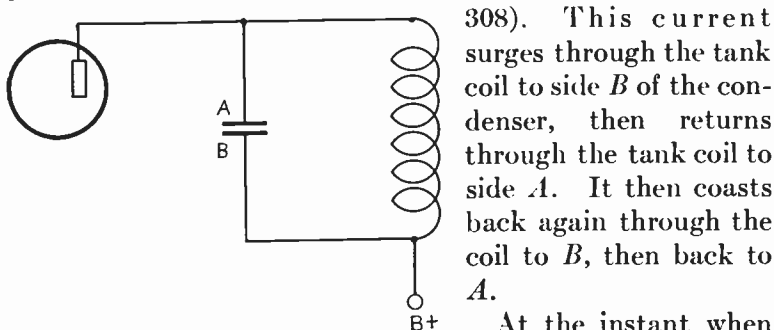


Fig. 308.   How the frequency doubler works.

toward $B$ again, the grid becomes positive (shown on the
wave picture at $X$, Fig. 307) and allows current to flow for an
instant through the tube and gives the current surge through
the tank circuit a push. Again the tank circuit coasts
through two complete oscillations before the grid becomes
positive enough (at $Y$, Fig. 307) to give the plate tank
another push.

The frequency of the doubler tank circuit is twice the
frequency of the surges of the grid on this circuit. This
doubles the oscillator frequency.

There is some loss of energy during this coasting. But
this loss is of far less importance than the expensive appa-
ratus this circuit replaces. Any loss in the doubler circuit

is made up in the amplifying circuits which precede and follow the doubler.

### Questions

**1.** What is the disadvantage of doubling the frequency twice in the same tube?

**2.** What might cause the plate of the tube to get red hot?

**3.** Why is the oscillator stage in a doubler circuit never keyed?

**4.** How much of the time is current flowing in the plate circuit of the doubler tube?

### 9. HOW TO NEUTRALIZE AN AMPLIFIER STAGE

Amplifier circuits which use a three-element tube, such as the type 45, type 10, or other tubes which do not have a screen grid, must be neutralized as was the type 01A tube when used as a radio-frequency amplifier in receiving circuits.

When the oscillator is on, the amplifier will oscillate at the frequency to which it is tuned. But when the oscillator is off, the amplifier will oscillate at a frequency that may be the same as the crystal frequency but probably is slightly different.

When the amplifier is a part of a radiophone set, the unwanted frequency is present all of the time and causes interference and broad tuning. It may affect the quality of the signals.

Neutralization is explained before the amplifier stage is studied because the amplifier circuit must be neutralized to operate efficiently.

**Neutralization Is Needed on the Amplifier.** Neutralization must be used because the capacity between the plate and grid of these tubes is great enough to feed back energy from a plate circuit to the grid circuit and set up oscillations which are not controlled by the oscillations from the preceding stage. The amplifier then acts somewhat like a

self-excited tuned-plate–tuned-grid oscillator.    It will prob-
ably oscillate at an unwanted frequency.    If the crystal
oscillator is turned off, the amplifier will continue to
oscillate.

### How to Wire the Circuit

The standard amplifier circuit is shown in the diagram in
Fig. 309.

The heavy lines show the connection for the neutralizing
condenser.
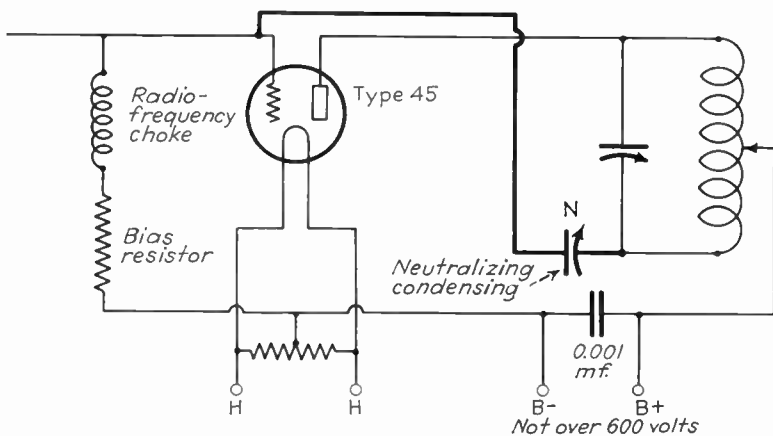


Fig. 309.    Standard amplifier circuit with neutralizing condenser.

**The Neutralizing Condenser.**    Use a 7-plate midget con-
denser or a 3-plate cut-down condenser for the neutralizing
condenser.    This condenser must have about twice the
capacity between the grid and the plate of the tube you
are using.

There are several methods of picking up the neutralizing
voltage from the tank coil, but the method shown in the
diagram (Fig. 309) is the most practical.    Make the B
positive connection a few turns from the end of the tank
coil with a clip so the connection can easily be changed.

**The Pickup Loop.** Make a test loop 2 inches in diameter of insulated wire soldered to the terminals of a flashlight lamp.

## How to Operate the Set

*Step* 1. Disconnect the B positive leads from all the amplifier stages.

*Step* 2. Heat the filaments of the oscillator and amplifier tubes.

*Step* 3. Connect the B positive tap a few turns from the end of the plate tank coil opposite to the connection to the tube plate. Find this point by trial. Disconnect the B positive lead to the B supply.

*Step* 4. Hold the test loop near the tank coil of the amplifier nearest the oscillator. If the lamp lights, the tank circuit is oscillating. You may also test for oscillation with a neon tube. The neon tube is very sensitive.

*Step* 5. Turn the neutralizing condenser $N$ until the lamp goes out even when the loop is held near or almost touching the coil. At this condenser setting the capacity of the neutralizing condenser and the capacity between the grid and plate of the amplifier tube are equal and the set is neutralized.

*Step* 6. Remove the test lamp. Attach the B positive lead to the tank coil.

*Step* 7. Neutralize the next amplifier or buffer stage.

### Questions

1. Why must these radio-frequency amplifiers be neutralized?

2. How should the size of the neutralizing condenser compare with the capacity between the grid and the plate of the tube?

3. How can you tell when a stage is neutralized?

**How the Unwanted Frequency Can Be Overcome.** When the set is in operation, a regular surging comes to this circuit over wire $D$ (Fig. 310) from the crystal oscillator

or from an amplifier stage between the oscillator and this
amplifier circuit.    The surges that are timed by the crystal
oscillator are the ones we want.    The surges that feed back
through the tube from the plate to the grid interfere with
the surges from the oscillator and set up unwanted surges
at another frequency.    We can prevent these unwanted
surges by neutralizing the amplifier stage.
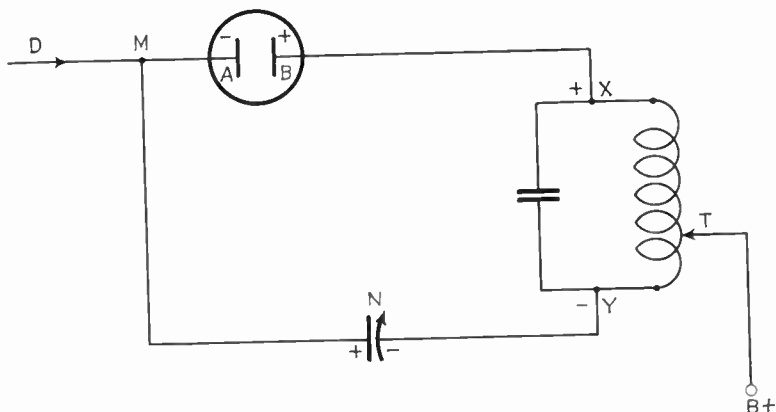


FIG. 310.    Simplified circuit used to explain neutralization of amplifier circuit.

The actual steps in neutralizing, or overcoming, the effect
of the tube capacity can better be shown by using a simpli-
fied circuit (see Fig. 310).    Since the tube elements act as
a condenser of a definite capacity, let us substitute a con-
denser A-B of this same capacity in this new circuit in
place of the tube.

In Fig. 309 is shown the amplifier circuit.    In Fig. 310 is
shown a part of the same circuit with a condenser drawn
at A-B in place of the tube.    Condenser A-B has the same
capacity as the capacity between the grid and the plate of
the tube.

We have learned that the voltages at opposite ends of a
tank coil are equal but of an opposite charge.    That is,

when one end is positive (has too few electrons), the other is negative (has too many electrons).

Now, when the end of the coil at $X$ (Fig. 310) is positive, it draws electrons from side $B$ of the condenser which then becomes positive.   But the electrons drawn to side $A$ when side $B$ is positive interfere with the regular surging from $D$. We can run a wire from the end of the coil $Y$ to $M$, where electrons from $Y$ will rush to $A$ to supply the demand created by the positive plate $B$.

When just enough electrons from $Y$ reach side $A$ to equal the demand from side $B$, there will be no interference with the surges from $D$, and the effect will be the same as if no extra electrons were brought to $M$.   But the current from the $Y$ end of the coil must be exactly the same as the current demanded by $B$.   We can control this current by a small variable condenser $N$ in the wire from $Y$ to $M$. We can set the condenser so it has the same capacity as condenser $A$-$B$.   It will then supply just as many electrons as are attracted through $A$-$B$.

Position of the B Positive Tap.  Since the voltage developed at $A$-$B$ is very small, we need only a small portion of the voltage developed at $Y$ to equal the voltage on $A$-$B$.   Therefore, we hook our B positive lead back along the coil a few turns instead of at the end $Y$, and we convert the coil into a sort of transformer in which the turns from $T$ to $Y$ act as the secondary.   The voltage produced in this small secondary then is used to neutralize the effect of the condenser at $A$-$B$.   It is theoretically possible to adjust the length of this secondary by moving the tap $T$ so that its voltage just equals the voltage across the condenser $A$-$B$.   For actual practice, it is handier to try several coil lengths until a spot is reached where the voltages are just about equal and then to adjust the variable condenser $N$ to exactly the right size to make

the voltage from $T$ to $Y$ equal to the voltage across condenser $A$-$B$.

The B positive lead is connected to the ground by means of a small condenser. The point on the coil where B positive taps in is always at zero or ground potential as far as the radio-frequency current is concerned, because any voltage which tends to develop here is by-passed through the condenser to the ground. The condenser, however, keeps the direct current of the B positive and B negative separated (see Fig. 309).

### Questions

**1.** What effect does the capacity between the grid and the plate have upon the operation of a radio-frequency amplifier?

**2.** When the $X$ end of the tank coil is positive, what effect would the grid have upon the feed line $D$ if the amplifier were not neutralized (see Fig. 310)?

**3.** If plate $A$ of the condenser had a ready supply of electrons, would it also try to pull electrons from line $D$?

**4.** Explain how the $Y$ end of the tank coil could supply the needed electrons to plate $A$.

**5.** What is the purpose of the neutralizing condenser?

**6.** Why is the $B$ positive lead not attached directly to the $Y$ end of the tank coil?

### 10. THE POWER AMPLIFIER

**Used as a Final Power Amplification Stage.** This is the power amplifier circuit which has several uses in the transmitter. It may be used for the final amplifier stage to build up the carrier wave to its maximum power before delivery to the aerial. This circuit is also used in the radiophone circuits.

**Used as a Buffer Amplifier.** When used as a buffer amplifier it is placed between the oscillator tube and the final amplifier to prevent any variations in voltage or power in the final stage from affecting the frequency of the oscil-

lation. This is especially important when a self-excited oscillator is used, because changes in plate voltage or coupling from the final amplifier will often change the frequency of the oscillator. It is of less importance between a crystal oscillator and the final amplifier, because the frequency of the crystal oscillator changes very little. A buffer is not a necessity with a crystal-controlled oscillator but it steadies the frequency. A buffer must be used with a self-excited oscillator.

A buffer amplifier is used also both ahead of and following a doubler amplifier in radiophone circuits.

The strong negative C bias must be used in the buffer amplifier. This will be explained in part 12 of this chapter.

**Tubes That Are Good Amplifiers.** The type 45 is a good amplifier tube. It is a steady oscillator and is easy to neutralize. A type 47 is a poor tube to use, as it is very hard to neutralize.

### Question

1. What is the purpose of the buffer in a set?

## How to Build and Wire the Set

**Set Board.** Use the small-sized set board. Place the parts as shown in Fig. 311.

**Condenser Ratings.** The coupling condenser, the blocking condenser, and the tank condenser must be rated at about half more voltage than you will use on the plate.

Use a 13-plate midget condenser or a cut-down broadcast condenser for neutralizing the set.

## How to Operate It

*Step* 1. Neutralize the amplifier as explained in part 9 of this chapter.

*Step* 2. Tune the tank circuit to the frequency to which the oscillator is tuned. Tune the amplifier to the doubler

frequency if a doubler is connected ahead of the amplifier.
Series feed, as shown in Fig. 312, is better than parallel
feed since no choke is needed.
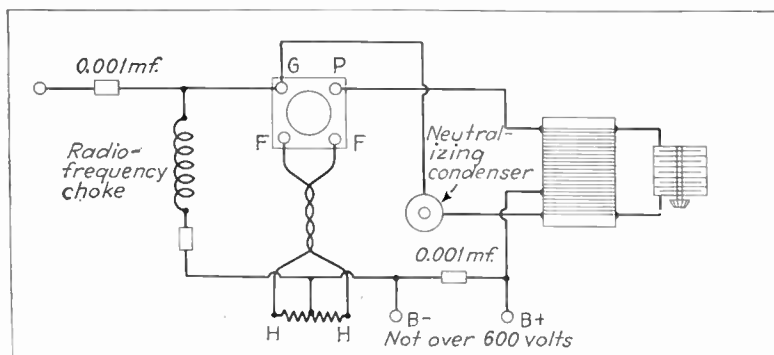


FIG. 311.    Power amplifier.
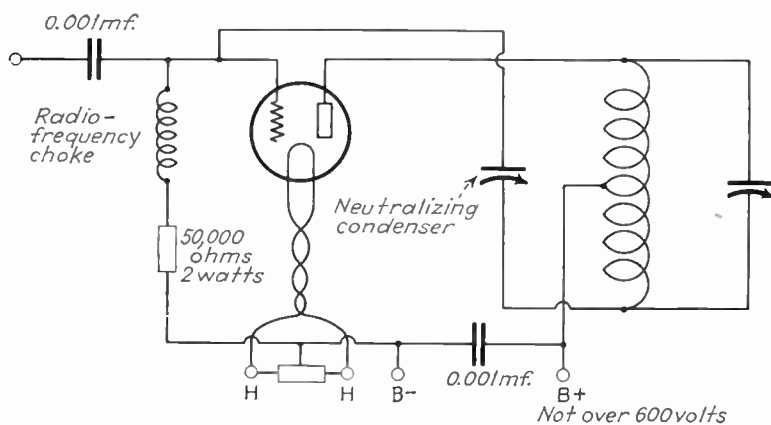


FIG. 312.    Power amplifier with series feed.

## Why It Works

Grid excitation. Surges from the stage ahead of the
amplifier (either the oscillator, an amplifier, or a doubler)
reach the grid through the coupling condenser.

The grid bias is set by the grid leak. The radio-frequency choke prevents the radio-frequency surges from the previous stage from shorting to the ground.

**The Tank Circuit.** Oscillation builds up in the tank circuit just as in the oscillator. The grid lets surges reach the plate often enough to keep the tank circuit oscillating.

### Question

1. What is the purpose of the radio-frequency choke in this amplifier?

### 11. THE PUSH-PULL POWER AMPLIFIER

The single-tube amplifier is used in both buffer circuits and sometimes in the final amplifier stage of the transmitter.
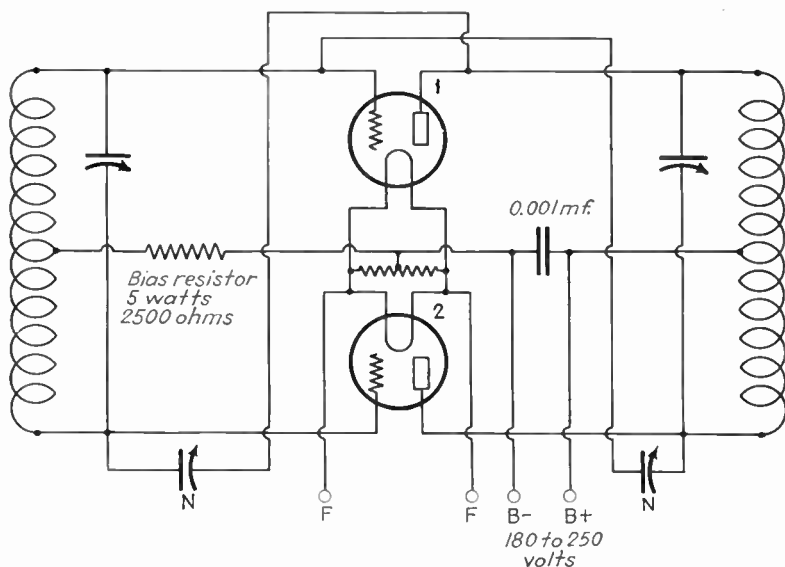


FIG. 313.   Push-pull power amplifier circuit.

But if much power is applied to this circuit by using high B voltage, the tube heats and does not operate efficiently. An improved circuit which uses two tubes operates in "push-pull." The push-pull circuit has many advantages.

It can use much higher B voltage and more power than can a single tube, yet the two tubes will not heat.

Some power is lost in a one-tube amplifier by energy which by-passes to the ground through the capacity between the grid and the filament. The capacities between the grid and the filament of the two tubes in this circuit are in series (see Fig. 313), which cuts down the capacity to ground so the loss of radio-frequency energy is low. The second harmonic which is generated in single-tube amplifier circuits is canceled out in the push-pull circuit. Other advantages of the push-pull amplifier circuit when used at high frequency will be taken up later.

The push-pull circuit is used in the final amplifier stage. It is more effective in developing high power output in the final stage than in the stages ahead of the final amplifier.

### Question

1. Make a list of advantages of the push-pull circuits over the one-tube amplifier.

### How to Build and Wire the Set

Build this amplifier on a larger board. Build two tank coils, both alike (see Fig. 314). This circuit is a tuned-plate–tuned-grid circuit so there must be a grid tank circuit and a plate tank circuit. Provide two sockets for tubes of the type you wish to use.

The circuit shown in Fig. 313 is for a three-element power tube, such as the type 45 or the type 10. Series feed is used in this circuit.

The plate blocking condenser must be rated at twice the plate voltage. Use a 5-watt bias resistor.

### How to Operate It

*Step* 1. Turn on the filament. Disconnect the B positive wire. When the filament is heated, you are ready to neutralize the circuit.

*Step* 2. When the oscillator is tuned to the proper frequency, enough current reaches the grid of the power amplifier tube from the previous amplifier stage to provide excitation so we can neutralize the amplifier.

*Step* 3. Neutralize each tube separately, setting one condenser at a time. You will find the push-pull amplifier easy to neutralize since it is stable and well balanced in its operation.
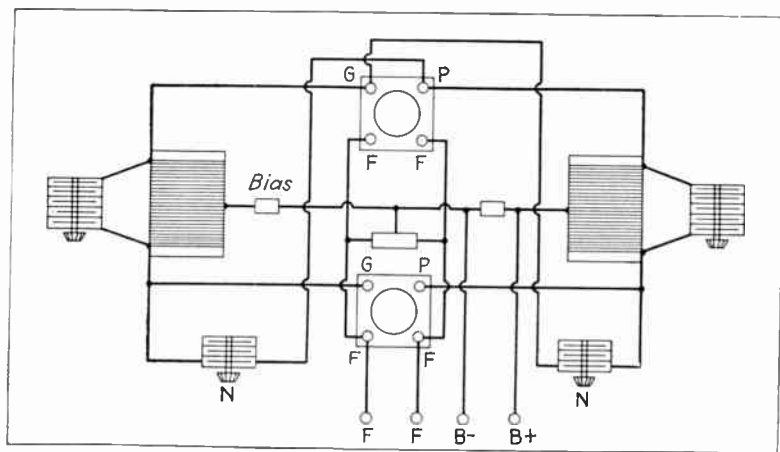


Fig. 314. Push-pull power amplifier.

Tune the first grid tank coil, then the plate tank coil to the desired frequency. Check the frequency with the absorption type wavemeter. The plate voltage must be off.

Set the neutralizing condensers wide open (at their minimum capacity). Enough energy will get through the tube so that you will get a good indication on the wavemeter tuning lamp.

*Step* 4. Now connect the B positive wire, turn on the plate voltage and the circuit is ready to operate.

## Why It Works

Current surges from the oscillator or from the amplifier stage set the grid tank coil in oscillation. When the electrons surge to the grid of tube 1, they make the grid so
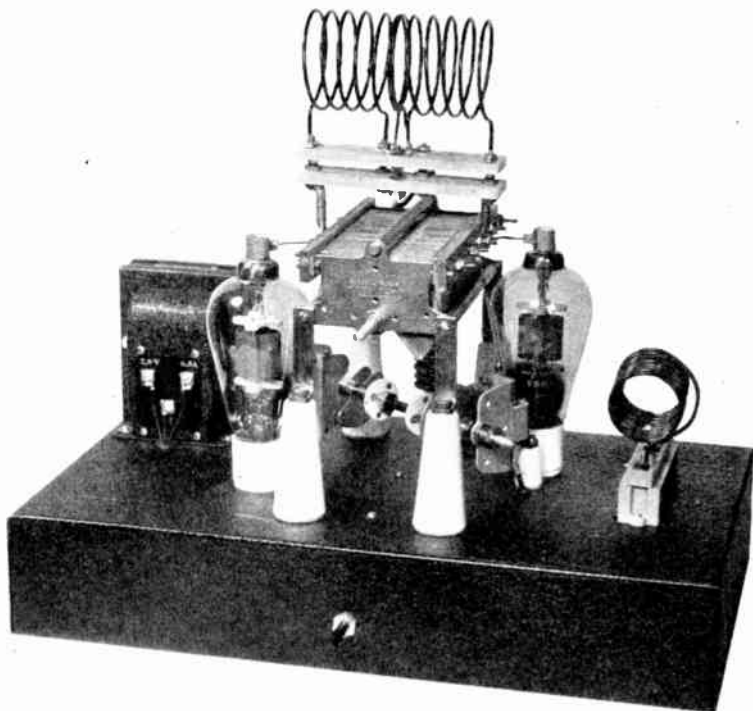
A PUSH-PULL POWER AMPLIFIER

This is one form of a push-pull power amplifier which is used by radio amateurs to communicate with distant stations.

negative that no current flows. At the same instant the grid of tube 2 becomes positive enough to allow current to flow through the tube at the peak of the surge.

In class C amplifiers the grid is biased by means of a bias resistor to twice cutoff. This means that the grid is so

negative that it will only allow current to flow through the tube at the peak of the excitation wave or surge.

In class B amplifiers the tube bias is adjusted to the point where plate current just stops flowing.

In class C amplifiers the tube bias is adjusted to twice this value.

Let us examine the plate tank circuit (see Fig. 313). A plate is connected at each end of the push-pull tank circuit, while in the single-tube amplifier a plate is connected only at one end of the tank circuit. The single-tube tank circuit gets a push from the plate once during each two surges, while the push-pull tank circuit receives a push from the plate at each end of the circuit during each surge. It is easy to see why the push-pull circuit develops so much more power than a single-tube amplifier without overloading the tubes.

**The Efficiency of the Power Oscillator.** The push-pull circuit we have just described is very efficient because the tube plates remain cool. This is because the average current between the filament and the plate is low. The current flows through the plate circuit of each tube only at the instant when the maximum current of the positive surge is on the grid. This means that during most of the cycle the tube is coasting; that is, no current is flowing through the tubes.

When we operate the two tubes as a class C amplifier, we can obtain from ten to twenty times the power that can be obtained from the same tubes operated as a class A amplifier.

**Class A, B, and C Amplifiers.** The difference between these three classes of amplification is simply the difference in the grid bias in each type of amplifier. See part 12 of this chapter.

### Questions

**1.** How does the push-pull amplifier resemble the push-pull circuit which was used as an audio amplifier?

**2.** How does the operation of this circuit differ from the push-pull audio amplifier?

**3.** Does the push-pull audio amplifier have a plate tank circuit?

#### 12. CLASS A, CLASS B, AND CLASS C AMPLIFIERS

**The Class A Amplifier.** The audio amplifier that we used in the receiving circuits was operated so that the grid had enough negative bias to prevent the grid from drawing current from the filament during any part of the cycle. The grid was biased so that it operated on the straight part of the characteristic curve. This type of amplification, which increases the strength of a signal without changing the wave shape, is called class A amplification.

**The Class B Amplifier.** By using a push-pull circuit and biasing the tube to cutoff, it is possible to get more power out of the tube than was possible with one tube.

In this arrangement, each tube delivers one half wave to the output transformer and rests during the other half cycle; thus it is possible to use much more power on the plates of these tubes than in the class A amplifiers. About four times the power can be handled in class B amplification. See How It Works in The Push-pull Power Audio Amplifier in part 7 of Chapter VIII. Class B amplifiers can be used as both audio-amplifier and radio-frequency circuits.

**The Class C Amplifier.** In class C amplification the tube is biased to twice its cutoff voltage. Plate current flows only at the peak of the exciting grid wave. The average current through the tube is less than for either class A or class B amplifiers. The tube runs cooler than in either of the other two classes of amplification. Class C amplifiers

have very high efficiency when used as radio-frequency power amplifiers. The class A amplifier is not used in radio-frequency circuits because it is very inefficient and heats badly.

**Power in Each Class of Amplification.** The efficiency of the amplifier depends upon the bias and upon the amount of energy which can be put through the tube into the tank circuit or into the output circuit. If this energy is used in heating the elements of the tube, little energy will get into the output circuit, and the set will not be as efficient as it should be. When continuous current flows in the plate circuit, as in the class A amplifier, the plates heat and the efficiency, especially at radio frequency, is very low. But in class B amplifiers, where the current only flows during half the grid-excitation cycle, less heating occurs, and the tube operates more efficiently.

A class C amplifier is by far the most efficient of the three for radio-frequency use. A class C amplifier can handle a great deal more power than can a class A amplifier. There is longer cooling time between current surges. The table given below shows an approximate power output for each class of amplification operated in push-pull.

| Amplifier Type | Tubes | Approximate Output |
|---|---|---|
| Class A | Two Type 45 | 5 watts |
| Class B | Two Type 45 | 20 watts |
| Class C | Two Type 45 | 60-100 watts |

Tube heating is the limiting factor in determining the power output. When energy from the B supply is used in heating the tube plate instead of being transferred to the output circuit, the circuit is inefficient. If the tube over-

heats and the plate gets red enough, gas is driven out of the metal of the elements and ruins the tube.

An amplifier may be changed from class A to class B or to class C by changing the grid bias. There is no change in the circuit diagram. See also Fig. 315.
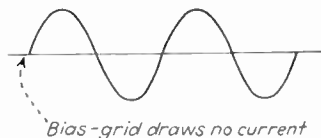
Class A—audio amplifier. Never used in radio-frequency stages; too inefficient.

*Bias - grid draws no current*
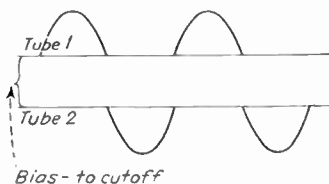
Class B—push-pull audio amplifier. Each tube delivers half of the wave; can be used for radio frequency.

*Tube 1*
*Tube 2*
*Bias - to cutoff*
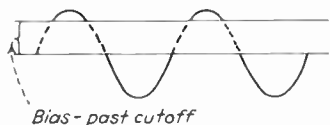
Class C—power amplifier. Radio frequency.

*Bias - past cutoff*

FIG. 315. Classes of amplifiers shown by output wave shape.

## Questions

**1.** What is meant by class C amplification?

**2.** How much bias is used on a class A amplifier?

**3.** Does current flow through the plate circuit all of the time in a class A amplifier?

**4.** Compare the wave shape of the plate current with the wave shape of the incoming signal in class A amplification.

**5.** How much bias is used on a class B amplifier?

**6.** How much of the time is current flowing in the plate circuit of a class B amplifier?

**7.** Compare the wave shape of the plate current with the wave shape of the incoming signal in class B amplification.

8. How much bias is used on the class C amplifier?

9. How much of the time is the current flowing through the plate circuit of a class C amplifier?

10. Compare the wave shape of the plate current with the wave shape of the incoming signal in class C amplification.

11. Which type of amplifier is the most efficient for radio-frequency amplification?

### 13. TRANSMITTER CIRCUITS

We have studied a number of oscillator circuits and their operating characteristics and peculiarities. We have also learned how to use power amplifiers and doublers. We have learned how to get a fixed frequency with the crystal oscillator, and we have learned methods of setting a frequency with the absorption-type frequency meter. Now, we may use this information to assemble these circuits into transmitters. Several circuits are studied in this part, showing how to arrange circuits we have studied as transmitters.

Notice how these circuits are keyed, which stages are neutralized, and the hints for refining these circuits to make them better transmitters. Notice in the operating cautions how the note of the transmitter may be heard by the use of a monitor and how the poor note may be corrected. When you study the keying circuits, notice where keying is properly done and how to prevent key clicks by the use of suitable filters.

**License Requirements.** Figure 316 shows the frequencies set for amateur use by the Federal Government. Your transmitter may operate in one of these frequencies only after you have passed the government license examination consisting of 10 questions selected at random from the list of questions which cover quite fully the principles and operations of amateur transmitting equipment, as well as its operation and the laws which you must know and observe while operating.
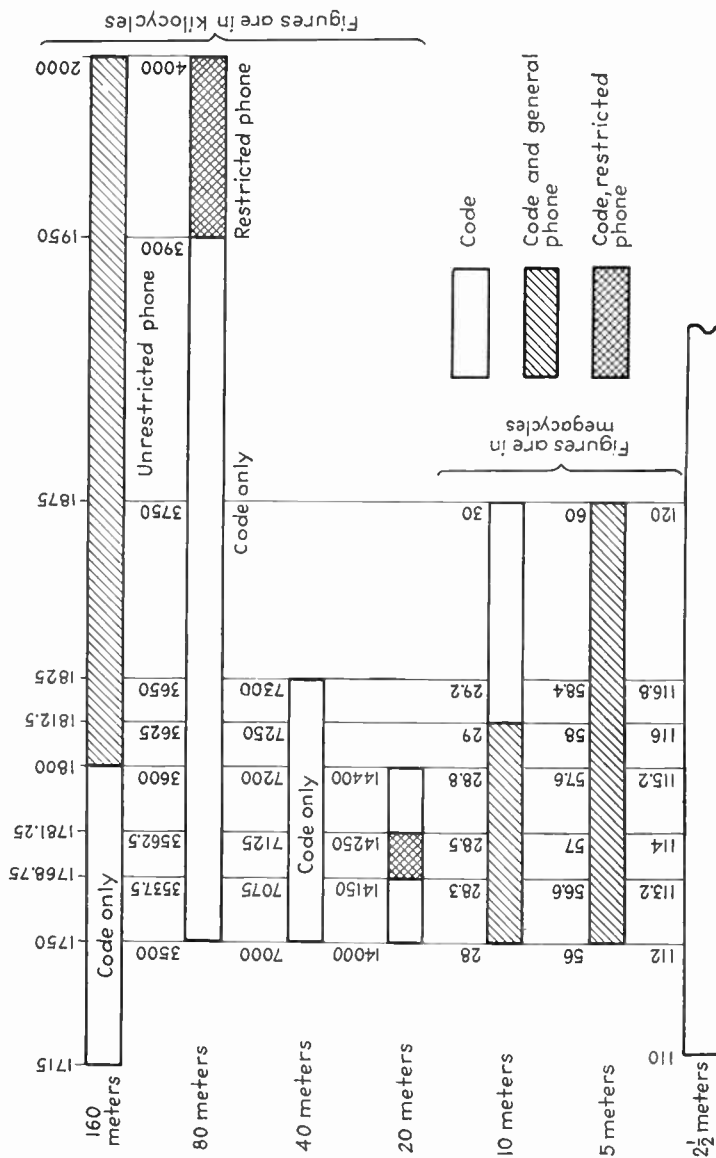
FIG. 316.  Amateur frequencies.  (*Used with permission of the Bliley Electric Company.*)

## Transmitter Circuit Combinations

**Oscillator Used as Transmitter.** Any of the oscillators given in this chapter may be used as a transmitter by connecting a key in the power leads as explained in the keying instructions later in this chapter. Any of the self-excited oscillators, such as the Hartley, tuned-plate–tuned-grid, the TNT, or the electron-coupled circuit may be used as oscillators and as transmitters, but they are so hard to adjust and to keep from changing frequency that we do not advise their use in a transmitter.

Swinging of the aerial or of the feeders in the wind will change their frequency. Slight changes in voltage in the power supply affect their frequency. Such frequency shifting will promptly bring a warning ticket from the Federal Communications Commission.

**The Oscillator-amplifier Transmitter.** *A Crystal Oscillator Connected to a Neutralized Amplifier, Then to the Aerial.* Key the amplifier. With this type of transmitter you may use any of the self-excited oscillators or the crystal oscillator described in this chapter. The amplifier acts as a buffer between the aerial and the oscillator, and there is less likelihood of frequency shifting than if you use a single oscillator. This circuit has the advantage of putting a stronger signal on the air than the single oscillator stage, with the reduction of possible key clicks. If the crystal oscillator is used, this makes a fine transmitter. The amplifier stage must be neutralized.

Swinging of the aerial here has little effect on the frequency, since voltage variations in the amplifier plate circuit do not change frequency as they do in the self-excited oscillator tank circuit.

**A More Powerful Three-tube Transmitter.** *A Crystal Oscillator Connected to a Neutralized Push-pull Amplifier, Then to the Aerial.* Key the amplifier. In this two-tube

transmitter we replace the single-tube amplifier with the push-pull amplifier.    The advantages of this circuit are still greater output in power and little difficulty with frequency.

**A Four-tube Transmitter.**    *A Crystal Oscillator Connected to a Neutralized Buffer Amplifier and a Neutralized Push-pull Final Amplifier, Then to the Aerial.*    This circuit puts a strong, steady signal on the air.    The push-pull final amplifier stage is keyed.    Both amplifiers must be neutralized.

**A Doubler Circuit.**    *A Crystal Oscillator (80 Meters), a Doubler Amplifier (40 Meters), and a Push-pull Final Amplifier into the Aerial.*    This circuit allows you to use a heavier crystal.

All amplifiers except the doubler must be neutralized. The final amplifier stage is keyed.

Other circuit combinations are possible, using as many tubes as the constructor wishes and can afford.    The limiting factor in building transmitters is in the amplifier circuits, which are expensive, especially at high power. The power supply for such units becomes a problem, particularly when high voltage is used.    High-voltage transmitting condensers are expensive, as are high-voltage transformers.

### Question

1. What are some of the purposes of the amplifier in the oscillator-amplifier transmitter?

## Coupling Between Transmitter Units

Several methods of coupling oscillators to amplifiers or amplifiers to amplifiers are explained.

**Method 1—Capacity Coupling.**    Coupling through a condenser, as in Fig. 317, has been studied in several other circuits already described.    This method is simple and quite effective.    The size of the condenser should be from .001 to .005 microfarad.    The condensers should be rated

well above the voltage of the plate circuits to which they
are connected.

**Method 2—Link Coupling.** The link coupling is
arranged as shown in Fig. 318. The plate tank coil and
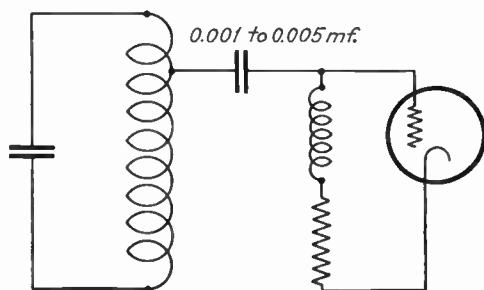


FIG. 317. Capacity coupling between transmitter units.

the grid coil of the amplifier must be over 6 inches apart.
The link is a single turn of wire about each coil, connected
by two twisted wires.

The wires are placed near the ground end of the coil.
Excitation of the amplifier grid is adjusted by moving the
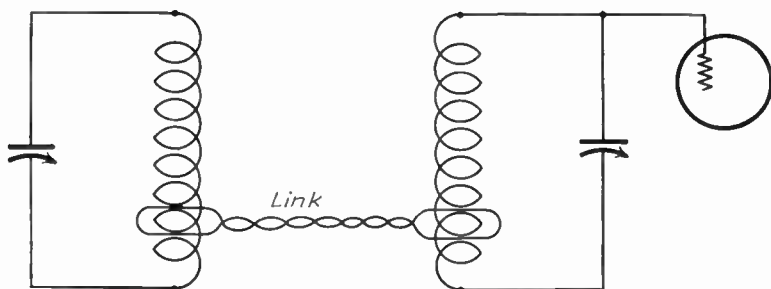


FIG. 318. Link coupling.

link upward to increase excitation. Use a milliammeter in
the amplifier grid circuit to find the highest exciting cur-
rent possible without overloading the previous stage.
Overloading occurs when the tube plate begins to turn red.

## Keying

**Purpose of Keying.**    An oscillator becomes a transmitter when it is connected to an aerial.    But such a transmitter would send out a steady radio-frequency oscillation that would be heard only as a steady whistle in the oscillating receiving set.    The radio-frequency carrier waves are broken by a telegraph key into the dots and dashes of the radio code so that you can "talk" with amateurs over the air.    This is done by putting the key in the leads that supply B power to the set.

Keying, or starting and stopping oscillation in the set, must be done so the receiving operator will hear accurate, clear-cut dots and dashes.

Experience shows that when the key is inserted directly in either the B positive or the B negative wires of a self-excited oscillator the keying is poor.    Annoying key clicks or thumps are produced.

**What Are Key Clicks?**    Key clicks are caused by the sudden rush of current from the power supply through the circuit which causes a spark at the key contacts.    The spark causes a wave to radiate which interferes badly with nearby broadcast receiving sets.    This wave is so broad it cannot be tuned.    This click, if bad, will be heard over considerable distances.    Key clicks can be prevented by using a suitable filter system when the oscillator must be keyed.    If the keying is done in the amplifier stages, part of this trouble is avoided.

The key-click filter is a system which will absorb the rush of energy when the key is closed or when it is opened so that no spark occurs at the key.

**Center-tap Keying.**    The crystal oscillator should not be keyed when two or more tubes are used.    When the oscillator is keyed, small changes in frequency occur as

the key is opened and closed. These frequency changes go on to the final amplifier and onto the air.

A simple and convenient keying circuit for an oscillator is shown in Fig. 319. Here the key is placed in the lead from the center-tap resistor to the B negative wire.

**Operation.** When the key is closed, current from the power supply rushes through the plate circuit. If this surge is too strong or too sudden, a thump or key click will
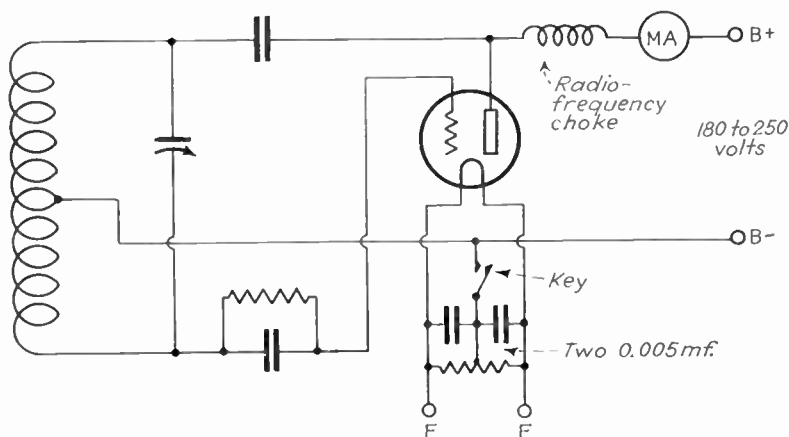


FIG. 319.    Center-tap keying circuit.

be heard. The key click is more pronounced when the key is raised because the spark between the key contacts is stronger than when the key was closed. Center-tap keying eliminates this thump because, when the key is raised, current surges to the grid, which becomes very negative and cuts off the plate current quite sharply, thus reducing or preventing the thump.

**Key-click Filters.** If the keying method of the circuit, shown in Fig. 319, still has key thumps, a 5000-ohm variable resistor such as the Bradleystat is connected in series

to a .01-microfarad condenser across the key contacts (see Fig. 320).

The rush of current through the key is absorbed by the condenser.    The resistor slows down the rush of current as the condenser charges and discharges.
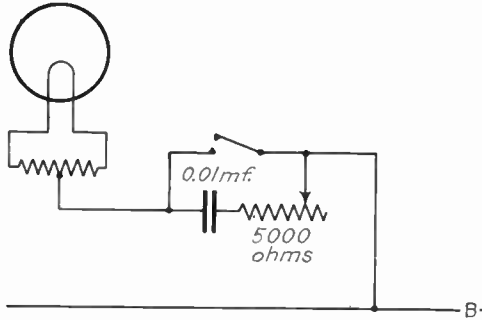


Fig. 320.    Key-click filter circuit.

A bell-transformer primary or other small choke coil is connected in place of the Bradleystat in series with a $\frac{1}{2}$-microfarad condenser in Fig. 321.    You will have to
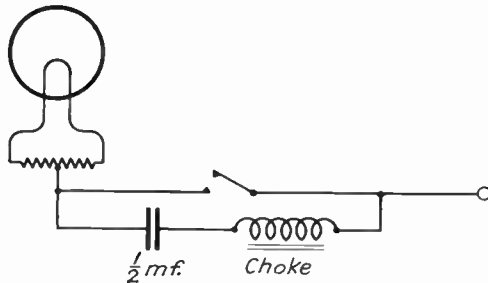


Fig. 321.    Key-click filter circuit.

experiment with the size of the condenser and the choke coil until you get best results.    If the parts of the filter are too large or too small, the set operates as poorly as though no filter were used.

The circuit in Fig. 322 shows a more satisfactory filter with the resistor and condenser and choke coil.    The choke coil may be one taken from an old A eliminator.    This
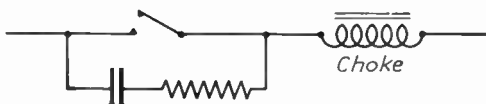


FIG. 322.    Key-click filter circuit.

circuit is probably the best key-click filter, yet it is hard to adjust.

See Fig. 323 for a keying circuit for a push-pull amplifier.
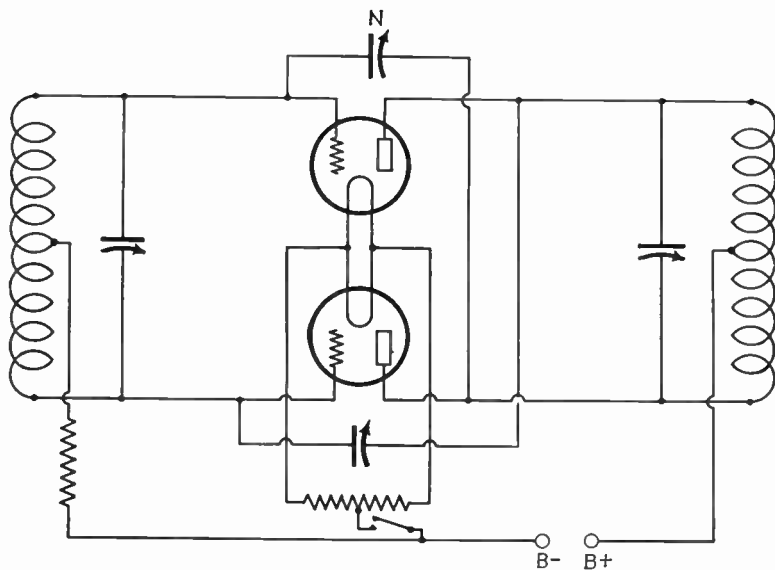


FIG. 323.    Keying a push-pull amplifier.

## How It Works

If the choke coil is too large, it will not prevent oscillations.    The energy stored in the choke coil when the key is raised will be dispelled as a heavy spark across the contacts of the key.    This will soon destroy the key contacts,

so a condenser is connected across the contacts to help absorb this spark. The variable resistor prevents sudden discharge of the condenser as the key is raised.

### Questions

1. How is the excitation of the amplifier grid adjusted in link coupling?

2. What causes key clicks?

3. How are key clicks prevented?

4. When should the crystal oscillator not be keyed?

5. Where is one of the simplest places to put the key in a circuit to give satisfactory results?

6. Explain how the method of keying prevents key clicks.

### 14. THE CONSTRUCTION OF A MONITOR

**What Is a Monitor?** When a transmitter is in operation, it must be adjusted so the radio wave it puts on the air will produce a clear, steady note in the receiver. The operator at the key cannot hear the carrier wave produced by the oscillator. This wave is at radio frequency. All the operator can hear while sending is the clicking as he opens and closes his key. A monitor is an oscillating circuit arranged so that phones can be coupled in the plate circuit. The monitor is shielded so it will pick up only a small part of the energy put out by the transmitter. By tuning the monitor to get a beat note with the transmitter frequency, an operator can hear a whistle as he keys the transmitter. This is desirable since it is very hard to key clearly unless you can hear the signals you are producing. If anything affects the transmitter causing a change in its note, you can hear it at once.

The monitor has another use. It may be used in setting the transmitter to a desired frequency.

### How to Build and Wire a Monitor

Mount a type 30 or a type 99 tube, plug-in coil, and a midget variable condenser in a completely enclosed metal

box. Also mount a phone jack in the plate circuit (see Fig. 324). This metal box or shield may be a cracker tin or a built up aluminum box large enough to contain a flashlight-cell A battery and a small 45-volt B battery.
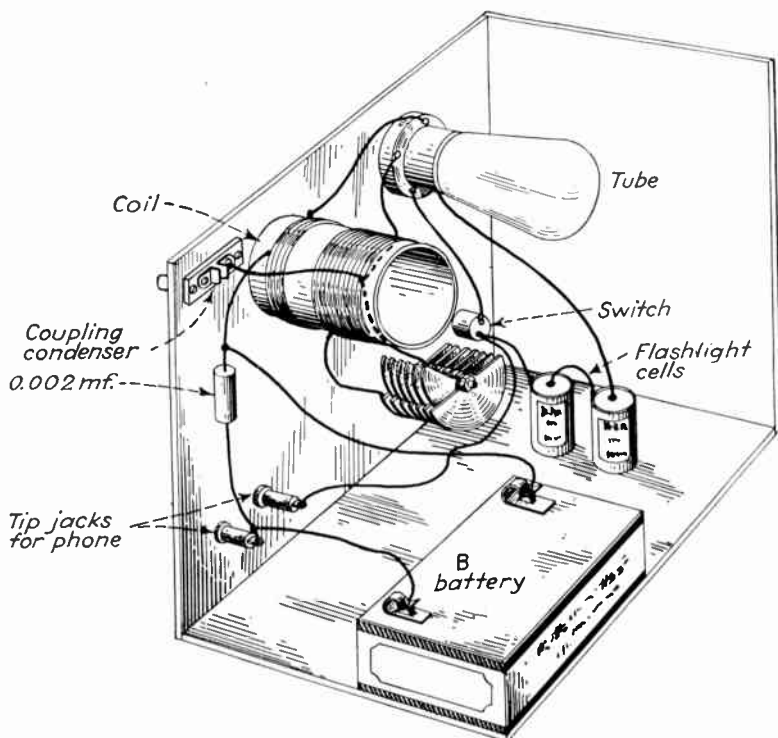


FIG. 324. Cutaway view of monitor in can.

Connect a condenser made of brass or aluminum sheets $\frac{1}{2}$ inch square, spaced about $\frac{1}{4}$ inch apart (see Fig. 324 and Fig. 325) to one end of the grid coil and the other side of the condenser to a binding post insulated from the shield can. Mount the tuning condenser with the shaft projecting through the can. Set an on-and-off switch in the filament

circuit of this tube. You can arrange a phone jack to turn on the filament circuit only when the phones are plugged in.

### How to Operate It

To hear your keying, plug the phones into the circuit and turn on the filament current. Set the monitor near enough to the transmitter to pick up a fairly strong signal in the phones. Tune the monitor until you hear a note
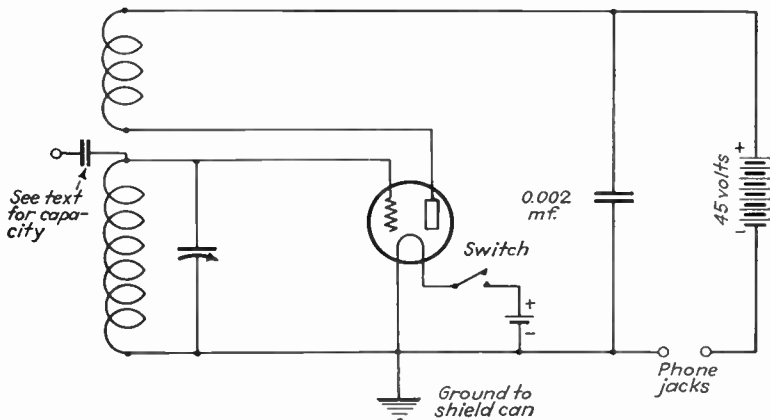


FIG. 325.    Monitor circuit.

put out by the transmitter. When a transmitting condenser burns out, when trouble arises in the power supply or the tube breaks down, in fact when anything occurs, which will cause a change in the transmitter note, you will hear it at once in the monitor.

Some amateurs build a relay operated by the key. Contacts on this relay switch the headphones from the receiving set to the monitor each time the key is closed. Otherwise, you will have to plug your phones into the receiver when you wish to listen over the air and plug them into the monitor when you operate the transmitter.

**The Monitor Used to Set Transmitter Frequency.** You will learn the locations on your receiver dials of certain stations whose frequency you know. You can use these dial settings to set the frequency on which your transmitter operates. You do this by tuning the monitor to your receiver, then tuning the transmitter to the monitor.

If you have a well-shielded receiver, it can be used directly as a monitor. A simpler method of setting your transmitter to a known frequency is to use a crystal oscillator.

*Step* 1. Turn on the receiver. Tune the receiver to a station in the frequency band on which you wish the transmitter to operate.

*Step* 2. Turn on the monitor. Tune the monitor to zero beat with the receiver. Turn off the receiver.

*Step* 3. Turn on the transmitter. Set the monitor near the transmitter. Tune the transmitter until you hear the transmitter note in the monitor. The transmitter now is set at the frequency on which your receiver was adjusted.

**The Note Put Out by the Transmitter.** Oscillators, if operated properly, will put out a steady radio-frequency wave. This wave, when picked up by the receiver, will produce a clear whistle in the phones. This whistle is called the note of the transmitter. Anything which interferes with the smooth operation of the oscillator will cause the pitch of this whistle to change.

Some conditions which arise in self-excited oscillators which cause them to produce a ragged or poor note follow.

*Condition* 1. The plate current must be a pure direct current. Any variation in the plate current affects the grid and introduces what is called amplitude modulation, or changes in the strength of the carrier wave. This causes the note to have a 60-cycle hum instead of a pure whistle-

like note.    This means that the strength of the carrier wave changes at the frequency of the hum in the plate voltage.

*Condition* 2.    Any variations in plate voltage on the self-excited oscillators also produce slight variations in the frequency of the plate tank circuit.    This produces a broad wave which is hard to tune and which is illegal.    By-pass condensers from the filament leads to the center tap are often used to clear up this note.    If these condensers are leaky, they will add to the trouble.    If you have a poor note, check these condensers.

*Condition* 3.    A radio-frequency choke in both the B positive and B negative leads sometimes will stop this defect.

*Condition* 4.    Jars caused by operating the key cause vibration of the tube elements and the wiring of the plate circuit in the oscillator.    These vibrations cause slight changes of spacing of tube elements and of wiring, which affect the frequency of oscillation.    Vibrations from the transformer or the choke in the power supply sometimes reach the oscillator and affect the note.    The remedy for this is to set the oscillator base on rubber, which will stop the vibration.

*Condition* 5.    If the coupling to the aerial is too tight, the aerial will draw too much energy from the tank circuit, which will affect the frequency of oscillation.

*Condition* 6.    Poor insulation in either the tube, the socket, the wiring of the tank circuit, or the tuning condensers causes leakage that effects the transmitter note. Leaky by-pass condensers also cause a poor note.    Look for blisters on the surface of the insulation where the radio-frequency current is creeping through.

*Condition* 7.    Poor tubes are another cause which make a poor note.

*Condition* 8. The crystal-controlled oscillator is less likely to have a poor note than is a self-excited oscillator, although variations in the voltage of the power supply will also affect the oscillation note.

*Condition* 9. A tank circuit with high $C$, that is, one which has a large capacity and a small coil, is more stable than one which has less capacity (low $C$) in the circuit.

A low $C$ set will have more power output, but the note will be poor and the frequency will not be stable.

Use low $C$ for an amplifier. This will improve the power output.

### Questions

**1.** Give some reasons for a transmitter producing a poor note.

**2.** What is meant by the term *amplitude modulation?*

# CHAPTER XI

## RADIOTELEPHONE TRANSMITTERS

The radiotelephone is becoming very popular among amateurs and experimenters. The radiotelephone has undergone tremendous development in the last few years.

The apparatus is now available so that many experimenters are building radiophone transmitters. There is much fascination for the experimenter who can talk directly to his friends "over the air." Basically the radiophone transmitter consists of oscillator-amplifier combinations we studied in Chapter X, to which are connected a microphone, speech amplifiers, and a modulator unit.

In this chapter we discuss the use of microphones that change sound waves into pulsating direct currents, how these currents are amplified in a speech amplifier, and how the amplified speech currents modulate the radio-frequency carrier waves.

The sets we describe in this chapter are easy to build. They operate with reasonable efficiency. Their design is such as to show the principles of operation rather than to be efficiently equipped for use on the air. We couple to a dummy aerial to absorb the power developed by the transmitter. On a typical circuit, an oscillator generates a radio-frequency wave which is used as a carrier for the voice waves. Speech currents, amplified by the modulator circuit, modulate the carrier wave. It then goes to the aerial. A more powerful circuit is shown in Fig. 326, where the carrier frequency is generated by an 80-meter crystal oscillator, goes through a doubler-amplifier at 40 meters,

494
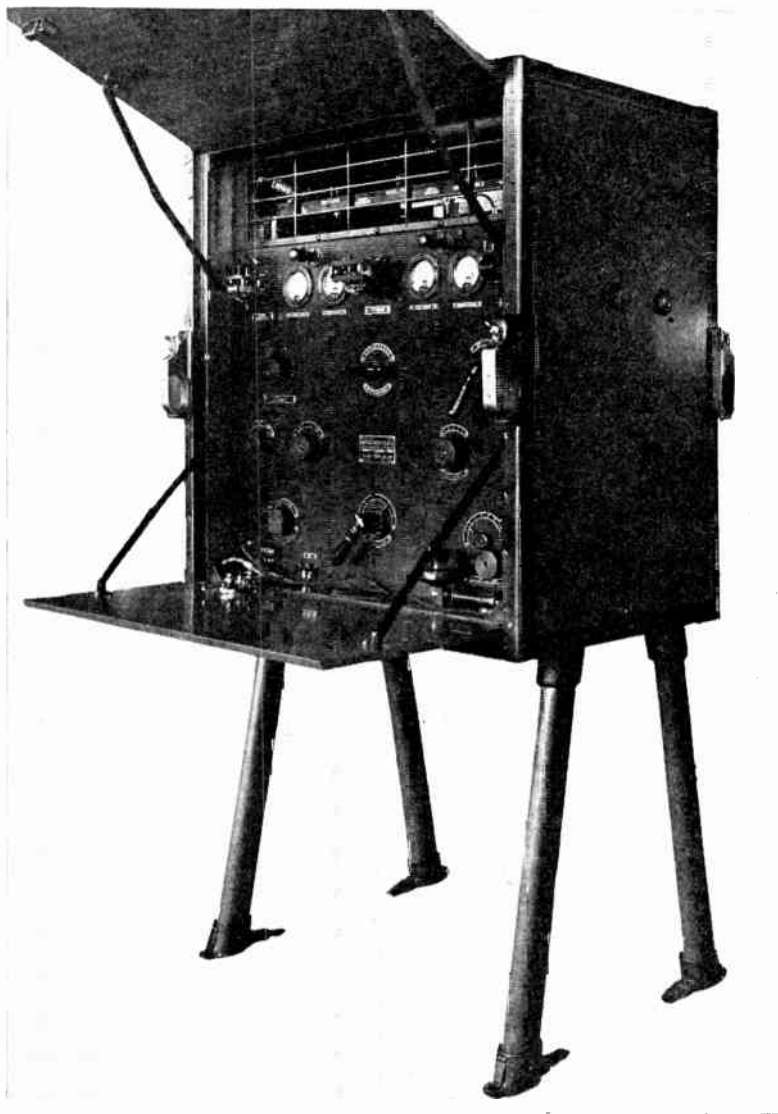
PORTABLE FIELD EQUIPMENT
Rugged, but portable, radio equipment is needed for military service.

to a buffer-amplifier at 40 meters, to the modulated ampli-
fier, and through a final amplifier to the aerial.

Speech currents from the microphone pass through the
modulator to the modulated amplifier (see Fig. 326).    You
can see from this set-up that many of the units we have
made and studied in the oscillator and transmitter chapter
are used in this circuit.    We shall study modulators and
microphones in this chapter.    A low-powered efficient set is
more likely to cover great distances than a poorly adjusted
high-powered set.    The sooner the carrier wave is modu-
lated, that is, the less amplification ahead of the modulator
tube, the less power you need in the modulator itself and
the less speech amplification will be needed.    You must
have as much power in the modulator as in the tube to be
modulated.    Notice the units which are to be neutralized.
They are marked with an $N$ in Fig. 326.    The buffer circuit
is an amplifier connected between the oscillator and the
modulator tube to prevent current changes in the modulator
circuit from reaching the oscillator.    Changes in the plate
voltage in the oscillator cause changes in the frequency of
the carrier wave.

### Contents of This Chapter

1. Microphones
2. The Two-tube Radiophone Set
3. Modulation
4. Methods of Controlling Modulation

### 1. MICROPHONES

The common transmitter used on the telephone in your
home is a single-button carbon microphone designed for
rugged service in the hands of persons who are not accus-
tomed to handling sensitive instruments.    This type of
microphone is used in experimental radio circuits; but when
you wish to build a radiotelephone transmitter which
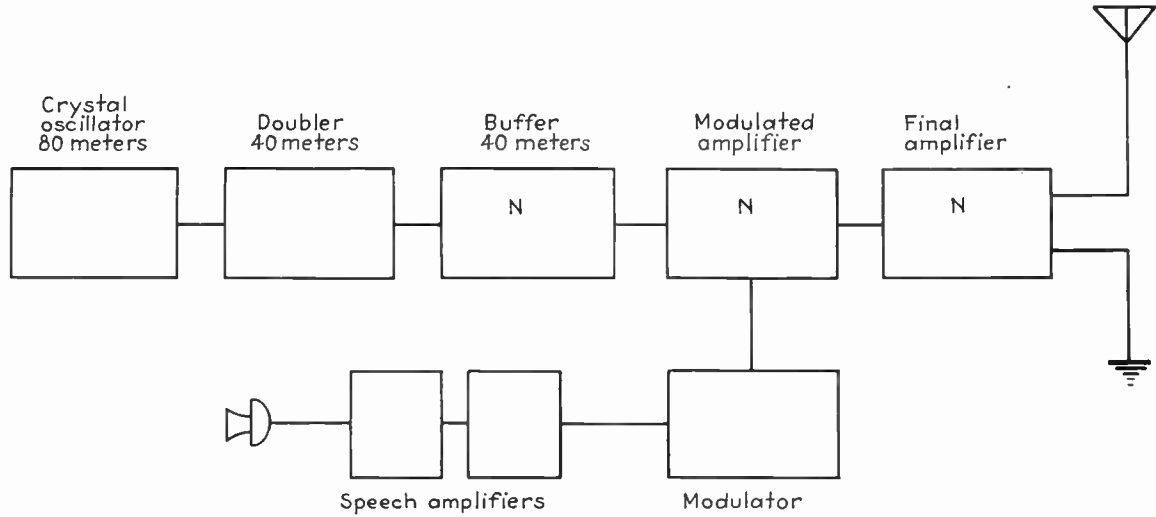
FIG. 326. Units in a radio telephone transmitter.

delivers clear, accurate speech or music, you will need a microphone which is well constructed and which will respond better to all of the voice frequencies than will the ordinary telephone transmitter.

### Carbon Microphones

Carbon microphones are used quite extensively on amateur sets because they are less expensive than other types, can be used for experimental work, and will produce music of reasonable quality. High-quality carbon microphones reproduce voice and music with excellent quality. Another reason why the experimenter prefers the carbon microphone is that it uses and requires less amplification between the microphone and the modulator tube than other types of transmitters. It needs the equivalent of about three stages of audio amplification using type 27 tubes. This microphone is not directional.

**How Made.** A double-button microphone uses a sheet of duralumin about .001 inch thick stretched between two heavy metal rings (see Fig. 327). The metal rings form a frame which not only supports the diaphragm but which is also used for attaching the complete microphone to the supporting stand. A small spot in the center of the diaphragm is plated with gold to make contact with the carbon grains which are held against the diaphragm in a small insulating cup. The carbon grains are prevented from spilling out of the cup by a felt ring placed around the insulating cup against the diaphragm. A single-button microphone has only one carbon cup or button. The double-button microphone—which has two buttons, one placed on each side of the diaphragm—is more sensitive than a single-button microphone.

Carbon microphones are hung in a ring about 5 inches in diameter by springs. Each spring is connected between

the frame of the microphone and the mounting ring.  The
springs support the microphone, yet prevent jars from the
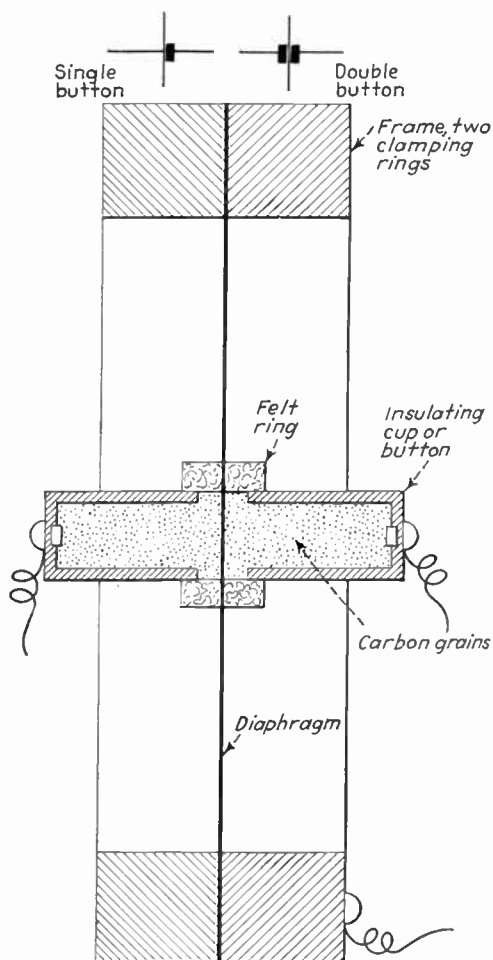


Fig. 327.   Double-button carbon microphone, and symbols.

floor from being transmitted to the carbon grains through
the stand and the frame of the instrument.

**Circuits.** The circuit shown in Fig. 328 is used for the single-button microphone, and the circuit shown in Fig. 329 is used for the double-button microphone. The
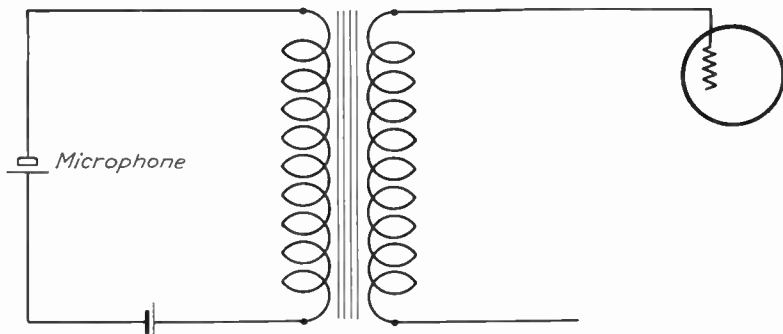


Fig. 328. Carbon-microphone circuit, single button.

external voltage required is from $1\frac{1}{2}$ to $4\frac{1}{2}$ volts, with a current drain of from 10 to 20 milliamperes. Dry cells furnish this voltage.
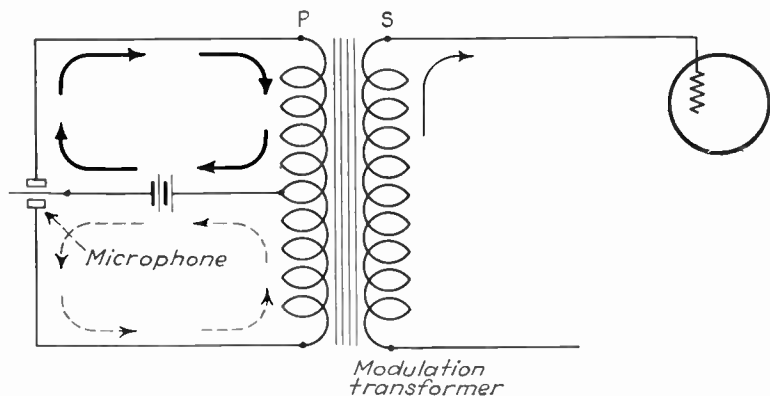


Fig. 329. Carbon-microphone circuit, double button.

**How the Single-button Microphone Works.** Direct current from the battery, as shown in Fig. 328, flows to the diaphragm through the carbon grains and the microphone-

transformer primary back to the battery. Sound waves cause the diaphragm to move. The compression part of the sound wave pushes the diaphragm in one direction, and when the rarefied part of the sound wave arrives, the diaphragm moves in the other direction. Suppose that during the compression part of the sound wave the diaphragm moves so that the carbon granules in the insulating cup are pushed together. This reduces the resistance of the granules to the passage of the battery current. Current can flow more easily through closely packed grains than through grains which are loosely packed. At this instant more current flows through the microphone.

**How the Double-button Microphone Works.** When an air wave hits the diaphragm and pushes it in one direction,
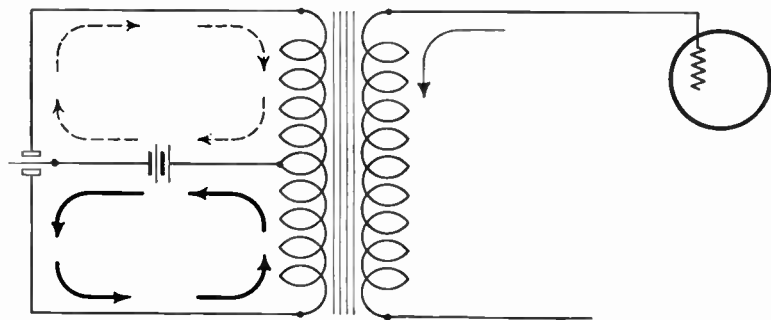


FIG. 330. Carbon-microphone circuit, double button.

the carbon grains in one button are compressed. Much current now flows through the button in which the grains are compressed, as shown by the heavy arrows in Fig. 329. At this same instant the carbon grains in the other button are separated, and a weak current flows, as shown by the dotted arrow. The strong current induces a surge in the microphone-transformer secondary as shown by the arrow in Fig. 329. The collapsing field produced by the weaker current induces a helping surge in the secondary.

Now when the air wave moves the diaphragm in the other direction, it compresses the carbon grains in the other button. A strong current now flows as shown by the arrows in Fig. 330. This current induces a current in the secondary of the transformer, as shown, which is in the opposite direction to the surge caused by the first part of the sound wave. This current makes the grid positive.

Then when the diaphragm springs outward during the rarefied part of the sound wave, there is more space between the carbon granules. They lie together more loosely and less current flows through them.

In this way, the freely moving diaphragm follows the air-wave variations caused by the voice or musical instruments and produces a pulsating direct current which is called a speech current. Speech currents have a wave shape which follows the variations of the sound wave almost exactly.

### Questions

**1.** Are the carbon button microphones easily injured?

**2.** Does jarring have any effect upon the operation of a double button microphone?

**3.** Give some reasons why beginning amateurs prefer the carbon-button microphones.

**4.** Does the current increase or decrease when a sound wave compresses the carbon granules?

**5.** Show how movements of the diaphragm back and forth cause the current to flow in opposite directions through the primary of the transformer.

**6.** Are the carbon microphones directional?

## The Condenser Microphone

The condenser microphone is a good all-purpose instrument which produces very fine quality speech or music. This instrument is delicate, however, and will not stand jars; neither can it stand extreme volume of sound. It is

quite expensive, which limits its use in the amateur and experimental field. It is not especially directional. It has a disadvantage of requiring more amplification than the carbon-button microphone. It needs about the equivalent of five stages of amplification corresponding to type 27 tubes.

**How Made.** A stretching ring similar to that used in the carbon microphone stretches or supports the .001-inch thick duralumin diaphragm at a distance of about .001 inch from a heavy metal back plate. The duralumin sheet is spaced and is insulated from the metal plate by



Fig. 331. Condenser microphone.

an insulating ring to form a condenser (see Fig. 331). No dust or moisture must get between the two condenser plates. The mounting for this instrument must be carefully made to prevent any jars or shocks from reaching the diaphragm.
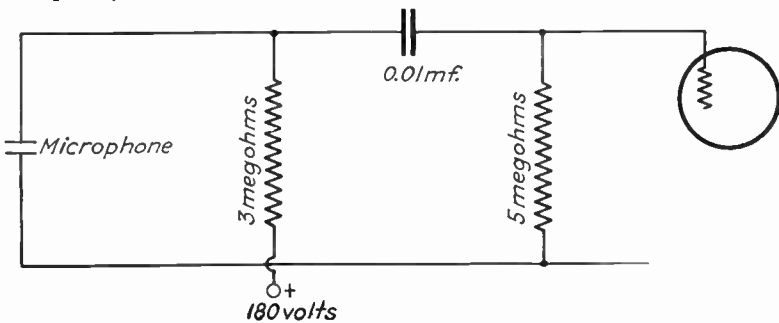


Fig. 332. Condenser microphone circuit.

**Circuits.** The wiring diagram (Fig. 332) shows that 180 volts must be connected across the plates of the condenser microphone.

**How It Works.** Air waves strike the diaphragm and cause it to move nearer or to spring away from the back plate. When the diaphragm is near the back plate, the capacity of the condenser is increased and more current flows through the circuit from the B battery. When the diaphragm springs away from the back plate, the capacity of the condenser is reduced and it will hold less current. These variations in current reach the grid of the first tube of the speech amplifier through the .01-microfarad coupling condenser.

### Questions

1. Is the condenser microphone a rugged instrument?

2. Is it a very expensive type of microphone?

3. Is it directional?

4. How many volts must be used across the condenser?

5. Does the current increase or decrease when the diaphragm bends toward the other plate?

6. Is the capacity of the condenser greater or smaller when the diaphragm springs away from the other plate?

7. How does the tone quality of the condenser microphone compare with the double-button type?

## The Crystal Microphone

This is one of the best types of microphones. It is very rugged and can be dropped while in use without serious



Fig. 333. Crystal microphone sound cells, magnified.

damage. Severe jars, of course, will break the mounting or the crystal. No external power is required for this microphone; and since it is fairly inexpensive, it makes a fine instrument for general use. It has very good tone quality. It requires four stages of speech amplification.

**How Made.** Two crystal slabs about .01 inch thick with foil cemented on both faces are clamped together to form a tiny sound cell (see Fig. 333).

Two sets of sound cells, separated by a spacer and covered by a light membrane which keeps dust and dirt out are shown in Fig. 333. Several of these units are connected in series parallel in the microphone.

**Circuits.** As shown in the circuit in Fig. 334, a crystal microphone is connected to the grid of the first speech amplifier stage through a coupling condenser. No external
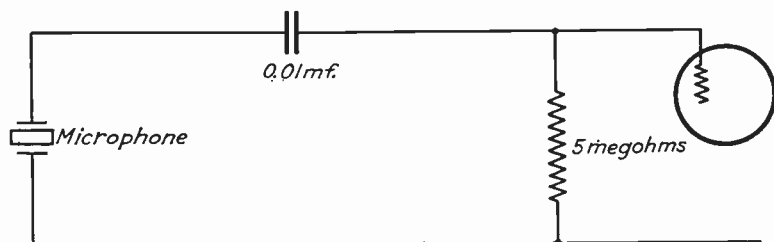


Fig. 334. Crystal microphone circuit.

voltage is needed with this circuit. Four stages of speech amplification are needed.

**How It Works.** Sound waves cause the slabs to vibrate and to bend apart in the center. This vibration sets up a weak voltage. Several of the sound units are connected in series parallel to put out more voltage than one unit would deliver.

Coupling between speech amplification stages should be of the resistance type. Resistance coupling between the stages produces music of good quality, and there is no pickup as with transformer coupling. Transformer coupling will pick up enough hum to make a hum in the output of the transmitter. This occurs on account of the very high amplification used in the speech-amplifier circuit.

Impedance coupling is not desirable because there is too much distortion in this type of coupling.

### Questions

1. Is the crystal microphone very rugged?
2. Compare its expense with that of the other types.
3. Is it directional?
4. How much amplification is needed?
5. Does this microphone have good tone quality?
6. Do you need a battery connected in the crystal circuit?
7. What type of coupling is best between the amplifier stages for this microphone?

## Velocity Microphones

The velocity microphone is a very rugged instrument which produces speech or music of good quality. It is
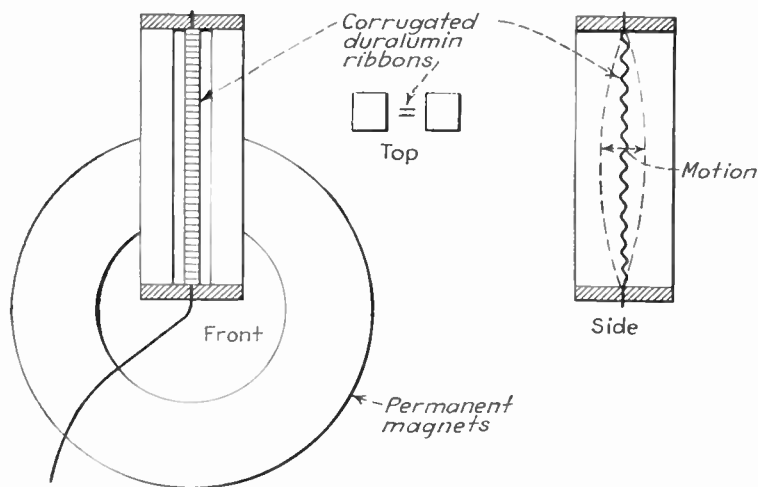


FIG. 335.   Velocity microphone.

about as expensive as a crystal microphone. It has the advantage that no external voltage is needed. It needs five stages of speech amplification. It has the advantage

that you must talk directly into it; it is very directional. This is particularly desirable for some classes of work.

**How Made.** The velocity microphone is essentially a thin corrugated duralumin ribbon suspended in a strong magnetic field.

The field is supplied by a heavy permanent magnet arranged so the ends of the cores form a long narrow opening (see Fig. 335).

The corrugated ribbon is stretched between the core ends so it can vibrate back and forth as sound waves strike it. Connection is made to the ends of the ribbon.
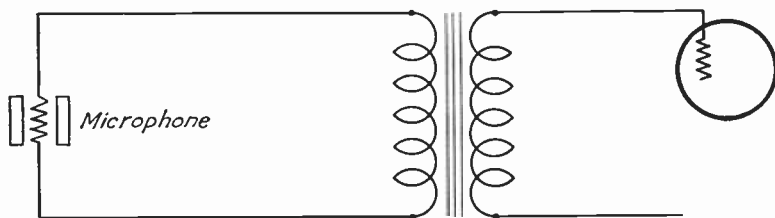


Fɪɢ. 336.    Velocity microphone circuit.

**Circuits.** As shown in the circuit in Fig. 336, the velocity microphone is connected directly to the primary of the microphone transformer.    No battery is needed.

**How It Works.**    Sound waves cause the long duralumin ribbon to move back and forth.    As you already know, when a wire or other conductor moves in a magnetic field, a current is generated in the wire.    The movement of the duralumin as it follows the compressed and rarefied parts of the sound waves produces currents of varying strength. These currents reach the first stage of the speech amplifier through the microphone transformer.

### Questions

1. Is the velocity microphone a rugged instrument?
2. Compare its cost with that of the other types.

3. Is it directional?
4. How much amplification is needed?
5. Do you need a battery connected in the circuit?
6. Compare its tone quality with that of the other microphones.
7. Compare the action of duralumin ribbon to an electric generator.

## Dynamic Microphones

The dynamic microphone is a rugged and not too expensive instrument. It has excellent tone quality. It is about as expensive as a crystal microphone. It uses four stages of amplification.

**How Made.** This microphone is similar in many ways to the dynamic speaker. A coil is mounted on the dia-
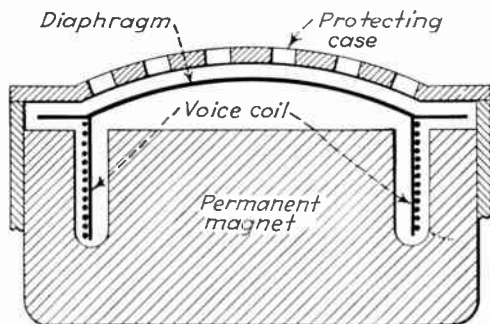


Fig. 337.   Dynamic microphone.

phragm as in a dynamic speaker (see Fig. 337). The powerful magnetic field in which the small coil moves is supplied by a heavy permanent magnet instead of by an electromagnet, as is done in a dynamic speaker.

**Circuits.** The voice coil, as shown in Fig. 338, is connected to the primary of the modulation transformer. The use of the permanent magnet makes unnecessary a field-supply current.

**How It Works.** Air waves cause the diaphragm to move back and forth. This causes the coil to move in the

powerful magnetic field of the permanent magnet. The variations in the motion of the moving coil follow the variations in the sound waves and produce pulsating direct currents in the primary of the microphone transformer. A current is produced in the wires attached to the diaphragm as the coil moves in the magnetic field.



Voice coil
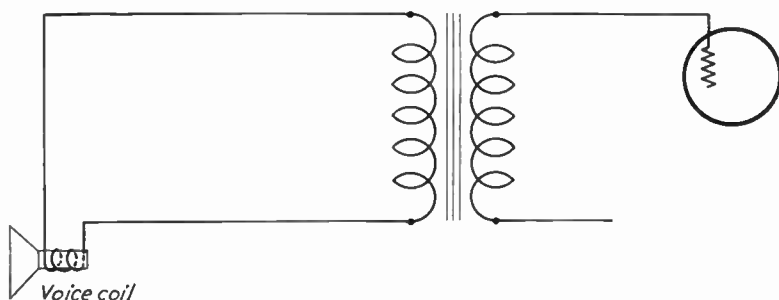
FIG. 338.    Dynamic microphone circuit.

### Questions

1. Is the dynamic microphone a rugged instrument?
2. Compare its cost with that of the other types.
3. Is it directional?
4. How much amplification is needed?
5. Do you need a battery in the circuit?
6. Compare its tone quality with that of the other types.
7. Compare its operation with the dynamic speaker.

### 2. THE TWO-TUBE RADIOPHONE SET

## How to Build and Wire the Set

**The Oscillator.** Use the Hartley oscillator that you built in Chapter X for this phone transmitter.

**The Modulator Board.** Mount the parts for the modulator on a small-sized baseboard as shown in Fig. 339.

**Wire the Modulator Circuit.** This circuit is the Heissing modulator circuit (see Fig. 339 and Fig. 340).
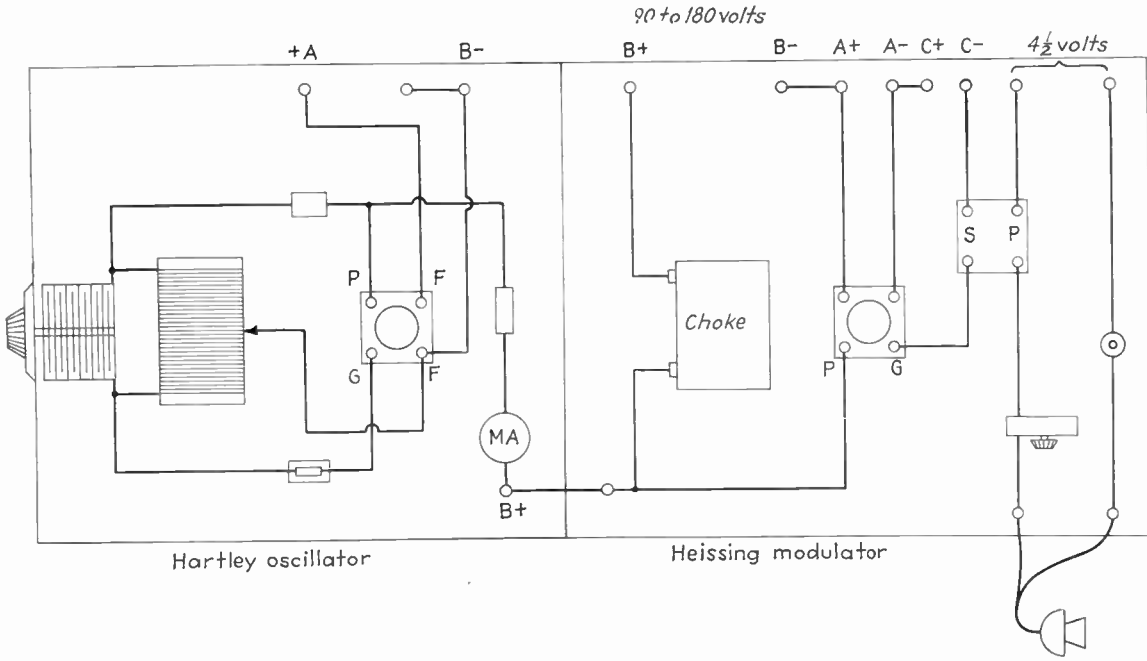
FIG. 339. Two-tube radiophone set.
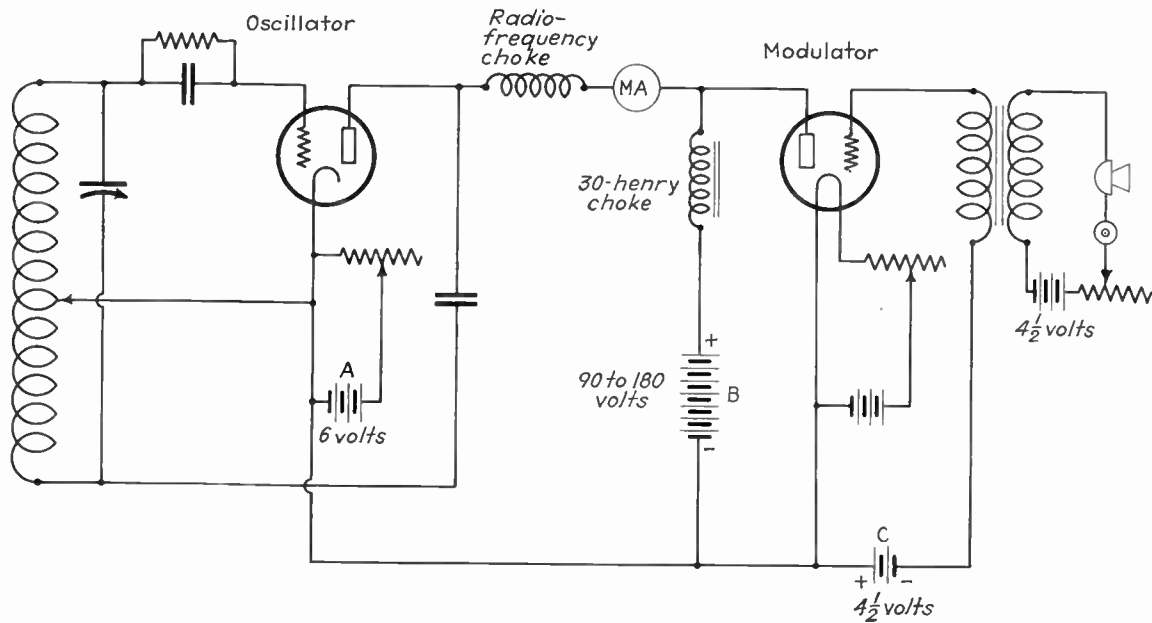
Fig. 340.   Circuit for two-tube radiophone set.

All of the wiring of this circuit handles audio frequency. No special care is necessary in placing the wiring, since little feedback occurs at audio frequencies.

**The Microphone Transformer.** Get either a new or a burned-out audio transformer, any ratio. Remove the burned-out winding (usually the primary). Wind about 15 to 20 turns for the primary next to the core. Then slip the secondary over the primary. Use wood or cardboard to hold it in place. Later you may want to try changing the number of turns on this winding.

**Hook Up the Batteries.** Put a type 01A tube in each socket.

Connect a 6-volt A battery to the leads on both the modulator and oscillator boards.

Connect 135 volts to the B positive binding posts on the modulator board.

Connect a $4\frac{1}{2}$-volt C battery to the C binding posts.

Connect $4\frac{1}{2}$ volts to the microphone battery posts.

The set is now ready to test.

### How to Operate It

*Step* 1.   Turn on the power to heat the oscillator- and modulator-tube filaments.

*Step* 2.   When the filaments are hot, turn on the B power.

*Step* 3.   Place a broadcast receiving set in the same room to test the operation of your phone set.

*Step* 4.   Tune the oscillator so the set is in oscillation.

**Caution!**   *Interference.*   Use not over 180 volts on the plate of your oscillator to prevent interference with nearby broadcast receivers.

*Step* 5.   Tune the broadcast receiver until you hear a thump or hiss.   The volume control must be set at high. Retune the oscillator if the sound cannot be heard in the broadcast receiver.

*Step* 6. Hold down the push button in the microphone circuit. Speak into the microphone. This is a "push-to-talk" connection. Hold the microphone at the side of the mouth so that you "talk past" it.

Test the effect on the quality of the sound the set transmits by speaking loudly, then softly. Test the modulation by speaking in a high-pitched voice, then in a deep voice. Make the same test by whistling.

This microphone and modulator circuit are not highly efficient, and you will find that the voice heard in the broadcast receiver is not like the natural voice; neither is it as good as when heard over the telephone. The movement of the plate meter hand shows the modulation of the set as you speak into the microphone.

**How to Control Power.** The power output of the Hartley oscillator can be increased or decreased both by the B voltage and by the voltage on the grid of the tube (the grid excitation). Adjust the grid excitation on the Hartley oscillator by moving the tap on the tank coil. Move the tap toward the plate end of the coil to increase the power output.

## Why It Works

**The Oscillator Board.** The explanation of how the oscillator board operates has been covered in Chapter X.

The purpose of the oscillator in this circuit is to generate a strong, steady radio-frequency oscillating current. This current is called the carrier wave. The frequency of the carrier wave is the frequency to which you tune your receiving set when you wish to hear a broadcast station or other radiophone transmitting station.

**What Are Sound Waves?** Sound waves produced by the voice, by musical instruments, or by other means are complex and complicated combinations of air waves. But

explained simply, a sound wave is an air vibration by which
the air is compressed, then rarefied (see Fig. 341).   The
sound wave is explained in Chapter VI, where the sound
wave is caused by the repeated vibration of the speaker
cone.   Sound waves travel through the air at the rate of
1100 feet a second.   Sound waves die out quickly.   They
carry only a few miles, so we find it necessary to transform
the sound waves into radio waves which will travel a tre-
mendous distance.
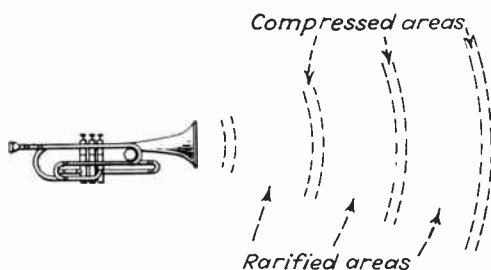


Fig. 341.   Sound waves.

**Purpose of the Microphone.**   Sound waves that strike
the microphone diaphragm cause it to vibrate back and
forth, as explained in part 1 of this chapter.    The vibrations
produce pulsating direct currents in the microphone circuit,
called speech currents.

These speech currents are faithful reproductions of the
variations in strength of the sound waves.

**Examine the Modulator Circuit.**   The microphone cur-
rent flows through the primary of the microphone trans-
former, which steps up the voltage and produces an
alternating current of increased voltage in the secondary
circuit.   These currents in the secondary circuit make the
modulator-tube grid alternately positive and negative.
The C battery keeps a negative bias on the grid to prevent
distortion of the audio-frequency voice current which would

occur if the grid became positive enough to draw current from the filament.

**How the Modulator Tube Operates.** When the modulator grid is positive, a swarm of electrons are pulled from the filament to the plate. These electrons rush to the
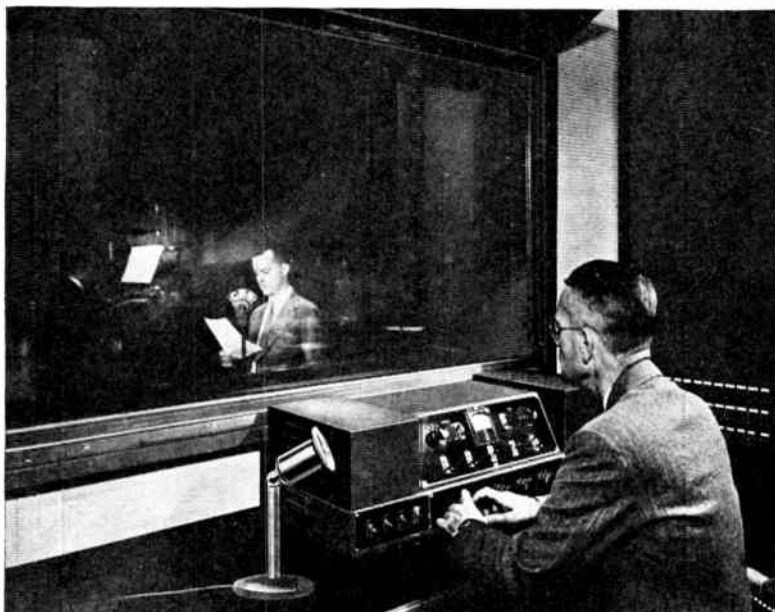
THE ENGINEER IN CHARGE
In the control room the engineer's deft fingers blend music and words from the studio into a pleasing radio program.

30-henry choke on their way to the B battery. But the inductance of the choke slows up the rush of electrons toward the B battery and forces the electrons to flow into other parts of the circuit. Some electrons flow to the plate of the oscillator tube. The effect is the same as if the oscillator plate voltage were cut down. This cuts down the flow of electrons through the oscillator tube and weakens the carrier wave generated by this tube.

But when the grid of the modulator tube becomes negative, few electrons reach the plate, and the current is weakened. The effect on the 30-henry choke is much the same as if the circuit had been broken. When the current flowing through the choke coil is suddenly stopped, the coil makes a powerful effort to get electrons to keep the current flowing. It now can only get electrons from the plate of the oscillator tube. So it adds its pull to the pull of the B battery. This has the effect of increasing the B voltage on the plate of the oscillator tube and now the carrier wave is much stronger.

The inductive pull from the 30-henry choke increases the voltage much over the 135 volts on the plate side of the choke.

This is how the sound waves, striking the microphone, strengthen and weaken the high-frequency carrier wave. This increase and decrease of the strength or amplitude of the carrier is called modulation.

The radio-frequency choke is put into the circuit to prevent the radio-frequency surges of the oscillator from reaching the plate circuit of the modulator tube, where they would interfere with the fidelity of the music or voice.

### Questions

**1.** Does the oscillator in phone sets do the same work that it does in code transmitters?

**2.** Describe the action of a sound wave as it travels through the air.

**3.** Show how the choke coil causes electrons from the modulator tube to pile up on the plate circuit of the oscillator tube.

**4.** When the grid of the modulator tube is negative, show how the choke coil will increase the voltage on the plate of the oscillator tube.

**5.** What is the meaning of the word *modulation?*

**6.** What is the purpose of the radio-frequency choke next to the oscillator plate?

.

### 3. MODULATION

The strong, steady radio-frequency wave set up by the oscillator and the amplifier is shown in Fig. 342. This wave, which is used in radio telegraphy, carries for thousands of miles. The speech currents control or modulate the strength of the radio-frequency carrier wave. When
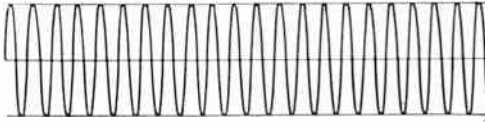


Fig. 342.   Carrier wave.

the speech currents are strong, they make the radio-frequency carrier strong, and when the speech currents are weak they weaken the radio-frequency carrier.

Perfect modulation occurs when the strong speech current doubles the amplitude of the radio-frequency carrier and the weak speech currents entirely cut off the carrier
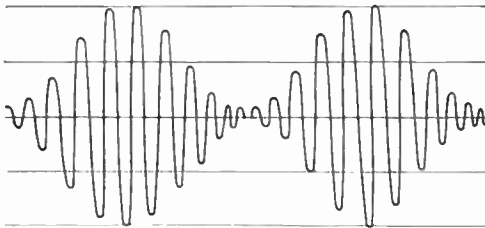


Fig. 343.   Carrier wave, 100% modulated.

wave (see Fig. 343). This is called 100% modulation. Such a signal will be heard clearly at the receiver.

When the modulation is not complete, that is, when the strong parts of the speech waves do not double the carrier current and when the weak parts do not completely cut off the carrier current, we have undermodulation (see Fig. 344). An undermodulated wave is of good tone quality,

but the signal will not carry as far as the 100% modulated wave.

When the voice currents are so strong that they more than double the strength of the carrier wave and when the weak parts of the wave shut off the carrier wave for several
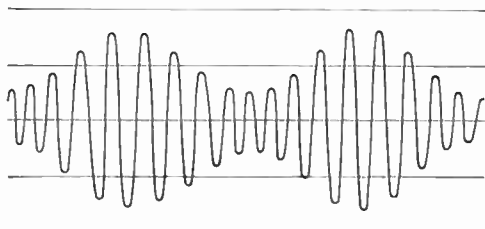


FIG. 344.    Carrier wave, undermodulated.
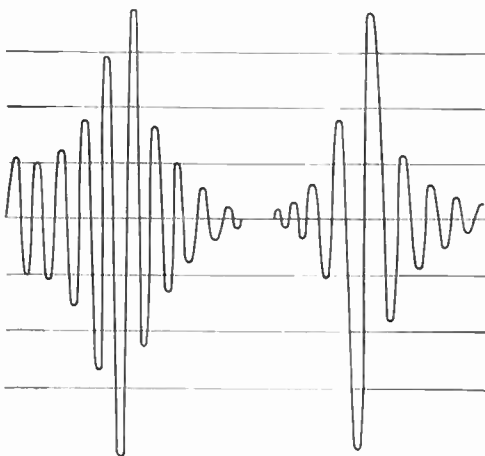


FIG. 345.    Carrier wave, overmodulated.

cycles, we have overmodulation (see Fig. 345).    This signal will carry farther than will a 100% modulated signal, but it is hard to understand.

Overmodulation produces harmonics which distort the music and produce interfering frequencies.    It causes broad

tuning and interferes with other stations.   Hiss, heard at
the receiver, is an indication of overmodulation.

**Side Bands.**   The voice and music frequencies of the
sound waves are combined with the carrier wave during
modulation to form a wave that covers a narrow band of
frequencies equal to the sound frequencies added to the
carrier and the sound frequencies subtracted from the
carrier.   These frequencies added to and subtracted from
the carrier wave are called side-band frequencies.   The
modulated carrier wave must be broad enough to include
the frequencies above and below the carrier if clear, accu-
rate music is to be produced by the receiver.   Without side
bands of at least 5000 cycles width, the fidelity of music is
poor because the high frequencies of the music are cut off.

### Questions

1.  What is meant by 100% modulation?

2.  Is the voice distorted in a set which has 100% modulation?

3.  Can you broadcast satisfactory distances with a set which is
modulating 100%?

4.  What is undermodulation?

5.  Can you send as great distances when the set is undermodulating
as when it is modulating 100%?

6.  Is there distortion in undermodulation?

7.  What is overmodulation?

8.  Can you send as great distances when the set is overmodulating?

9.  Is the voice distorted when it is modulated over 100%?

**Coupling Methods.**   Methods of coupling a modulator
to an oscillator or to an amplifier circuit are shown here.
We shall show only the radio-frequency choke and the wire
from the modulation circuit.   In Fig. 346 and Fig. 347 the
modulator is shown connected directly to the B positive
terminal on the oscillator or amplifier board.

The circuit shown in Fig. 348 has the wire from the
radio-frequency choke connected directly to the plate of
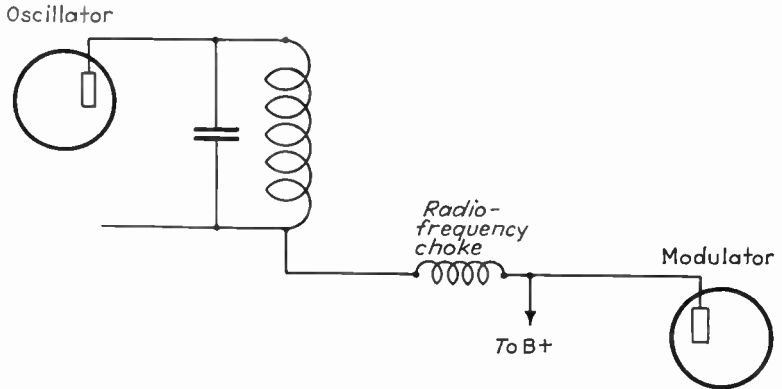
Oscillator



FIG. 346.　Oscillator-modulator coupling; modulator connected to B positive terminal.
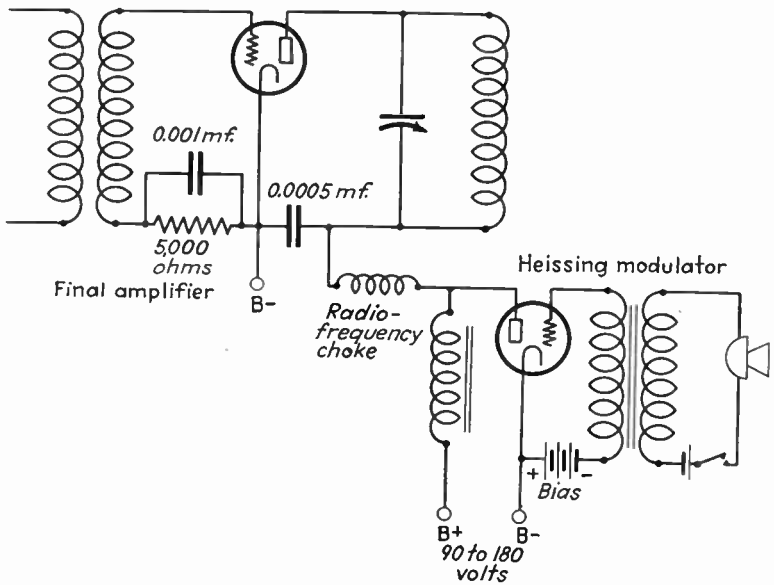


FIG. 347.　Amplifier-modulator coupling; modulator connected to B positive terminal.

the oscillator tube. It is necessary to insert a plate blocking condenser of .0005-microfarad capacity between the plate and the tank coil to prevent the direct current from the power supply from shorting to the ground.
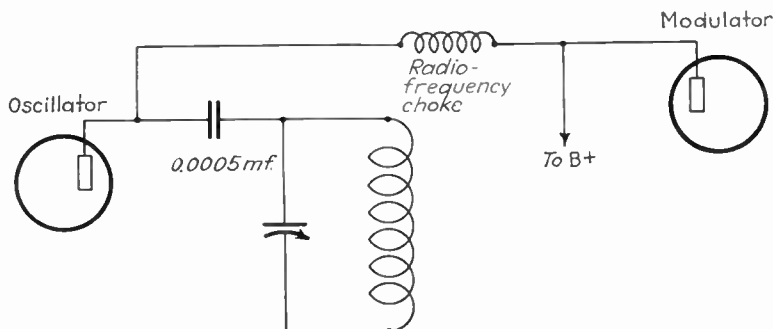


FIG. 348. Oscillator-modulator coupling; modulator connected directly to oscillator plate.

## 4. METHODS OF CONTROLLING MODULATION

### Method 1

**When to Use This Circuit.** A modulation transformer is used in this circuit to match the plate impedance of the tubes used (see Fig. 349). The alternating-current resistance of the primary is selected to be the same as the plate resistance of the modulator tube. The alternating-current resistance of the secondary must be the same as the oscillator plate resistance.

This transformer is more expensive than a choke but produces better modulation.

**How to Change the Circuit Wiring.** Connect a 3:1 modulation transformer in place of the 30-henry choke on the modulator board (see Fig. 349). This is a special transformer to fit the tubes used.

Connect one end of the primary to the modulator plate.

Connect the other ends of the windings together.

**Why It Works.**    If neither the choke nor the transformer
were in this circuit, the B battery would exert the same
pull upon the electrons on both the oscillator and the
modulator plates.    But the purpose of the modulator tube
is to control the pull upon the electrons on the oscillator
plate, modulating or controlling it to fit the variations of
the voice current.    The circuit must be arranged so the
changes in modulator pull can force the plate current to
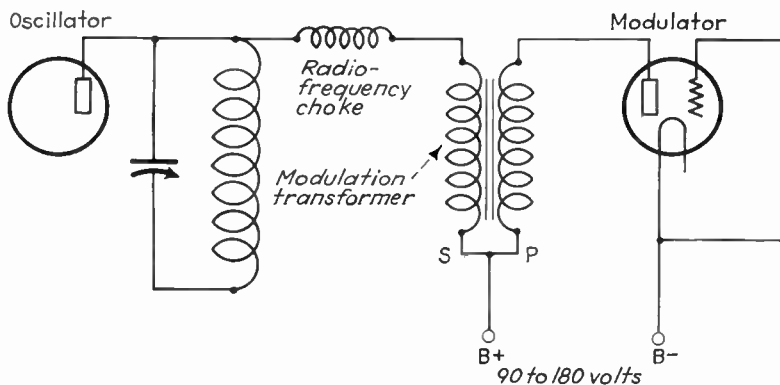


Fig. 349.    Plate modulation, method 1.    This method is used to match tube
impedances.

change.    This can be done if the modulator voltage gains
an advantage in some way over the plate voltage.

When the 30-henry choke was used, its effect on the
current was added to the modulator plate voltage and
gave it the advantage over the oscillator voltage.

In this circuit the step-up in voltage through the modu-
lation transformer supplies the increase in voltage on the
modulator plate needed to control the oscillator plate
current.

When the modulator grid is positive, a large number of
electrons are pulled to the plate.    On their way to the B
battery they rush through the transformer primary.    These

electrons flowing through the primary induce a current of electrons in the secondary but flowing in the opposite direction toward the oscillator plate.

The secondary voltage has three times the drive of the voltage in the primary. But now the secondary drives electrons toward the oscillator plate opposing the pull of the B battery. At this instant the B battery pull is weakened by the interference from the modulator voltage that operates through the 3:1 transformer, and the strength of the carrier wave is cut down.

But when the grid of the modulator tube is negative, the flow of electrons through the tube is cut down and the plate current is weaker. Less current flows through the transformer primary, and less current is induced in the secondary.

A sudden drop in current flowing in the transformer primary will induce a current in the secondary that flows in an opposite direction to the flow when the grid was positive. The secondary now tries to pull electrons off the plate of the oscillator. This makes the plate current stronger, which will increase the amplitude of the carrier at this instant.

The radio-frequency choke keeps the radio-frequency surges in the oscillator circuit out of the modulator circuit. Radio-frequency surges in the modulator circuit cause tubes and other apparatus to burn out, as well as causing distortion in the speech currents.

### Questions

**1.** Explain the action of the modulation transformer.

**2.** In what direction does the current flow in the secondary of the modulation transformer when the current through the primary coil is flowing down?

**3.** Compare the action of the modulation transformer with that of the choke coil.

## Method 2

**When to Use This Circuit.**  In this circuit (Fig. 350), a
resistor and a by-pass condenser are used when the modu-
lation tube is powerful enough to overmodulate the radio-
frequency oscillation of the carrier current.   The resistor
reduces the voltage changes that reach the oscillator plate.
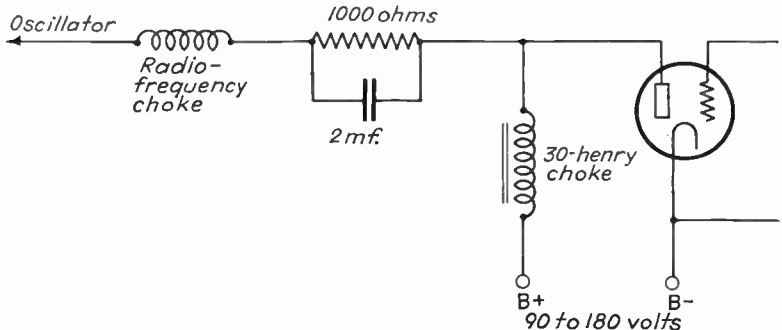


FIG. 350.   Plate modulation, method 2.   Use when overmodulation occurs.

**How to Change Circuit Wiring.**  Connect a 1000-ohm
carbon resistor and a 2-microfarad condenser between the
30-henry choke and the radio-frequency shown in the circuit
in Fig. 350.   Shunt the 2-microfarad condenser across the
resistor as an audio by-pass.

**How It Works.**  When the modulator tube causes too
great a change in voltage on the plate of the oscillator tube,
it will produce overmodulation.

If we put a resistor in the circuit, it reduces the voltage
changes caused by the modulator circuit which cause over-
modulation.   It weakens the effect of the modulator tube
in the oscillator circuit.

Another way to overcome this difficulty is to use either
a more powerful oscillator tube or a less powerful modu-
lator tube.

## Questions

**1.** What is the purpose of the resistor and by-pass condenser in this circuit?

**2.** Why is it necessary to place a by-pass condenser around the resistor?

## Method 3—Grid Modulation

**Where to Use This Circuit.** Grid modulation is used in the final amplifier stages (see Fig. 351). It is an inexpensive method of modulation used on high-power sets.
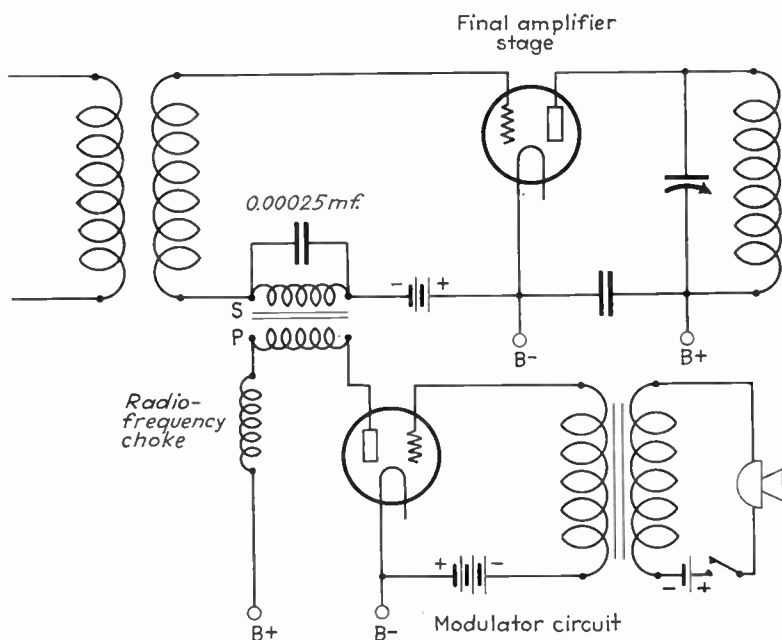


Fig. 351. Grid modulation used in final amplifier stages.

**New Coupling Method.** By connecting the output of the modulator plate circuit to the grid circuit of the oscillator through a transformer, we control the excitation of

the last stage by controlling the flow of electrons on the
grid of the tube.

Plate modulation is more popular for small tubes, while
grid modulation is used almost exclusively for large tubes
and in the higher-powered sets.

**The Modulator and Oscillator.**    This is the same modu-
lator hookup (Heissing) used in earlier experiments.    The
final amplifier stage is the same as that described on pages
465 and 470, except that it must be neutralized.    The  ·
method of coupling the modulator to the final stage is new.

**How to Wire the Set.**    Connect the primary of an audio
transformer in the plate circuit of the modulator tube.
Connect the secondary in the grid circuit of the final
amplifier tube.    The secondary winding must be able to
carry the grid current of the amplifier stage.    Shunt the
secondary by a .00025-microfarad radio-frequency by-pass
condenser.    If it has too high resistance, it will change the
grid bias.    See Fig. 351.

A radio-frequency choke is hooked in the B positive lead
to keep radio-frequency currents out of the power supply
and out of the modulator plate circuit.

Several stages of amplification may be added to increase
the amplitude of the modulated carrier current before
coupling the output of the last stage to the aerial.    The C
bias is furnished by a C battery or by a small power supply.
A bias resistor cannot be used here.

**Why It Works.**    When many electrons flow in the modu-
lator circuit, a strong current flows through the coupling-
transformer primary.    This current induces a current
in the opposite direction through the secondary of the
transformer.

The secondary current draws electrons from the ampli-
fier-tube grid and makes it more positive.    The positive or
electron-hungry grid attracts electrons from the filament

and thus adds to the flow of current through the oscillator tube and strengthens the carrier current at this instant. More carrier current now flows in the aerial.

When the modulator current is weak, few electrons flow, the current through the transformer primary is weakened, and the current induced in the transformer secondary flows in the opposite direction. This forces more electrons on the oscillator grid, and it becomes more negative. The negative grid cuts down the flow of electrons through the oscillator tube, and the plate or carrier current is weakened.

Let us trace the carrier current through this hookup. A strong carrier current is surging into the circuit from the amplifiers at the left of the circuit. The amplitude or strength of the input carrier current is steady. But when you talk into the microphone, it changes the modulator plate current which interferes with the electron flow in the grid circuit of the amplifier. This interference modulates or changes the carrier strength, or amplitude, to fit the amplitude and wave form of the voice wave.

### Questions

1. Does the grid become positive or negative when a strong current flows through the primary of the audio transformer?

2. When the current increases in strength in the primary of the audio transformer, does this increase or decrease the strength of the carrier wave which is broadcast?

# CHAPTER XII

## AERIALS

The aerial has two important jobs to perform in radio transmitting and receiving circuits. Energy from passing radio waves sets up weak radio-frequency currents in the wire of the receiving aerial. These current surges flow through the lead-in wire to the coil of the receiving set. In transmitting equipment the aerial absorbs energy from the oscillating circuit of the transmitter. It then transforms this energy into the effect, which we have called radio waves, that travels through space from the transmitter.

**Types of Aerials.** Many different kinds of aerials have been designed and used both for receiving and for transmitting. We shall describe in this chapter only those types of aerials which will be useful to the student or to the experimenter. All of these aerials are essentially the type of aerial discovered and used by Hertz. The different constructions of aerials and the methods used in suspending them look different but in principle all are the same. The difference is in the method by which energy is fed from the set to the aerial. In this section are described the different constructions for the Hertz aerial as well as the different methods by which the aerial is fed.

**Operation on Harmonics.** Some types of aerials will operate efficiently on only one frequency. If you want to operate on several frequencies, you will have to have an aerial for each frequency. The doublet aerial is an example.

The Marconi aerial, the end-fed Hertz or Zeppelin aerial, and the off-center-fed Hertz operate well on several fre-
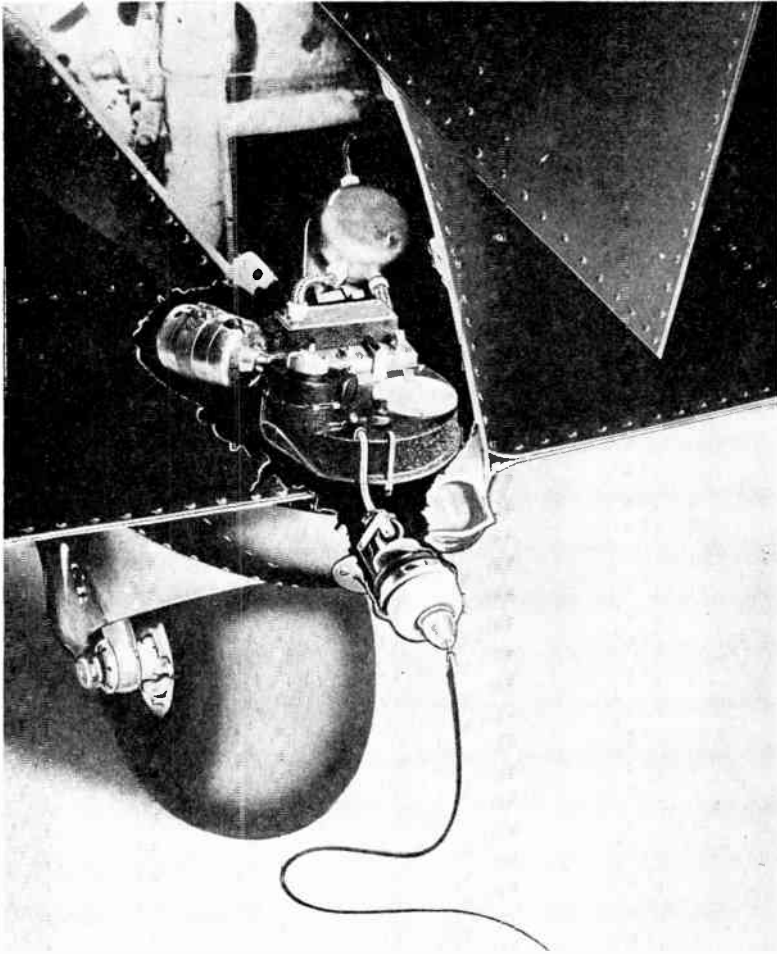
AIRCRAFT ANTENNA REEL

Part of the rear of the plane has been cut away to show how the electrically driven reel controls this aerial. It can be released while the plane is in motion.

quencies.    So one aerial, built for a low frequency, is often
used.    Such an aerial is then operated on higher frequencies,
which are harmonics of the low frequency.

For the advanced experimenter the gain in efficiency by
using separate aerials more than offsets the inconvenience
of building and switching.

### Contents of This Chapter

1. General Construction Information
2. The Fundamental Operating Theory of Aerials
3. The Marconi-type Aerial
4. The End-fed Hertz Half-wave Aerial
5. The Hertz Off-center-fed Aerial
6. The Doublet Aerial

### 1. GENERAL CONSTRUCTION INFORMATION

**For Receiving Aerials.**    Make receiving aerials of size 14
enameled copper wire.    (Hard-drawn copper wire will
stretch less than ordinary soft-drawn wire.    Soft-drawn
wire will stretch enough in heavy wind or ice loads to
effect the operation of the aerial.)    Bare copper wire, when
new, is as efficient as enameled wire; but bare wire will
corrode rapidly when exposed to the air.    On the enameled
wire this corrosion is prevented, and the aerial will remain
in good condition for an indefinite length of time.

Many amateurs use separate receiving doublet aerials,
one for each frequency band on which they wish to receive.
A doublet is inexpensive.    An 80-meter doublet may be
used for the 80-, 40-, 20-, and 10-meter bands, but it is not
as effective as separate aerials.    There is too much loss in
signal volume.

Receiving aerials need insulators at the ends of the aerial
wire and where the lead-in is fastened to a support.    Use
an insulator between the wire and the rope at the ends of

the aerial. In general, the insulator should be long enough
to provide a long leakage path between the wire and the
support. A short corrugated insulator has as long a
leakage path as a longer straight insulator. Glazed
insulators are best. The common glass type of insulator
is satisfactory for receiving aerials.

**For Transmitting Aerials.** Aerials that carry much
power are made of size 12 or size 10 enameled copper wire.
Insulation should be much better than for receiving aerials,
since much higher voltages are used. Either use larger
insulators or string several small insulators together.

**Height of the Aerial.** The aerial should be at least a
half wave length above ground for best efficiency. The
higher aerials are better radiators than the lower aerials.
If the aerial is lower than a half wave length above ground,
interference occurs between the aerial and trees, buildings,
and other surrounding objects.

**Position of the Aerial.** The aerial should be placed at
as great an angle as possible to power lines or wiring in the
house or building near which it is erected. This prevents
unwanted stray currents from being induced in the power
lines and also prevents the receiving aerial from picking up
hum from the power lines. The position in which the
aerial is built has some effect on the direction from which
it will receive and transmit most efficiently.

### Questions

1. Which type of aerial will operate satisfactorily on only one fre-
quency?

2. What types of insulators should be used?

3. What is the minimum distance above the ground that an aerial
should be placed?

4. Describe the best position of the aerial with respect to nearby
power lines.

## 2. THE FUNDAMENTAL OPERATING THEORY OF AERIALS

**Electron Surges in the Receiving Aerial.**  Let us follow
the surges of electrons through a receiving aerial like the
one that we used in Chapter IV (see Fig. 352).  The
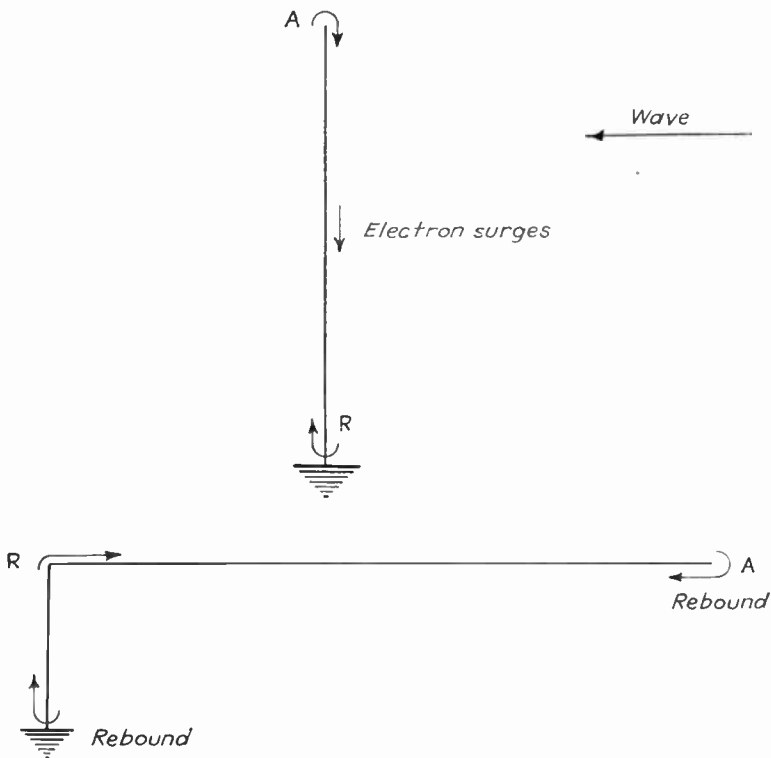


Fig. 352.   Electron surges through a receiving aerial.

receiving set is at $R$, as near the ground as is convenient,
and tuned to radio waves of a certain frequency.   When
a radio wave strikes the receiving aerial wire, it starts a
surge of electrons which flow from $A$ through the wire to
the receiving set at $R$ and on to the ground.   The electron

surge then reflects or rebounds from the ground to the set at *R*, and surges back to the end of the aerial at *A*. When the electron surge arrives at *A*, it again rebounds and surges back through the aerial. At the instant of rebound the next radio wave arrives and starts another surge which gives the first surge a boost.

Some of the power of the first electron surge was lost forcing its way through the aerial wire and against the resistance of the ground, as well as in overcoming the resistance of the receiving coil. This second surge replaces the energy lost by the first surge and builds it up to its former strength. A steady surging or oscillation of electrons through the aerial circuit will continue as long as the radio waves supply energy.

**How Electrons Are Distributed in Each Surge.** The arrows used in this discussion show the direction in which an electron surge travels through the wire. In Chapter II an electron surge was compared to the grouping of a charge of shot flying away from a shotgun (see Fig. 17). At the front of the charge there are few shot. Then the number increases until at the center of the charge there are a great many shot and the grouping tapers off to a few scattered shot at the end of the charge. This is the way we believe an electron surge acts. Only a few electrons are disturbed at the front of the surge, then the disturbance increases until it is very strong, after which it tapers out gradually to the end of the surge.

At the ends of the aerial, where the electrons in the surge can go no further, they crowd together, and the pressure at this point is very great. This is another way of saying that at the ends of the aerial the voltage is greatest and that here no current is flowing while in the center of the aerial, where the electron surges travel swiftly through the wire, there is much current and little or no voltage.

**The Receiving Aerial and the Transmitting Aerial Operate in the Same Way.** Now suppose we replace the receiving set at $R$ with a power oscillator $X$ (see Fig. 353). The oscillator acts as an electron pump. When coupled to the aerial, as explained in Chapter X, this electron pump will set up powerful electron surges through the aerial.

Let us follow a surge through the aerial wire. The aerial shown in Fig. 353 is arranged so that its lower end is connected to the ground and the upper end is free. This aerial is generally seen in the form shown in Fig. 354, since this construction is more convenient to build than the straight aerial. Electrons surge from $X$ to the end of the aerial at $A$. At once a tremendous crowding of electrons occurs at $A$; then their energy forces electrons back through the wire to $X$. This is a half cycle. Electrons now are forced into the ground at $G$ by the oscillator; they rebound and surge back to $X$ again, thus completing the full cycle or one oscillation.
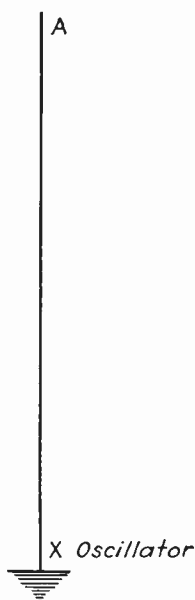
A

X Oscillator
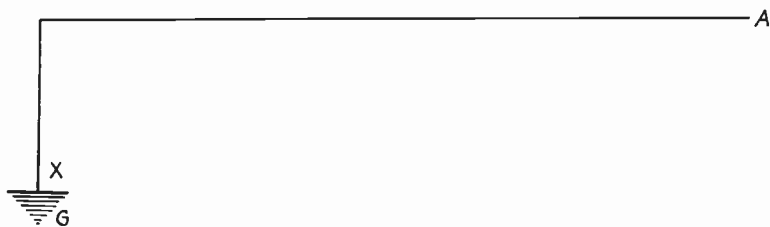
FIG. 353.



FIG. 354.

**What Happens When an Aerial Is Too Long.** Now suppose we watch the action of electrons in an aerial that is too long (see Fig. 355). The oscillator starts electrons

through the aerial. The surge reaches $A'$ and builds up a
pressure. Then it reverses and surges back toward $X'$
again. But the surge reaches $X'$ too late to get the full
help of the oscillator, which has just forced a surge toward
the ground $G'$. The surge will
go to ground $G'$ and start back
toward $X'$.

Just as it reflects back from
$G'$, the second surge collides
with the first surge. The
second surge is stronger than
the first surge, which has trav-
eled twice the length of the
aerial and has lost some of its
energy. Both the first and
second surges lose energy in
trying to oppose each other,
with the result that the total
current left is quite weak.

This, as you will remember,
is what happened when you
unwound the wire on the aerial
reel in Chapter IV. At one
certain length the wire was just
right to receive a station per-
fectly. But when you in-
creased the length a few feet,
the electron surges began to
mix up and oppose each other as they surged through the
aerial. Finally you found a length where the surges were
traveling in opposite directions through the wire and
canceled each other so that you lost this station entirely.

**When the Aerial Length Is Increased Three Times.** Let
us compare the electron surge through this longer aerial to
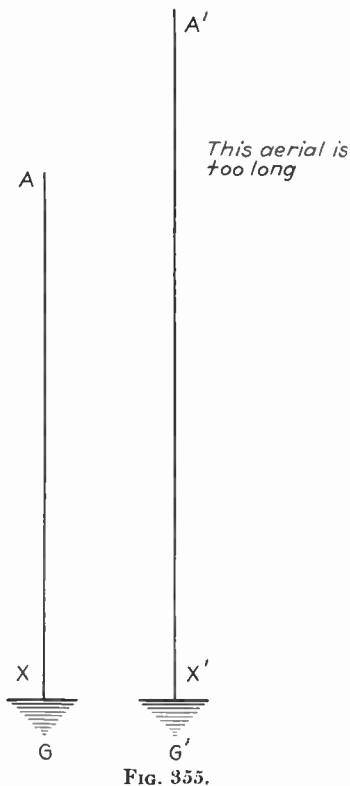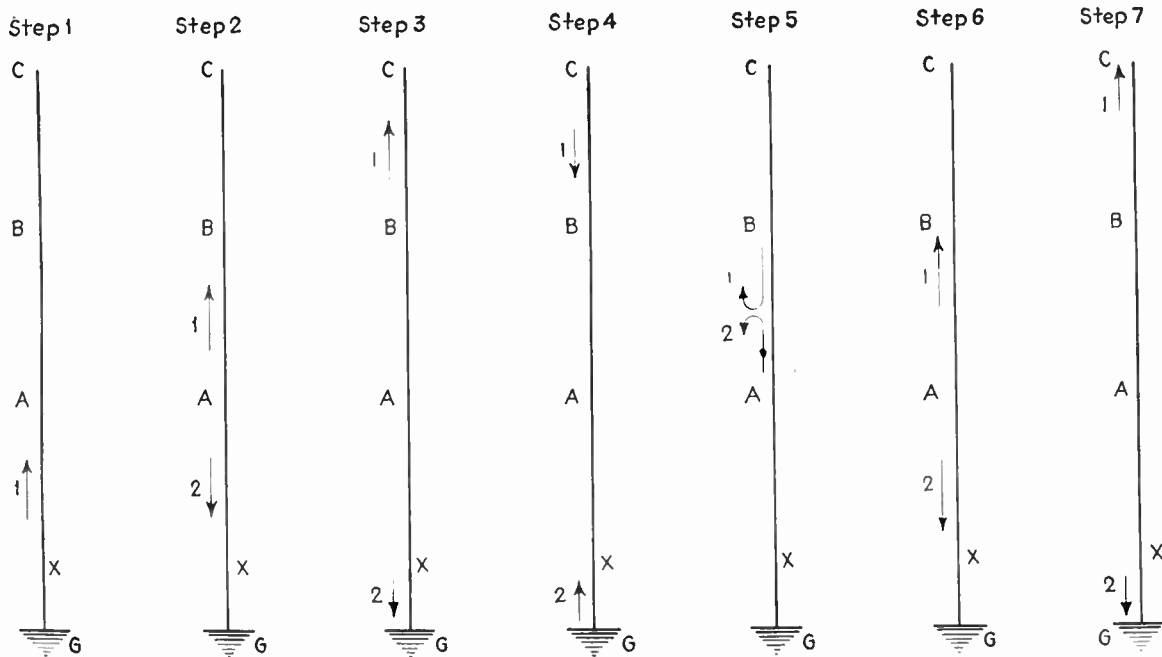
Fig. 355.

FIG. 356. Electron surges in aerial of triple length.

an electron surging through the aerial in Fig. 353. We will do this by diagram (see Fig. 356).

*Step* 1.   The oscillator drives a surge of electrons from *X* toward *A*.   We will call this surge 1.

*Step* 2.   The current in the oscillator reverses direction and starts pulling a new surge (surge 2) toward *X*.   When the oscillator has pulled surge 2 to *X*, surge 1 has reached *B*.

*Step* 3.   The oscillator drives surge 2 to the ground. By now surge 1 has coasted on and reached the end of the aerial at *C*.

*Step* 4.   Surge 1 rebounds from the end of the aerial and starts back toward *X*.   At the same instant surge 2 rebounds and is pulled from *G* by the oscillator.   When surge 2 reaches *X*, surge 1 has returned to *B*.

*Step* 5.   The oscillator drives surge 2 towards *A*, where it meets surge 1.   Surge 2 and surge 1 reach *A* at the same instant, where they collide and repel each other since both are negative.

*Step* 6.   The surges rebound and surge 1 starts back toward *B*.   When surge 1 reaches *B*, surge 2 has coasted back into the pull of the oscillator at *X*.

*Step* 7.   The oscillator now drives surge 2 past *X* into the ground and surge 1 has reached the end of the aerial at *C*.

The surging of electrons continues as outlined for as long as the oscillator furnishes power to the aerial.

**Where the Energy of the Oscillator Is Used.** Energy from the oscillator is used to drive surge 2 into the ground, then on toward *A*.   The energy in surge 2 is used up in driving surge 1 back toward the end of the aerial.   The energy in surge 2 also is used up in rebounding from the ground.

The energy in surge 1, which travels back and forth between *A* and *C* as a radio-frequency oscillation, is

radiated in the form of radio waves into the space around
the aerial. Some of the energy in surge 2 is radiated as
radio waves. A small part of the energy in both surges is
used to overcome the resistance the wire of the aerial has
to the surging of electrons.

Most of the energy from the oscillator is used up in
causing surge 1 to radiate radio waves. The oscillator at
$X$ replaces energy lost by surge 2 in oscillating between $A$
and $G$, as well as in the transfer of energy to surge 1; surge
1, oscillating between $A$ and $C$, must have energy to replace
that lost by surge 1 in radiating waves into the space.

**The Position of the Oscillator Can Be Shifted.** The
position of the oscillator in the aerial wire can be shifted,
and the aerial will oscillate as it did in the aerial in Fig.
353. At certain positions of the oscillator the aerial will
operate most efficiently; that is, it will both absorb much
energy from the oscillator and radiate the largest possible
amount of energy as radio waves. This will be explained
for each aerial type as we study it later.

### Questions

**1.** Why is the voltage high at the end of an aerial?

**2.** Explain why there is much current at the center of the aerial
with little or no voltage.

**3.** When an electron surge is driven by the oscillator out to the end
of the aerial and back, what part of a cycle has it covered?

**4.** Trace the path of an electron surge through a complete cycle.

**5.** Explain why surges interfere with each other when the aerial is a
little too long.

**6.** Explain why the surges reinforce each other when the correct
length of the aerial has been increased three times.

**7.** When the correct aerial length has been increased three times,
does a given surge continue to oscillate between the extreme end of the
aerial and the ground?

**8.** What are the two different ways in which the energy of surge 1
is used up?

### 3. THE MARCONI-TYPE AERIAL

**Advantages.** This aerial is simple to build. Neither its length nor the length of its feeder (the lead-in) is as important as in the Hertz-type aerial. The Marconi is a quarter-wave aerial used mainly on broadcast and ship stations.
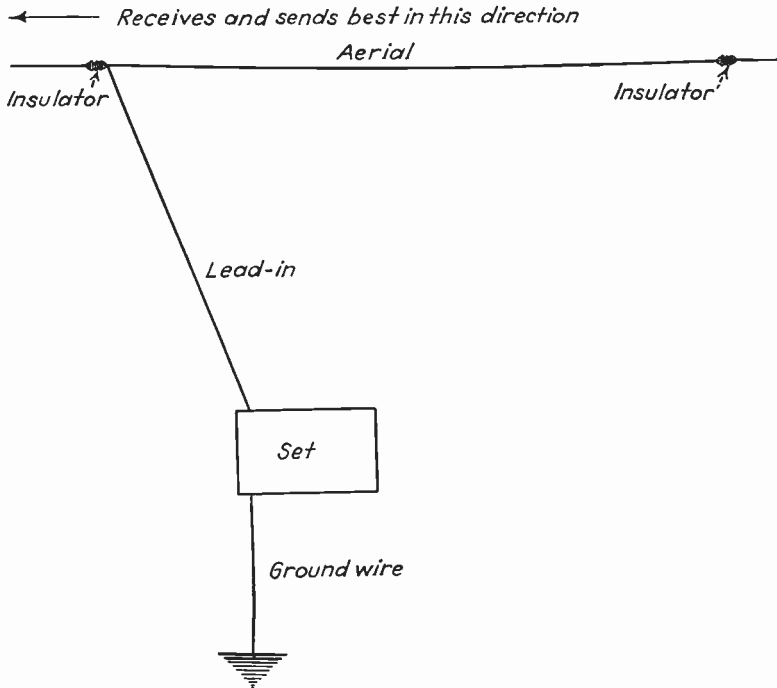


Fig. 357. Marconi aerial.

When dry earth or the location of the station in a building makes it impossible to reach a good ground, a wire called a counterpoise is used to replace the ground. It is also used when there is not enough space for a Hertz-type aerial. The counterpoise is a better conductor than most ground connections and so is more efficient than the ground.

**Disadvantages.** The Marconi is not good as an aerial for short-wave work since you cannot always get it high enough in the air. If you can get it up a half wave above ground, you will find less interference from buildings and other objects. This aerial needs a ground connection which is not always convenient to make.

## How to Build the Aerial

Build the aerial in the form of an inverted L, as in Fig. 357, or in the form of a T. Make the aerial any odd number of quarter wave lengths long.
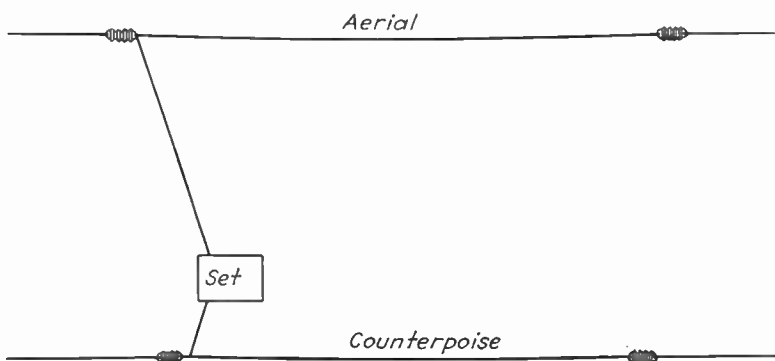


Fig. 358.    Marconi aerial and counterpoise.

Count the ground as one quarter wave. Measure the length of the aerial from the ground to the end of the aerial. The wire from the set to the ground and the lead-in from the aerial to the set are counted as part of the aerial.

Make the counterpoise the same length as the aerial (see Fig. 358). Place it directly under the aerial and well above the ground or other near-by objects.

**The Ground Connection.** A good ground connection must be used with this aerial. Make the ground connection to a ground clamp attached to a cold-water pipe.

Scrape the pipe clean and bright where the clamp is attached.

A 6-foot rod driven into the earth makes a fair ground. This rod has not enough surface to be efficient.

Sheet metal or a copper boiler buried deep enough to be in earth that is always damp makes a good ground. The best ground has a large area in contact with moist earth.

Connect the set in the lead-in wire as near the ground connection as possible. Keep the wire from the set to the ground short and direct. This aerial sends and receives best in a direction opposite to the free end of the wire (see Fig. 357). Build it with this end pointing away from the group of stations you want to receive from and send to.

**Transmitting Aerial.** Use a loop of three turns of wire the same size and diameter as the plate tank coil to couple the aerial to the tank circuit. Arrange the coupling coil at the plate end of the tank coil so it can be moved to change the coupling.

## How to Operate It

This aerial is cut to a convenient length as it is built. So it is not tuned to a special frequency as are the Hertz-type aerials.

It may be operated on a higher frequency by connecting a variable condenser in series with the ground wire (see Fig. 359).

Connect a coil in the lead-in wire if you wish the aerial to operate on a lower frequency (see Fig. 360). A condenser shunted across the aerial coil will also cut down the frequency (see Fig. 361).

**As a Transmitting Aerial.** Read the plate milliammeter before you couple the aerial to the set. Move the aerial coil toward the tank coil to draw more energy from the set. Watch the plate current.

Move the coil toward the tank coil until the plate current rises to about five times what it was before the aerial was coupled to the set.   By still closer coupling more cur-
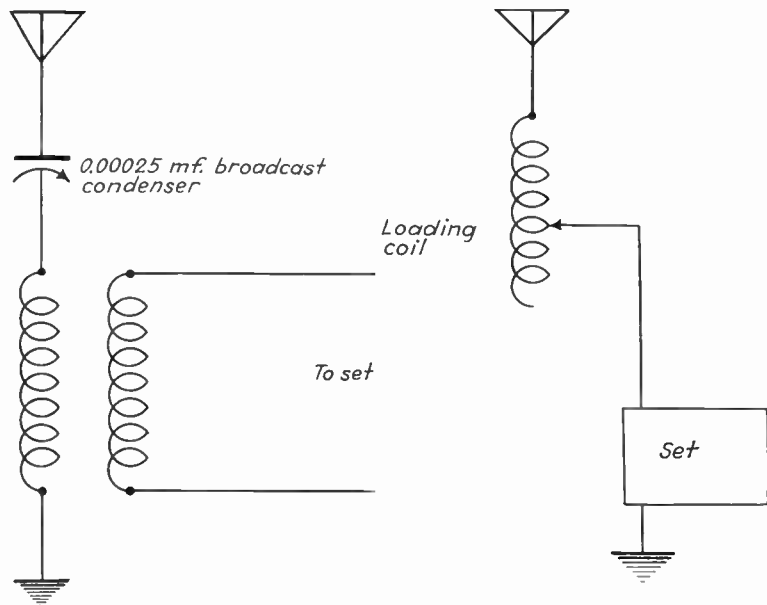


FIG. 359.   Tuning marconi aerial to     FIG. 360.   Tuning marconi aerial for
        higher frequency.                          lower frequency.

rent will be drawn, but the plate of the tube will heat. When the plate heats, the set is operating inefficiently.

## How It Works

See part 2 of this chapter.

### Questions

1. What wave length is the Marconi aerial?

2. Is the Marconi aerial highly satisfactory for short-wave transmission?

## 4. THE END-FED HERTZ HALF-WAVE AERIAL

**Advantages.** This aerial is used when lead-in feeders must be at the end of the aerial on account of the location of the operating room and of the available supports for the ends of the aerial wire.
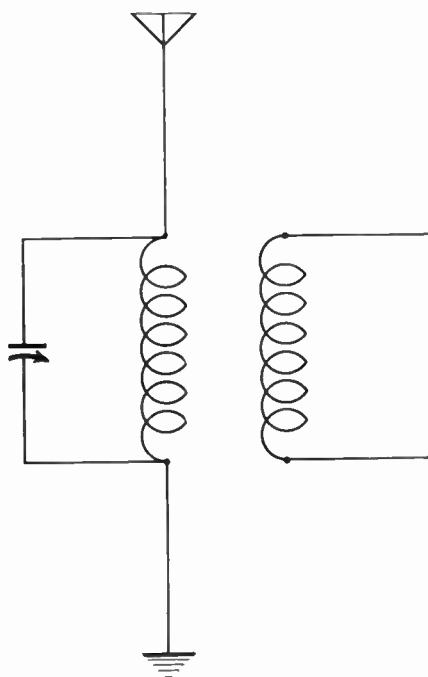


FIG. 361. Another method of tuning marconi aerial to a lower frequency.

**Disadvantages.** The feeders must be tuned to each frequency on which the set operates.

### How to Build the Aerial

The aerial proper is one half wave long (see Fig. 362). Place the insulators as shown in the diagram.

**Feeders.** The feeders are each one quarter wave long. They may also be any odd quarter wave length, as three quarters long, five quarters long, etc. The feeders must be parallel and both the same length.

The spreader insulators (see Fig. 362) may be purchased or may be homemade. Porcelain spreaders are best.
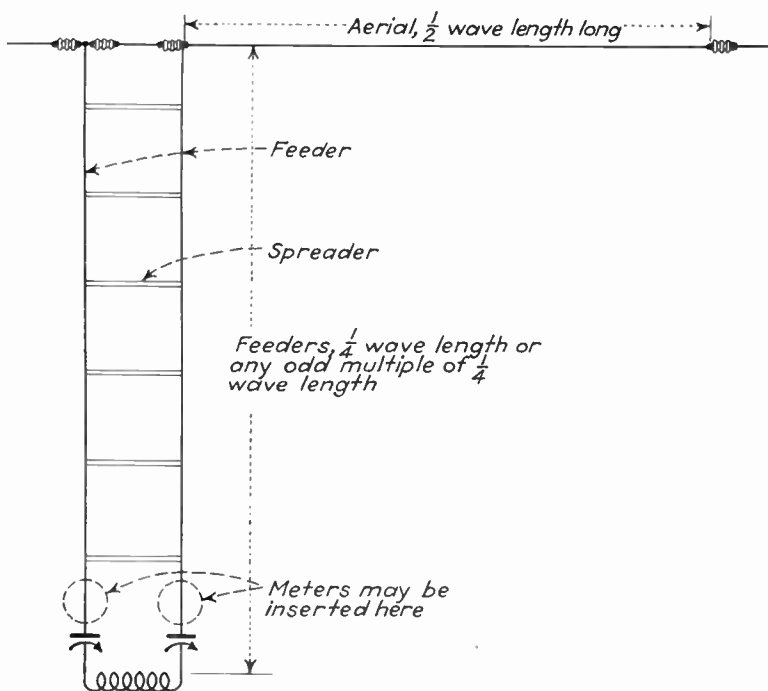


FIG. 362.   Hertz end-fed half-wave aerial.

Maple dowel boiled in paraffin makes satisfactory spreaders. The spreaders should be from 6 inches to 12 inches in length.   This length is not critical.

### How to Operate It

Couple the aerial to the tank coil by an aerial coil of about four turns.

Tune the feeders by means of two 23-plate broadcast variable condensers connected as shown in Fig. 362. Watch the plate milliammeter to see at what setting of the condenser the aerial takes the most power.
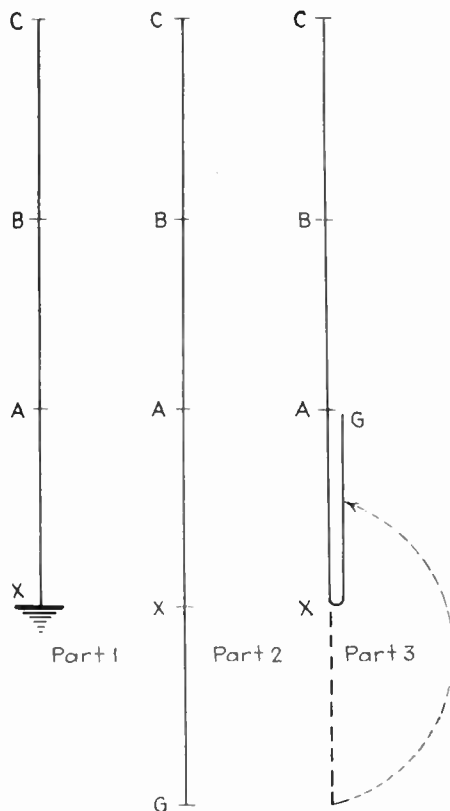


Fig. 363. Hertz end-fed aerial.

A hot-wire radio-frequency ammeter or a thermocouple milliammeter, placed in each feeder wire as shown in dots in Fig. 362, is more accurate than the plate milliammeter for tuning. These meters, however, are quite expensive.

## How It Works

Now, suppose we use the long aerial which was developed in Fig. 356, but substitute a wire one quarter wave long for the ground (see part 1 and part 2, Fig. 363). As shown in part 1, this aerial will operate efficiently with the oscillator connected at $X$. Now suppose that we change the construction of this aerial by folding the part of the wire from $X$ to $G$ back parallel to the wire from $X$ to $A$ (see
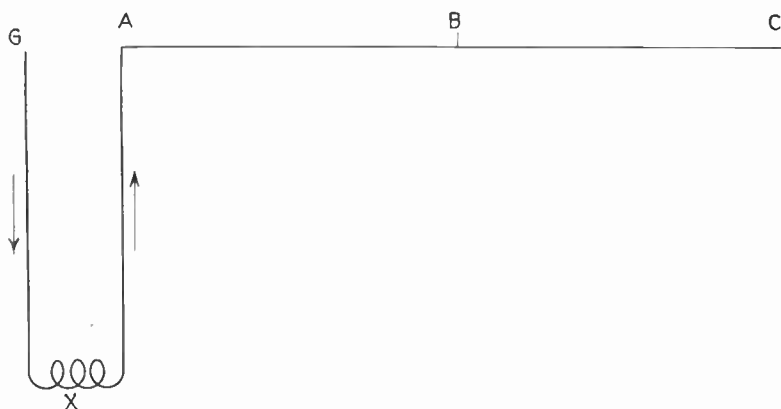


FIG. 364.   Hertz end-fed aerial.

part 3, Fig. 363). Now the part of the wire from $A$ to $C$ will be one half wave long, and we shall call this the radiating part of the aerial. The two parallel wires from $X$ to $G$ and from $X$ to $A$ we shall call feeders. The electrons will surge through this aerial as shown in Fig. 364.

When the oscillator at $X$ drives a surge of electrons through the wire, it is drawing electrons out of $GX$ and forcing them to $XA$. Electron surges build up and continue to surge between $A$ and $C$ as was explained in part 2 of this chapter. Now when the two wires $GX$ and $XA$ are placed side by side, waves set up by one wire oppose and

kill waves from the other wire. The condensers shown in
Fig. 362 adjust the timing of the surges in the feeders so
they are exactly 180° out of phase. This leaves the "flat
top" part of the aerial *AC* to radiate waves without inter-
ference from feeder wires.

### Questions

**1.** Explain why the sections of wire *GX* and *XA* do not radiate radio
waves.

### 5. THE HERTZ OFF-CENTER-FED AERIAL

**Advantages.** This aerial can be built a half wave above
ground conveniently because the length of the feeder is not
important. When placed this high, it will be more efficient
than if it is lower. The angle of radiation of this aerial at
this height is low. When it is used as a transmitting
aerial, the radio waves travel over great distances. The
low angle of radiation means greater skip distance, and
therefore more range for a given amount of transmitting
input power.

The feeder is a single wire which is very simple to
insulate. This aerial probably is the best all-around aerial
for general use.

This aerial is directional at right angles to the length of
the wire. This aerial may be used both with the trans-
mitter and with the receiver. It works well on harmonics,
so the length of the top is cut for the lowest frequency on
which you expect to operate. Then, tuning the trans-
mitter to the different harmonic frequencies gives efficient
operation, using only the one aerial.

## How to Build the Aerial

Use good insulators at both ends of this aerial where the
voltage is highest to prevent losses by leakage. Connect
the feeder exactly 14% of the total length of the aerial

from the center (see Fig. 365). The feeder must run at
least one quarter wave length away from the aerial at right
angles to the wire. This must be done or the feeder will
radiate, and the efficiency of the aerial will be reduced.
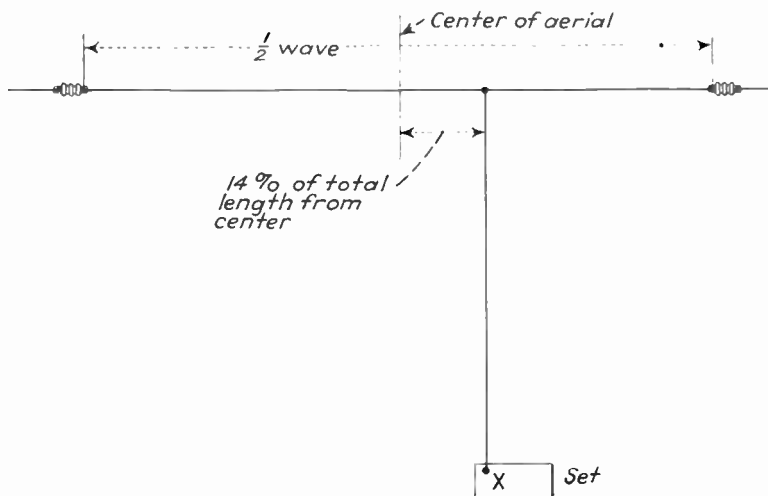


FIG. 365.   Hertz off-center-fed aerial.

## How It Works

This aerial is connected to the oscillator or amplifier
tank coil by means of a small series condenser. The .006-
to .01-microfarad condenser must have a high voltage
rating.

Couple the tap from the condenser to the tank coil about
two turns off the current node on the tank coil. Move
the tap toward the plate end of the coil to increase the
current which the aerial draws from the set. The current
node is at the ground or the filament connection on the
tank coil.

*Step* 1. Tune the set with the aerial disconnected. See
Chapter X for tuning methods. Read the plate current.

*Step* 2. Then connect the aerial and retune the plate condenser until the plate milliammeter shows the aerial is drawing the highest possible current. This should be about five times the current before the aerial was connected. If the tube plate gets red, the aerial is drawing too much current, and the tap must be moved back to decrease the current.

## Why It Works

Let us compare the action of the electron surge in the aerial to the action of a swing. The swing will repre-
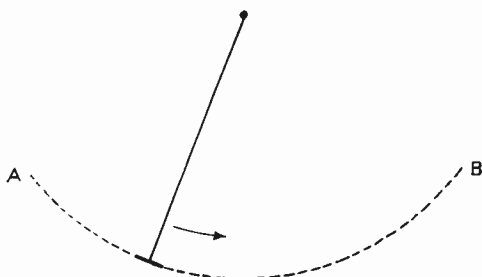


FIG. 366. Off-center feed: aerial action compared to a swing.

sent the aerial, and the person pushing the swing will represent the oscillator (see Fig. 366). The person can stand at *A* and push the swing, or he can stand at any point between *A* and *B* and give the swing a push as it goes by him.

In the aerial shown in Fig. 362 we studied the condition where the driving surges reached the aerial at point *A* as in the swing. We can apply the surges anywhere between *A* and *B* or at any other position along the aerial wire. But we find that there is a point 14% of the length of the aerial from the center point where the aerial operates most efficiently. With the feeder connected at this point, the

aerial will draw the most power from the transmitter and will oscillate most efficiently.

## Questions

1. Is this a good aerial for distance?
2. Does it have great or small skip distance?
3. At what angle to the wire is this aerial directional?
4. Does this aerial work well on harmonics?
5. Is it possible to maintain an oscillation in an aerial regardless of where the driving current is applied on the wire?

### 6. THE DOUBLET AERIAL

**Advantages.** This aerial is particularly good for receiving; it picks up less noise than other kinds of aerials. The same aerial may also be used for low- and medium-power transmitters. This aerial is directive at right angles to its length.

**Disadvantages.** This is a tuned aerial which operates only on one particular frequency. It operates poorly on harmonics. For amateur use, several doublets are put up, one for each frequency on which the receiver will operate.

The several doublets can be fairly close together but not parallel.

## How to Build the Aerial

Cut each half of the aerial accurately to a quarter wave length for the desired frequency. Place an insulator at each end of the wire and two insulators at the center. The two insulators at the center are spaced so the ends of the aerial wire are exactly 12 inches apart.

This aerial should be 30 feet or higher above ground.

**The Feeder.** Use two wires twisted together (as is ordinary drop cord) for the feeder. You may use special feeder wire, weatherproof telephone wire that is in the form of a twisted pair, or ordinary size 14 weatherproof rubber-insulated wire.
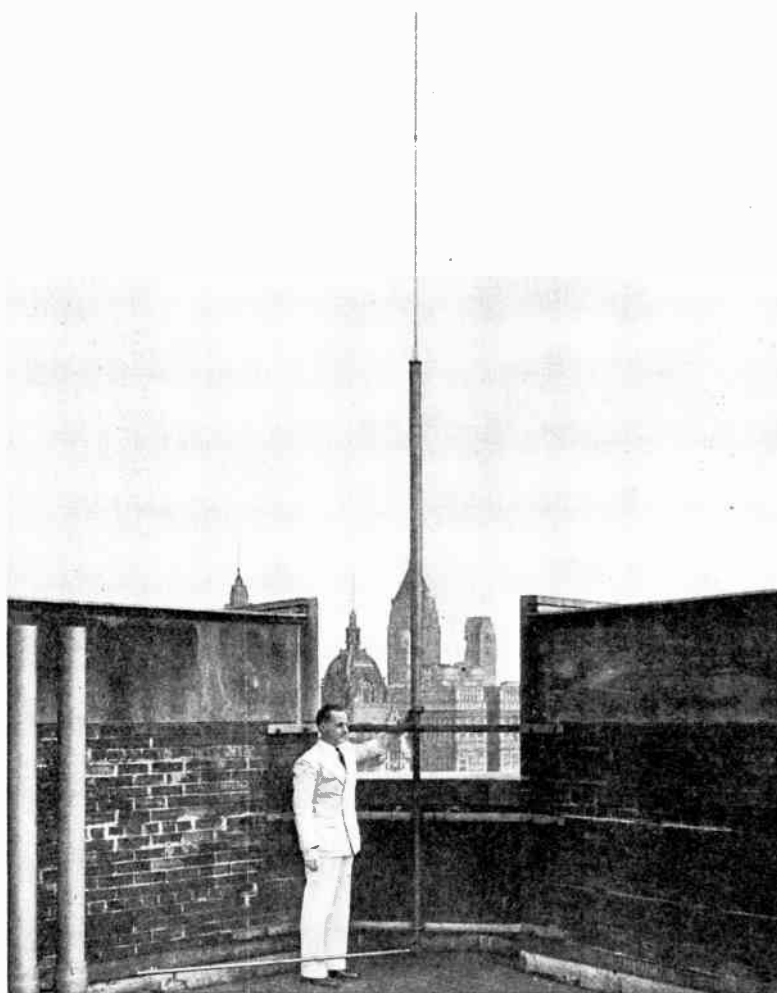
ULTRA-HIGH FREQUENCY COAXIAL ANTENNA
This is a special type of coaxial aerial which has been developed for use in police
radio work.

The efficiency of this type of aerial depends on the feeder. The size and spacing of the wires affect the resistance of the feeders to the alternating current surges. The special feeder wire is designed to be efficient. The telephone wire is a good substitute. The size 14 weatherproof wire is probably the poorest to use. You cannot give it a twist
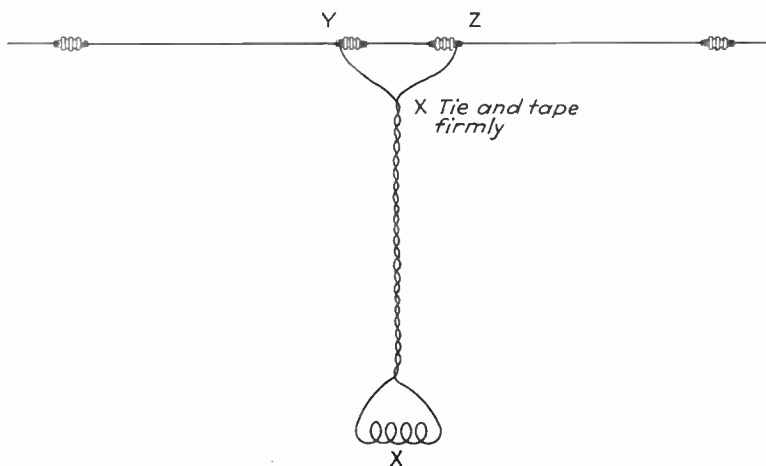


FIG. 367. Doublet aerial.

as good as the machine job done on the other two forms, and it loses efficiency from weathering.

Spread the ends of the wire, tie and tape firmly at $X$ and splice to the aerial at the two center insulators at $Y$ and $Z$ (see Fig. 367). Make the length from the tie at $X$ exactly 12 inches to the attachment of each wire at $Y$ and at $Z$.

## How It Works

The oscillator is coupled to the feeder by the coupling coil $X$ as shown in Fig. 367. If the aerial were a straight wire, as in Fig. 368, the surges would travel from $A$ to $B$, from $B$ to $C$, and back.

If we were to cut this wire in two and connect feeders from the coupling coil at $X$, it would still oscillate in a similar manner. At the instant the oscillator drives a surge into one feeder wire, it is drawing electrons from the other feeder wire. At any point along the feeder, electrons

A               B                 C
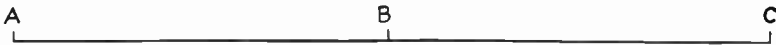
Fig. 368.

are traveling in opposite directions, so the radiation from one feeder is canceled by the radiation of the other feeder. At any instant electrons are being drawn to one of the feeders and are being forced out at the other end. The aerial shown in Fig. 369 is the same as the aerial in Fig. 368, except that the one is cut at the center. A surge
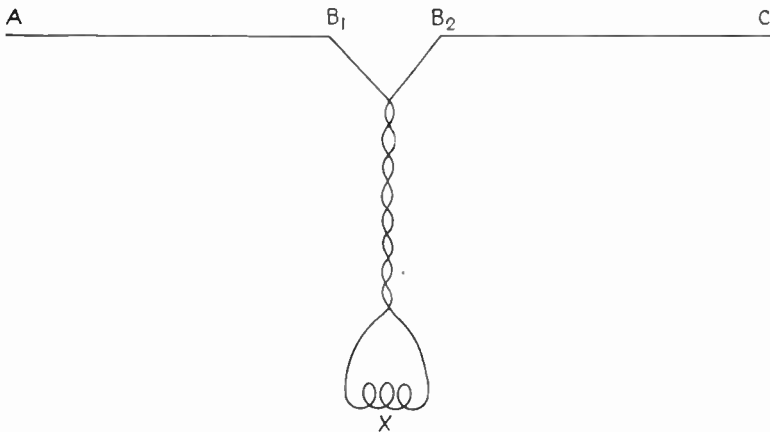


Fig. 369. Doublet aerial, simplified.

starting at $A$ in the aerial shown in Fig. 368 will travel to $B$ and then will travel on to $C$. Here it will reverse and return to $B$ and then to $A$. The action of the surges on this aerial is the same as the action of the doublet aerial in Fig. 367.

The surge which starts at $A$ arrives at $B_1$ at just the instant a surge through the feeder arrives at $B_2$ (see Fig. 369). The feeder pulls the surge at $B_1$ off and drives another surge on to the aerial at $B_2$. The surge at $B_2$ starts on toward $C$. When the surge at $C$ returns to $B_2$, the feeder pulls it toward $X$ and at the same instant drives the surge from the feeder to $B_1$, where it travels on toward $A$.

In effect the doublet shown in Fig. 369 oscillates in exactly the same manner as the half-wave aerial in Fig. 368.

There are several standard constructions of the feeder which are designed to reduce interference to the current flow for better efficiency. The ends of the feeder are spread at $X$ for better efficiency. This will prevent heating if the aerial is used on a medium-power transmitter.

### Questions

**1.** Compare the current flow in a doublet aerial to the current in the straight half-wave type.

**2.** Is the feeder to the doublet an application of the statement that an aerial will oscillate regardless of the point at which it is fed?

**3.** Show how the current in one wire of the feeder will kill any radiation from the other feeder wire.

# CHAPTER XIII

## ULTRASHORT-WAVE SETS

For years little could be done with wave lengths shorter than 10 meters. Sets operating on 10 meters were hard to get into operation and were erratic during operation. Only the more skillful and experienced operators could get the sets to work. The wave lengths below 10 meters (frequencies above 28,000 kilocycles) were thought to be useless, and little operating was done on these frequencies. But after much experimenting, it was found that these higher frequencies could be used for certain classes of service. The frequencies of above 28,000 kilocycles, also written as 28 megacycles or 10 meters, are called the ultrahigh frequencies. The waves sent out by aerials on these frequencies seem to travel best for short distances. These waves do not, as a general rule, follow the curvature of the earth. Since these waves die out very rapidly, it is possible to install many sets in the community for crosstown and short-distance operation without causing serious interference.

The ultrashort waves act like light waves. They travel in a straight line, and they are stopped by trees, hills, buildings, etc. The range of these sets can be increased by placing the transmitting equipment on hills, mountains, etc., where there is little interference by other hills, by trees, or by buildings with the direct line between the sending and receiving stations. The curvature of the earth also seems to prevent these waves from traveling far.

A new type of receiver must be used for ultrashort waves. This is called a super-regenerative receiver. The small size of the coils and condensers makes possible construction of complete transmitting and receiving equipment in a small box. Transmitting circuits follow the standard types with which we are familiar, since the Hartley, the push-pull, and the tuned-plate–tuned-grid circuits work quite well on the high frequencies.

### Contents of This Chapter

### 1. CONSTRUCTION PECULIARITIES

Wiring in ultrashort-wave sets is very important. There is about a foot of wire in the tuning coils for a 5-meter set. The most noticeable thing about the 5-meter sets is their size. The tuning coils and the condenser are smaller than a tube. The tiny coils must contain the working inductance to make the set oscillate at the proper frequency. If the wires between the tube, condensers, resistors, and coils are too long, they have an effect on the coil frequency. An ordinary lead in a broadcast or short-wave set may be as long as all of the wire in an ultrashort-wave coil. Therefore, all connecting leads must be as short as possible.

The parts must be mounted closely together so the wires can be short. Watch, especially, the wires of the oscillating plate circuit and the grid tuning coil. But since the receiver is in constant oscillation, other connection wires will oscillate and interfere with reception. Often a set which does not superregenerate will work well if filament leads are cut an inch shorter.

**Set Insulation.** Ultrahigh-frequency currents have a greater tendency to leak across insulation than do the lower frequencies. Bakelite strips for insulation and bakelite tube bases will blister and burn and form a conducting path between the tube base prongs. Two hacksaw cuts in the tube base prevent this (see Fig. 370).

Tubes and sockets for the ultrashort-wave work are made of porcelainlike material across which ultrahigh-frequency currents will not leak. Isolantite is the trade name of one such material.



Fig. 370. Ultra-high-frequency insulation. Saw tube base to prevent ultrahigh-frequency leakage across tube base.

### 2. A TUNED-PLATE–TUNED-GRID OSCILLATOR

## How to Build and Wire It

**The Tubes.** Use two type 45 tubes.

**The Baseboard.** Use the small-sized baseboard for this experiment.

**Position of the Parts.** Place the parts for the transmitter, the alternating-current step-up power transformer, and the on-and-off switch on the same board.

Mount the two four-prong sockets on a bakelite or wood strip 2 inches above the board (see Fig. 371).

Mount the two-plate tank condenser on a bakelite strip screwed to the front of the board or to a block fastened on a board.

**The Coils.** Make the plate and grid coils the same size. Wind each coil of six turns of size 14 or 16 enameled wire on a $\frac{3}{8}$-inch wooden dowel. Remove the dowel when the coil is completed.

Space the turns evenly so the coil is $\frac{3}{4}$ inch long. Leave about 2 inches of wire on each end of the coil.

The **Radio-frequency Chokes.** Wind two radio-frequency chokes on a $\frac{1}{4}$-inch dowel. Use 15 to 20 turns of size 28 or 30 double cotton-covered or enameled wire. Remove the dowel. The coils will hold their form.

The **Grid Leak.** This may be a Bradleystat which has over 50,000 ohms resistance.

**How to Wire the Set.** Bend the wires on the ends of the plate and grid coil to fit the plate and grid terminals
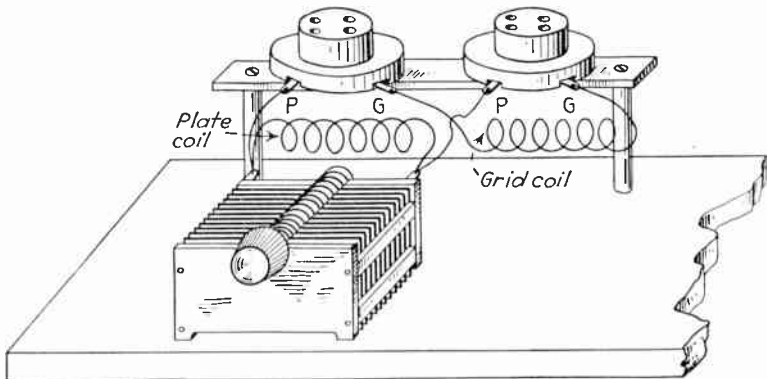


Fig. 371. Tuned-plate–tuned-grid oscillator for ultrahigh frequencies. Only part of circuit is shown.

on the sockets (see Fig. 372). Arrange these coils so that they are as close to the sockets as they can be placed without touching. It is highly important that the length of all wires in the circuit be kept as short as possible. Solder the plate tank coil to the connection lugs on the tuning condenser. Cut the wires on the end of the coil as short as they can be arranged. Remember that the wire in the coil is more important than the connecting wire; but the connecting wires affect the frequency at which the set will oscillate.

Connect the two radio-frequency chokes in the circuit, as shown in Fig. 372. Keep the wires to the power transformer as short as possible.
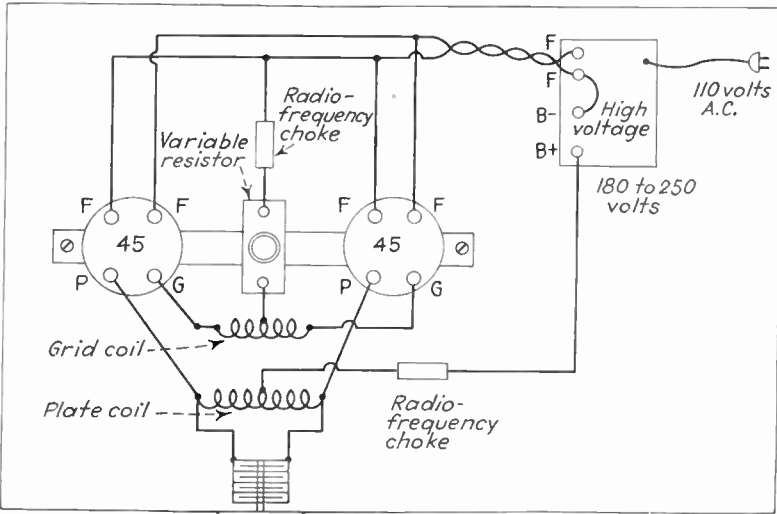
Fig. 372. Ultrahigh-frequency oscillator board.
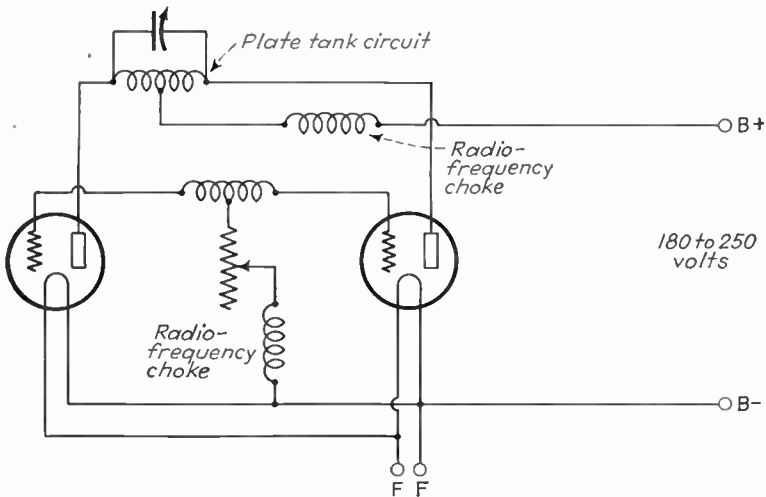


Fig. 373. Ultrahigh-frequency oscillator circuit.

Solder a wire to the center of each coil, as shown in Fig. 373. Try to find the exact center for this connection.

Connect the wires from the secondary of the power transformer to the B negative and B positive terminals. If ordinary type 45 tubes are to be used, it will be well to saw slots in the tube bases as shown in Fig. 370 to prevent leakage of high-frequency current across the bakelite.

**Caution!** Do all wiring and soldering with rosin-core solder. Acid-core solder or soldering flux is a good conductor of high-frequency alternating-current, and you will get enough leakage through flux smeared on the surface of the bakelite to interfere badly with the operation of the set.

### Questions

**1.** Compare the length of connector wires on ultrashort-wave sets with the length of the same type of connections on broadcast sets.

**2.** Also compare the insulators and tube bases on ultrashort-wave sets with those on other sets.

### 3. HOW TO USE LECHER WIRES FOR MEASURING WAVE LENGTH

## How to Build and Wire the Set

Stretch two No. 18 bare copper wires between supports (see Fig. 374). Place an insulator at each end of each wire.
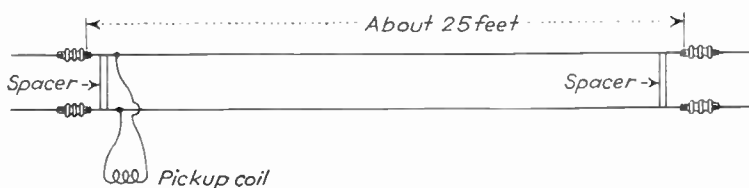


Fig. 374.　Lecher wires used for tuning ultrashort-wave oscillator.

Space the wires $2\frac{1}{2}$ inches apart. Make the spacer out of dry pine or a piece of bakelite. Make a saw cut in the ends of each spacer (see Fig. 375). Slip the spacers between the wires at the insulators. The wires must be accurately

spaced to operate correctly. Cut a piece of pushback con-
nection wire 3 feet long. Wind a three-turn coupling
coil in the center of the pushback wire; make the coil $\frac{1}{2}$ inch
in diameter. Solder the ends of this pushback wire to each
Lecher wire at the insulator (see Fig. 374).
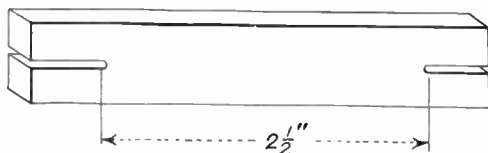


FIG. 375.  Spacer.

Make a shorting bar of bare copper wire, size 18 or larger.
Form the ends of this wire into loops (see Fig. 376). The
shorting bar must be arranged so that it will slide along
the Lecher wires and will keep the spacing of the wires the
same at all times.

## How to Operate It



FIG. 376.  Shoring bar.

Turn on the ultrashort-
wave oscillator current. Place an accurate milliammeter
in the plate circuit of the oscillator. Place the pickup
coupling loop near the oscillator coil and thread its turns in
between the turns of the coils. Place the shorting bar across
the two Lecher wires at the insulators.

Use a yardstick or a piece of dry wood at least 2 feet
long to slide the shorting bar down the Lecher wires.
Slide the shorting bar slowly along the wires until the
milliammeter shows a sharp dip. The dip occurs at half-
wave distances along the wire.

Move the shorting bar back and forth until you have
accurately determined the position at which the meter
showed the dip. Mark this point with a piece of string
tied around the wires. Now slide the shorting bar on out
the Lecher wire until a second point is found where the

meter shows a sharp drop in plate current. Find the position of this point quite accurately as before and mark with a string. These are node points. If you have sufficient space and wire, make the Lecher wires long enough for a full wave length. If the Lecher wire is long enough, slide the shorting bar on until you find a third position where the meter shows a sharp drop in the plate current. You may find the position near the end of the wires where there seems to be a drop in plate current weaker than before. This is a point where the wave has been reflected back from the ends of the wires and should be disregarded.

## How to Determine the Aerial Length and the Frequency

Measure the distance between the nodal points where the meter shows a sharp drop in plate current. The distance between two of these points is equal to one-half the length on which the oscillator is operating. This will be the length of the aerial which you use for this transmitter. To find the wave length, measure the distance between the strings accurately and multiply by two. If your Lecher wires are long enough, measure the distance between the first and third strings. This is a full wave length.

### Questions

1. Why is it necessary to use rosin-core solder on ultrashort-wave sets?

2. What fraction of a wave length is the distance between two spots on the Lecher wire where the meter reading dropped?

3. How can you locate the reflected waves on the Lecher wire?

#### 4. THE SUPER-REGENERATIVE RECEIVER

## How to Build and Wire It

Mount this receiver on the small-sized baseboard. Mount a type 27 tube socket, five-prong, on a piece of bakelite set in the middle of the circuit board (see Fig.
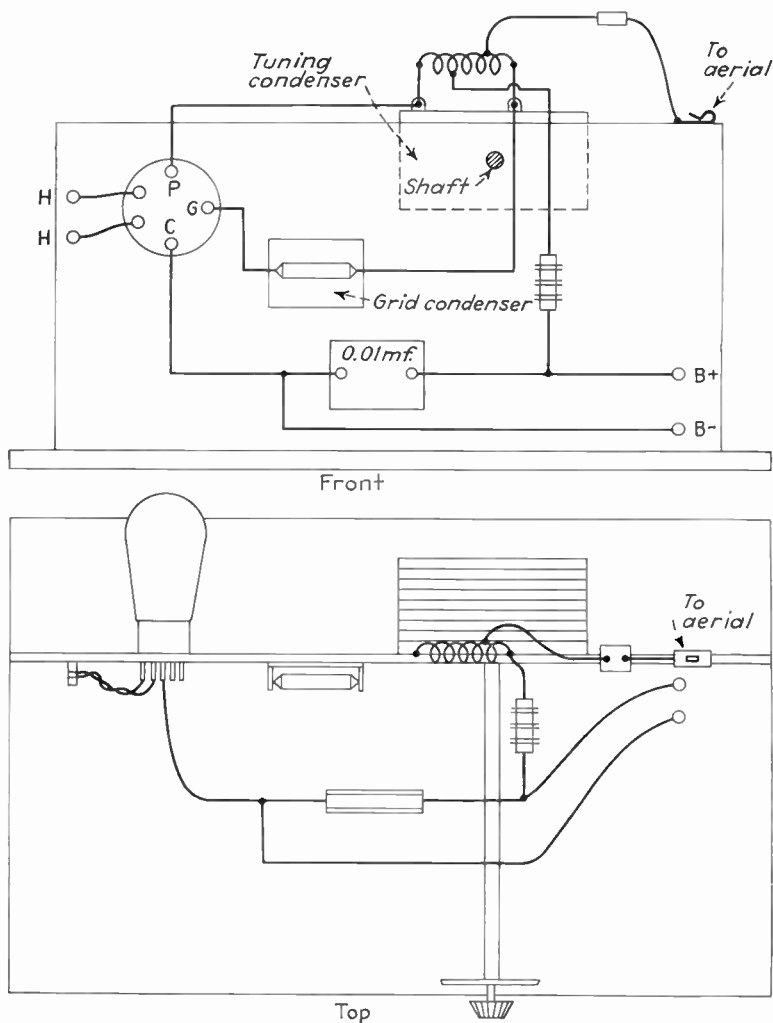
FIG. 377. Super-regenerative receiver.

377). Mount a three-plate midget variable condenser on the bakelite frame as near as possible to the tube socket. Set the tube socket so that the plate and grid connection are close to the condenser. Make a coil of nine turns of size 14 enameled wire wound on a $\frac{1}{2}$-inch dowel. Space the wires of the coil a distance as great as the wire diameter. Leave about 2 inches of wire on the ends of the coil.
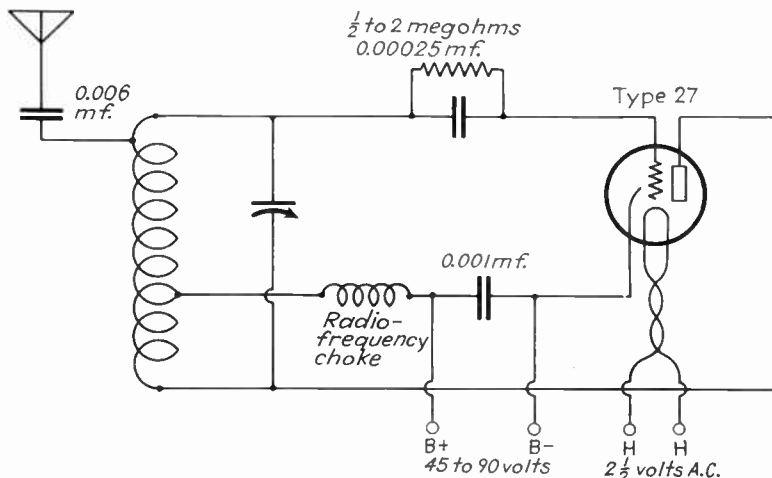


Fig. 378. Super-regenerative receiver circuit.

Mount the coil directly on the connection lugs of the tuning condenser. The wires from the ends of the coil to the lugs should be as short as you can make them. An extra inch of wire in this circuit will make the wave length to which this tiny tank circuit will tune far too low. All other leads, including leads in the filament and plate tank circuit, must also be kept short, for they all affect the operation of this set.

Use only rosin-core solder for making joints. Soldering paste is a conductor for ultrahigh-frequency currents and should not be used.

Connect an extension handle to the shaft of the midget condenser. This extension handle should be of bakelite or wood long enough to extend to the front of the baseboard. This will keep the hand far enough from the set to prevent tuning effects due to body capacity. Take one plate off the midget variable condenser so its capacity will be reduced enough to permit the set to operate on 5 meters. Connect a receiving-type radio-frequency choke as shown in the circuit in Fig. 378. Use a by-pass condenser of .001-microfarad capacity across the B positive and B negative leads. Use a grid leak and condenser, the condenser .00025-microfarad capacity and the grid leak of from $\frac{1}{2}$ to 2 megohms resistance. Connect the aerial to a point somewhere near the grid end of this coil through a .006-microfarad series condenser.

## How to Operate It

The operation of this set is very simple. With the filament hot and the B voltage on, the set will go into super-regeneration at once. If the set does not super-regenerate, you will find some fault in the circuit.

**B Voltage.** Try changing the B voltage until you find a voltage at which your set will super-regenerate over the entire tuning range of the condenser. This should be somewhere around 90 volts. Check the circuit carefully to see that the set has been properly wired. Try a different-sized grid leak. A grid leak of comparatively low resistance must be used in this circuit. Try values from 4 megohms to 50,000 ohms until one is found which will cause the set to super-regenerate evenly. Super-regeneration produces a steady strong hiss in the receiver. If no hiss is present, the set is not operating correctly. You will find that the hiss stops as you tune the set to resonance with the signals you wish to hear.
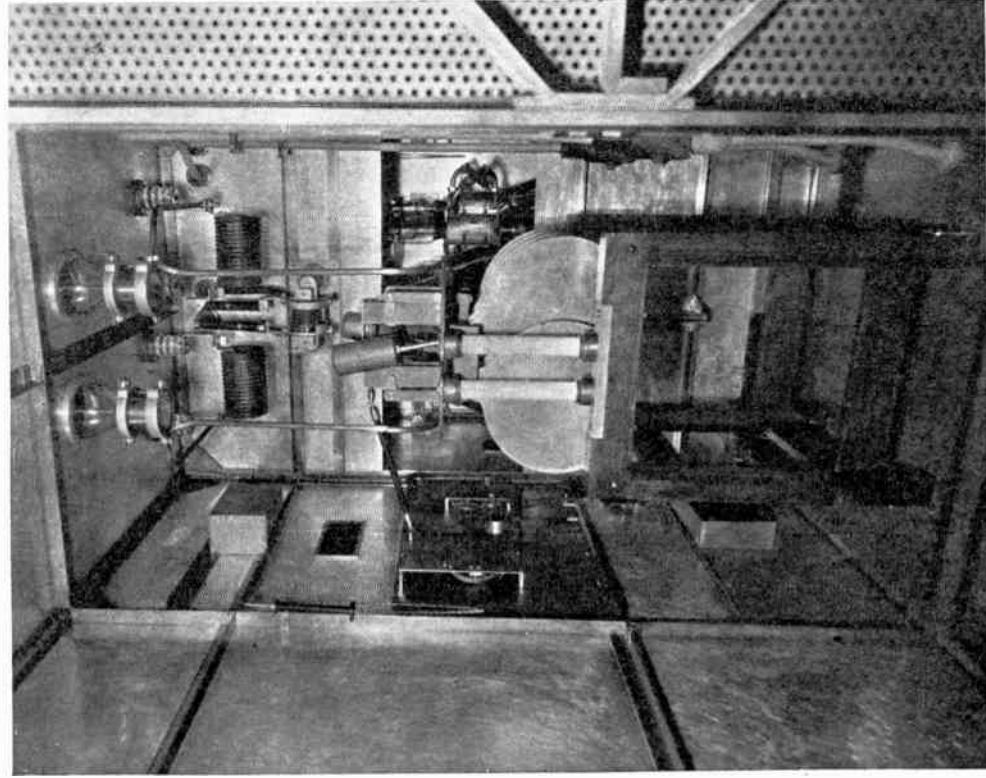
Courtesy Pacific Telephone and Telegraph Co.

CONDENSER PLATES OF THE TRANSPACIFIC TRANSMITTER

Each of these plates is 14 inches in diameter and about half an inch in thickness.

See if any soldering paste or flux has melted and run down the soldering lugs onto the insulation on any of the parts. Ultrahigh-frequency currents follow this flux as if it were a piece of wire. It is common to find that this set will not operate because paste flux has been used and has run across the insulation, shorting out parts of the circuit.

You may also find that changing the size of the aerial coupling condenser will allow the set to go into super-regeneration.

### Questions

1. How do you know when the set is super-regenerating?

2. What are some ways for correcting the trouble when the set will not super-regenerate?

## Why It Works

The regenerative type of receiver which we have used both in the long-wave and short-wave receiving circuits is extremely sensitive. Its sensitivity is brought about by feeding back energy from the plate circuit to the grid circuit. You will remember that the set is most sensitive when adjusted just below the oscillation point. Here the signals are clearest and loudest; when you try to increase the volume still more, the set pops into oscillation and the signals become distorted. The nearer you can adjust your set to the oscillation point, the more sensitive your set will be.

**The Sensitivity Curve.** Let us draw a curve which shows the sensitivity of the receiver by a line. We shall use the setting of our regeneration-control condenser as one base line and the sensitivity of the set as the other base line. See the curve in Fig. 379. You will notice that when you turn the control from 0 to about 40 there is very little sensitivity in your set. The height above the sensitivity

line shows how sensitive this set is at any setting of the condenser. When the curve is near the base line, the set is not sensitive. When the curve rises, it means that the sensitivity of the set is increasing. If the curve goes up steeply, it means that very little motion of the regeneration-control dial is increasing the sensitivity very rapidly. You will notice that between 40 and 60 the sensitivity increases
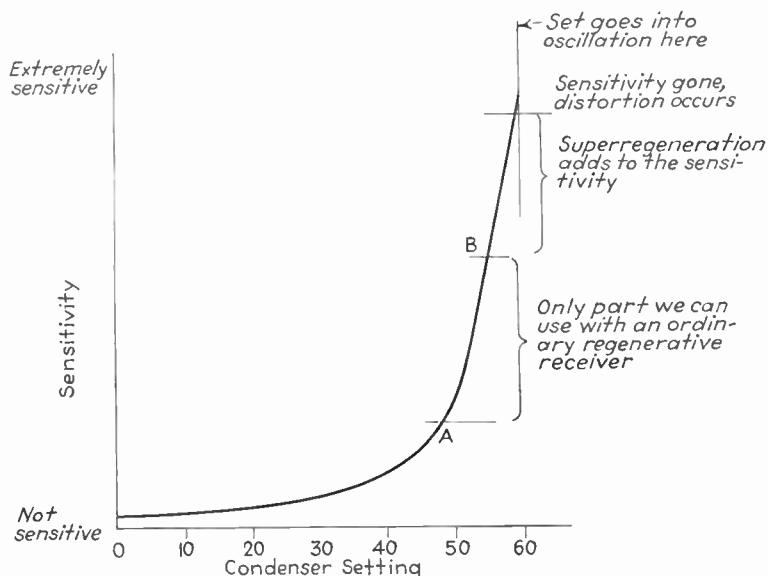


FIG. 379. Sensitivity curve of super-regenerative receiver.

with extreme rapidity and that at about 60 the smallest adjustment you can make on the condenser will throw the set into oscillation.

The part of this curve between the lines *A* and *B* is the part you can use with the ordinary regenerative circuit. You will notice that you are able to use only a part of the sensitivity of this set because it will go into oscillation. You cannot adjust the set by the mechanical movement of

turning the condenser dial and get anywhere close to the maximum output of the set. When we are operating close to the oscillation point, a surge of static or a loud signal will be enough to throw the set into oscillation. So we must back the control away from this oscillation point far enough so that it will not be thrown into oscillation by static or loud signals. We need some method then that will allow us to operate closer to the point of oscillation yet will prevent the set from spilling over and causing distortion by oscillating.

The Quench Frequency. There is an electrical method of doing this. Suppose that the regenerative circuit uses 90 volts on the plate of the tube. In the resistance-control circuit a resistor controls regeneration by adjusting the plate voltage. Suppose that the set would oscillate at 75 volts. A heavy surge of current to the grid of the tube, caused either by a loud signal or by a roar of static, causes enough more current to flow through the plate circuit to throw it into oscillation. The strong signal on the grid will have the same effect as increasing the plate voltage. It will cause more current to flow in the plate circuit.

By coupling an oscillating circuit to the plate of the regenerative receiver we can control the oscillation point electrically. If the condenser is too large, the aerial will draw power from the tank circuit and cause it to stop oscillation.

The other circuit will be adjusted to oscillate at a frequency of from 20,000 to 50,000 cycles a second. The coupling coils are arranged so that the current flowing in the oscillating coils opposes the plate current of the regenerative receiver and reduces the plate current to a value below the oscillating point 20,000 cycles a second. The result is that the signals can build up to a maximum volume without dropping into oscillation and causing distortion.

Any distortion that occurs in this circuit is above audibility. Consequently, the circuit works at the most sensitive point on the curve, with the result that this type of receiver is far more sensitive than the ordinary regenerative receiver.

The fact that this circuit tunes very broadly is an advantage in the ultrashort-wave band because it allows you to tune across the comparatively wide band and pick up the signals you wish to hear. Interference is produced by this receiver because it is in continuous oscillation. It acts as a weak transmitter. This circuit defect is overcome by the use of the superheterodyne type of receiver.

**How the Circuit of Fig. 378 Works.** Another system of regeneration makes use of a grid condenser and a grid leak of very low resistance (about $\frac{1}{2}$ megohm) to interrupt the oscillation of the superregenerative detector. When the grid of the tube becomes positive, enough grid current flows through the grid leak to use practically all of the electrons pulled through the tube. This stops the oscillation of the tube at a frequency above 20,000 times a second, and provides super-regeneration.

The low-resistance grid leak allows electrons to flow off the grid very rapidly, preventing the tube from blocking on strong signals. Notice that there is a high B voltage on both the grid and the plate in the circuit shown in Fig. 378. The radio-frequency choke is highly important. Without it, this circuit will not super-regenerate. The plate blocking condenser completes both grid and plate circuits to the filament or cathode.

### Questions

1. Are you able to operate an ordinary regenerative set close to the limit of sensitivity?

2. Is it possible to adjust the set mechanically so that it will operate near the peak of sensitivity without its going into oscillation by itself?

3. Show how the quench frequency will permit the set to build up to the peak of sensitivity and then stop it just as it goes into oscillation.

# CHAPTER XIV

## LOOKING AHEAD IN RADIO

The history of inventions is a striking tribute to human ingenuity. In almost every scientific field, one finds the same pattern. There is a new invention, sometimes revolutionary in its possibilities. Then, sooner or later, this invention is carried to a degree of perfection where additional development seems impossible. Invariably when it seems that no further progress can be made, another invention or new type of development appears which opens up a new area of activity by a method entirely different from the one that seemingly could be improved no further.

The history of radio furnishes many examples. When Fleming tried to adapt Edison's discovery of current flow through a vacuum to his needs for a more efficient detector, he found himself in a blind alley. Before long, however, de Forest had added the grid. His revolutionary new principle solved the problem of detection and at the same time gave tremendous possibilities of amplification. This new principle also led to the development of the oscillator which is now the backbone of our transmitting and broadcasting systems. Again, when radio seemed at a stopping place in its development frequency modulation came in and enlarged the possibility of transmission even beyond the dreams of those who were experimenting in radio.

The first receiving sets had so many controls and were so difficult to adjust that few but the specially trained could

use and enjoy them. Gradually, tuning controls were eliminated, and the operation of sets was simplified. The coming of the neutrodyne circuit brought a combining of circuit controls. This circuit, in turn, made possible the use of additional tubes for radio-frequency amplification. The whole system of neutrodyne reception and the use of the three-element tube for a radio-frequency amplifier were swept away by the introduction of the screen-grid type tube.

Years ago, when the crystal detector and the hissing electrolytic detectors were in their prime, a person would have been ridiculed who said that one day every home would have a radio. Few could see far enough into the future to vision the revolutionary changes that took place in radio during the nineteen twenties, which saw both the development and the passing of the direct-current vacuum tubes.

Static has for years been an unconquered nuisance to all radio listeners. A startling and revolutionary system of radio now bids fair to solve the problem of static in an unexpected manner. Other developments too numerous to mention here have helped to make possible our modern highly efficient set. Some have brought back the battery set, others repopularized the phonograph industry, and others have taken "fading" out of short-wave programs from overseas.

There have always been persons who are ready to say about any new idea, "It can't be done." In 1903 a director of the patent office claimed that until a new and revolutionary material was developed flight was impossible by any human means, yet within the same month Orville and Wilbur Wright made their first epoch-making flight using only ordinary materials in the construction of their airplane. You sometimes hear this same kind of comment

EDISON AND STEINMETZ.
These two men found unlimited opportunity in the field of electricity.

in regard to radio—that it has reached its highest possible efficiency. However, many thrilling developments are under way today which refute this statement.

**The Amateur Radio Operator.** Amateur radio constructing and operation offer interesting and worth-while recreation. When you have become one among the more than fifty thousand licensed amateur operators in the United States, you will know the pleasure of selecting circuits, assembling parts, and building your own receiver and transmitter. There is a peculiar thrill in receiving signals on a set you have built yourself. There is a greater thrill after you receive your Federal operator's and station license, when you send out your first call on a set you have built yourself and receive an answer. You will rapidly make a group of friends over the air as you operate your "ham" telegraph transmitter or the more expensive radio telephone transmitter.

You will build or buy your receiving set while you are learning the code. You will find a fine supply of ideas in the amateur publications, *QST* and *Radio*. To pass the Federal license examinations, you must be able to send with a hand key at the rate of 13 words per minute (65 consecutive characters of the continental Morse Code), receive at the same speed, and answer 10 questions picked at random from a comprehensive set of questions that cover the theory and operation of radio telegraph and radio telephone transmitters, aerials, power supplies, and radio telephony, as well as Federal laws and regulations and penalties.

As a licensed amateur you will enjoy building your transmitting equipment and operating it while "rag chewing," as carrying on conversations over the air is called.

Radio operation pursued as a hobby has many times furnished a steppingstone to young men who wished to make some commercial use of their experience. There are many opportunities for those who are willing to put energy and imagination into their work. In making a choice among the various possibilities, it is important to investigate the different fields of specialization. There follows a brief outline of some of the opportunities open to one trained in radio principles and experienced in their application.

**Servicing Radio Sets and the Closely Allied Business of Selling Radio Sets and Parts.** The millions of radio receivers used in homes, offices, and cars require occasional adjustment and, less frequently, replacement of tubes and parts. This is the work of the radio service man. If you are a service man and are employed by a radio dealer, what will be some of your daily activities? You will check over new sets before they are delivered to their purchasers. You may have to put up masts and install aerials. Actual servicing of sets will occupy a good deal of your working day. This work is fascinating because it is seldom the same. Each set is a new service problem to solve. Some you will recognize at once; others will offer a more serious challenge to your knowledge of radio and your skill in diagnosing needed repairs.

You will have to keep up to date on circuits and devices constantly being built into new sets. You will find new equipment described and its operation explained in the several trade magazines. Radio is developing rapidly. Television, with its picture transmission and reception methods, has added to the development problem you must follow. This means that to be a successful service man you must be ready for the new developments as they arrive.

If you are an enterprising service man, your contact with the public will give you a good opportunity to add sales to your technical servicing. Training in merchandising methods and in salesmanship will make you more valuable to an employer. Training in speech will add to your confidence and efficiency in meeting customers. Typing, bookkeeping, and accounting are well worth knowing. Training in these subjects will help you to build a solid background for a future business of which your technical knowledge and skill are but a part.

If you prefer to open your own service shop, you will find that the sale of sets, rental and installation of public address equipment, as well as sales of amateur supplies are other sources of income in addition to your income from servicing. You will find experience or training in business and in salesmanship to be invaluable. Your income will depend on the choice of location of your shop, on the number of competing service men, and especially on your own ingenuity and energy. Any good servicing magazine, such as *Radio Retailing* or *Radio Servicing*, offers ideas that a wide-awake service man can use to increase his business.

**Acoustics and Sound Engineering.** Sound offers many interesting possibilities either as a side line or as a complete business. Public address equipment is used at dances or, mounted on a sound truck, is used at picnics, rallies, ball games, political meetings—wherever groups of people get together. There are an increasing number of public buildings that are equipped with public address units; many churches and school auditoriums have built-in units, complete with microphone installations, amplifiers, control units, and speaker systems. Many business firms are equipped with interoffice telephones which are simply two-way public address units. They are easily installed and are a good source of business. Your training and

experience in servicing will enable you to install and maintain sound systems.

Your experience with sound installations will put you in frequent contact with more technical sound problems. You will find opportunities to design installations of sound equipment or to correct the faults of buildings or audi-
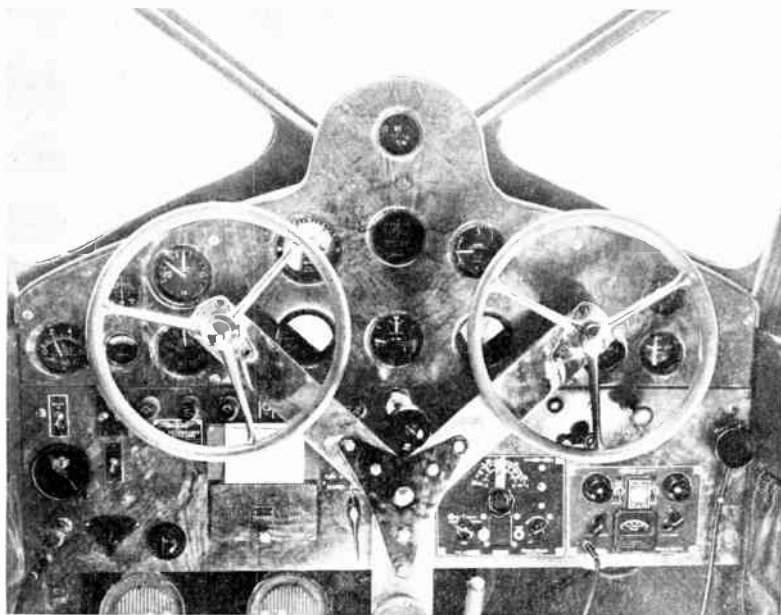


*Courtesy Western Electric Co.*

INSTRUMENT BOARD OF A MODERN AIRPLANE
The modern aviator has added the two-way radio to his navigational aids.

toriums by means of insulating materials. This is the field of acoustics and sound engineering. For this work you will need thorough training as a radio or acoustical engineer.

**Radio Engineering.** There are many opportunities for a graduate radio engineer. But to be successful, you must be resourceful and energetic. If you are interested in

research, there are places for you with the corporations which maintain research laboratories. Here radio engineers are constantly experimenting to open new fields of radio.

The college training for such work involves a great deal of mathematics and electricity, followed by advanced work in the field of radio in which you wish to specialize. Your income will be low at first. Experienced engineers often find places as builders of broadcasting stations or as maintenance men. These men are expected to be experienced in construction, good operators, and expert designers. The magazine *Electronics* describes the problems and products of these men.

**The Marine Radio Operator.** The training needed includes such things as principles and operation of motors and generators. As a commercial operator you must know how to use a typewriter and be able to keep certain kinds of records. Your first job at sea will probably be that of a combination radio operator and clerical assistant. At sea you have a good chance to save money, if you are so inclined. Many have used their savings from a marine operator's job to start a business, or they have used this money for further technical training.

**Possible Future Jobs in Radio.** The set we dial today, with its many automatic features, its nearly automatic tuning, its fine tonal quality, merely points to what the future may hold for radio and to new opportunities for you. Television offers many places for new men. For a number of years it will demand highly trained specialists to work out its complex technical problems. As one of these experts, you may help to answer the question of how television will be "piped" between cities.

To you may fall the job of perfecting and simplifying the portable television pickup camera and broadcasting

station equipment. It, like other new equipment, is now complex in its structure and its adjustment as well as being difficult to control. Simplification will come with revision of design and as a product of experience gained by using the equipment. Here is a wide field of new applications of the radio principles that you have studied about in this
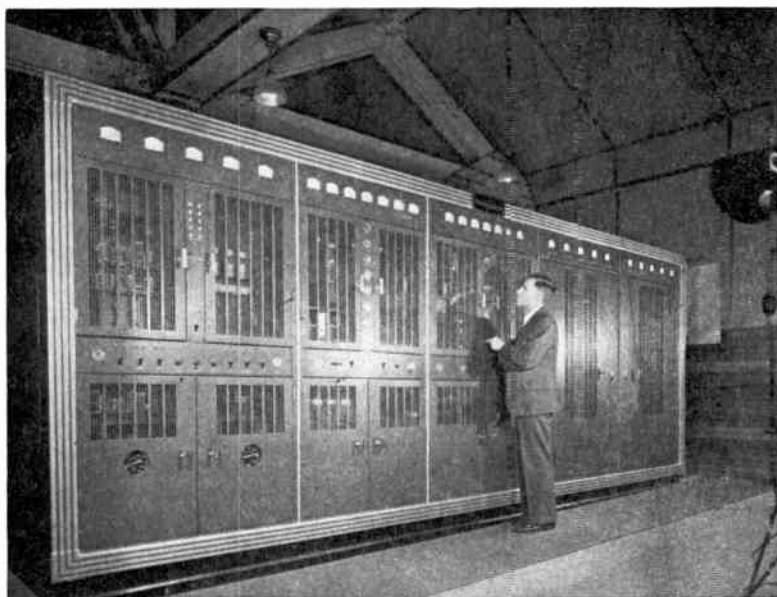


*Courtesy Western Electric Co.*
AN EXPERIMENTAL 50-KILOWATT TRANSMITTER
The circuits used in this transmitter point the way to the elimination of static.

book. It offers opportunities to the men now in radio who want to step out into the new field; it offers opportunities to you, because many men now in radio will not care to go to the trouble of mastering this new and different field.

Sales and service of television receivers is an opportunity for you, if you are a prepared service man. Installing and adjusting these sets will be complex at first, compared with

the average radio set, and these sets will probably need frequent adjustments. To work with television, you will have to be more highly trained than for working on ordinary receiving sets.

There may be many opportunities in connection with the system now being developed by Major Edwin H. Armstrong, a professor at Columbia University. This system, called "static-less" radio, points to major changes in the design of the present radio broadcasting and receiving circuits. The cost of changing present radio circuits from amplitude modulation and detection to frequency-modulated operation is likely to be offset by the public demand for static-free and high quality programs.

Another field that is opening rapidly is the use by aircraft of two-way radio. While radio is widely used by air lines, the use of radio by the private flier is a barely touched field. This field offers opportunities not only in the design of light and reliable equipment, but in its installation in airplanes and in its upkeep. This will be a specialty field.

Ultrashort-wave sets are being placed in model airplanes and model boats to control their operation. Radio control is a fascinating field which offers many opportunities to you if you are an ingenious experimenter.

These are but a few of the high spots in the vast and growing radio industry where alert prepared men are needed.

**Keeping Up with Radio.** The following list of books may be helpful in furnishing you with additional information about the vast and growing field of radio.

### Background Electrical and Radio Information

BOUCK, ZEH, *Making a Living in Radio*, McGraw-Hill Book Company, Inc., New York, 1935.

BURNS, ELMER E., *Radio; A Study of First Principles* (3rd ed.), D. Van Nostrand Company, New York. 1938.

CROFT, TERRELL W., *Practical Electricity* (revised by G. H. Hall), McGraw-Hill Book Company, Inc., New York, 1940.

DUNCAN, R. L., *Foundations of Radio*, John Wiley & Sons, Inc., New York, 1931.

HENNEY, KEITH, *Principles of Radio* (3rd ed.), John Wiley & Sons, Inc., New York, 1938.

SWOOPE, COATES W., *Lessons in Practical Electricity* (17th ed., revised by Erich Hausmann), D. Van Nostrand Company, New York, 1926.

## Radio Servicing

GHIRARDI, A. A., *Radio Physics Course* (2nd ed.), Radio Technical Publishing Company, New York, 1933.

HICKS, H. J., *Principles and Practice of Radio Servicing*, McGraw-Hill Book Company, Inc., New York, 1939.

RIDER, J. F., Booklets on Specialized Servicing Methods, Radio Treatise Company, Inc., New York, 1929–1933.
——, *The Cathode Ray Tube at Work*, The Author, New York, 1935.
——, Rider's Service Manuals, The Author, New York, 1933–1937.

## Radio Engineering

MORECROFT, JOHN H., *Elements of Radio Communication* (2nd rev. ed.), John Wiley & Sons, Inc., New York, 1934.

TERMAN, FREDERICK E., *Fundamentals of Radio*, McGraw-Hill Book Company, Inc., New York, 1938.

## Radio Amateurs

American Radio Relay League, *The Radio Amateur's Handbook*, The League, West Hartford, Conn., 1940.

Jones, F. C. and Technical staff of "Radio," *Radio Handbook*, Radio, Ltd., Los Angeles, 1940.

### *Commercial Radio Operators*

General Electric Company, Radio Department, *Radio Operators' Manual* (2nd rev. ed.), The Company, Schenectady, N. Y., 1938.

Nilson, Arthur R., and J. L. Hornung, *Practical Radio Communication*, McGraw-Hill Book Company, Inc., New York, 1935.

———, *Radio Operating Questions and Answers*, McGraw-Hill Book Company, Inc., New York, 1936.

# COMMONLY USED RADIO ABBREVIATIONS

These abbreviations are taken from *Webster's New International Dictionary* and from current radio magazines. Those from magazines are starred (*). For many words the abbreviations have not yet been standardized, especially when they are used on diagrams.

| | |
|---|---|
| A.C. *or* a.c. | alternating current |
| ACW | alternating continuous waves |
| A.F. *or* a.f. | audio frequency |
| Am. *or* am. | ammeter |
| amp. | ampere |
| * Ant. | antenna |
| * A.R.R.L. | American Radio Relay League |
| * C | capacity (of a condenser) |
| c *or* ca | cathode |
| cm | centimeters |
| con. | connection |
| cond. | conductor, conductivity |
| cop | copper |
| * c.t. | center tapped |
| CW | continuous wave |
| cy. | capacity |
| * db. | decibel |
| D.C. *or* d.c. | direct current |
| D/F | direction finding |
| * dia. | diameter |
| diag. *or* diagr. | diagram |
| d.p. | double pole (switch) |
| d.t. | double throw (switch) |
| DX *or* D.X. | distance |
| elec. *or* elect. | electric, electrical, electricity |
| E.M.F. *or* e.m.f. *or* emf | electromotive force |
| * FCC | Federal Communications Commission |
| * fils. | filaments |
| FM | frequency modulation |
| freq. m. | frequency meter |

| * G.M.T. | Greenwich Mean Time |
|---|---|
| H. | Henry |
| * ham | amateur |
| H.F. | high frequency |
| * High C | high ratio of capacity to inductance |
| h.t. | high tension |
| H.V. | high voltage |
| ICW | interrupted continuous waves |
| * i.f. | intermediate frequency |
| instr. | instrument |
| * I.R.E. | Institute of Radio Engineers |
| K *or* kilo | thousand |
| k | capacity |
| KC | kilocycle, kilocycles |
| kw | kilowatt |
| * L | inductance of a coil |
| * L/C ratio | ratio of inductance to capacity |
| L.F. | low frequency |
| M. | mega (million) |
| m | milli (thousandth) |
| Ma. | milliampere |
| mag. | magnet, magnetic |
| * Mc. | megacycle—millions of cycles |
| mf. | microfarad, millifarad |
| mfd. | microfarad |
| mfds | microfarads |
| M.G. *or* m.g. | motor generator |
| mh | millihenry |
| * M.O.P.A. | master oscillator—power amplifier |
| * mu *or* μ | amplification factor |
| mv | millivolt |
| N.G. *or* n.g. | no good |
| o | ohm |
| * osc. | oscillating, oscillator |
| PA | public address |
| * par. | parallel |
| PD | potential difference |
| phone | radio phone |
| prim | primary |
| * QRM | man made interference |

| | |
|---|---|
| * QRN | static |
| R *or* r | resistance |
| * r.a.c. | raw alternating current |
| react. | reactance |
| recd. | received |
| res. | resistor, resistance |
| R.F. *or* r.f. | radio frequency |
| * RFC | radio frequency choke |
| rheo. | rheostat, rheostats |
| R.M.S. *or* r.m.s. *or* rms *or* RMS | root mean square |
| r.p.m. | revolutions per minute |
| sec. | secondary |
| s.g. | specific gravity |
| * stn. | station |
| stor. | storage |
| * superhet | superheterodyne receiver |
| * S.W. | short wave |
| tel. | telephone |
| teleg. | telegraphy |
| term. | terminal |
| * TNT | simplified form of tuned-plate—tuned-grid power oscillator |
| T.P.S. | earth telegraphy, (French) *telegraphie par le sol* |
| * T.P.T.G | tuned-plate—tuned-grid oscillator |
| trans. | transformer |
| * t.r.f. | tuned radio frequency |
| * tri-tet | oscillator circuit |
| TU | transmission unit |
| * U.H.F. | ultra high frequency |
| v. | voltage |
| var. | variometer |
| * Vee | antenna shaped like the letter *V* |
| vm. | voltmeter |
| * V.T. | vacuum tube |
| * W | the prefix *W* is assigned to all American amateur operators' call letters. The number indicates the district in which his station is located, as W6PRD. |

| W. | watt |
| * W.A.C. | worked all continents |
| W.G. | wire gage |
| wh. *or* whr. | watt hour |
| * WL | wave length |
| * wm. *or* Wm. | wattmeter |
| * W.T. *or* W/T | wireless telegraphy |
| * wx | weather |
| * xtal | crystal |
| * Z | impedance |
| * Zepp | Zeppelin type antenna |

# INDEX

587