GETTING ACQUAINTED WITH RECEIVER SERVICING

★ Lesson Number Four ★

SAMPLE LESSON

PIONEER HOME STUDY RADIO SCHOOL

NRI

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STUDY SCHEDULE NO. 4

To master this fourth part of your NRI Course most speedily and thoroughly, divide your study into the steps given below. First read the specified pages at your usual reading speed. Next, reread them slowly one or more times, endeavoring always to *understand* as well as remember. Finish with one quick reading to tie the ideas together in your mind, then write on scrap paper your answers to the questions specified for that step. After finishing the Lesson, copy all answers neatly on an Answer Sheet.

☐ 1. **We Study a Modern Radio Receiver........................Pages 1-5**

Read this section at least once, to find out *why* a knowledge of radio receiver servicing problems is important to *YOU*, to get a *preview* of how receivers are taken up in this Lesson, to study a *radio map* which will guide you through a modern superheterodyne receiver, to become acquainted with the knobs and dials on the front of a receiver, and to learn how the chassis is removed from the cabinet of a receiver. Answer Lesson Question 1.

☐ 2. **Radio and Television Receiver Tubes........................Pages 6-10**

Since a tube is one of the most important parts in modern receivers, you study first the five tubes used in the average superheterodyne receiver which serves as our example for this Lesson. Tubes will mean a lot more after you finish this interesting section. Answer Lesson Questions 2 and 3.

☐ 3. **Above-Chassis Parts....................................Pages 10-17**

You take up one by one the parts which are mounted on top of the chassis of our superheterodyne receiver—the loudspeaker, the output transformer, the gang tuning condenser, the trimmer condensers, and the i. f. transformers. You find out how each one is constructed, what it does, how it might fail, and how it is repaired or replaced. Answer Lesson Questions 4, 5, and 6.

☐ 4. **Under-Chassis Parts....................................Pages 17-26**

You turn the chassis upside-down, and study in turn, the soldered joints, resistors, condensers, r. f. coils, power transformer, power cord, on-off switch and volume control, tone control, dial lamp, and tube sockets. Answer Lesson Questions 7, 8, and 9.

☐ 5. **Radio Receiver Servicing Techniques.....................Pages 26-28**

Here's your first real introduction to actual servicing techniques. You learn how a radio man uses various techniques to find first the defective section or stage, then the defective circuit, and finally the defective part. Answer Lesson Question 10.

☐ 6. **Mail Your Answers for Lesson 4FR-3 to NRI for Grading.**

☐ 7. **Start Studying the Next Lesson, on Resistors.**

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GETTING ACQUAINTED WITH RECEIVER SERVICING

We Study a Modern Radio Receiver

IF RADIO and television servicing is to be your chosen work, you will unquestionably deal with receivers most of the time. And no matter what other branch of radio you intend to get into, you will still work with receivers part of the time.

For example, in practically every radio and television station there is at least one receiver. This receiver is tuned to the station frequency, and enables the operator on duty to receive the program exactly as the public is receiving it. An operator at a huge transmitter would certainly feel embarrassed if he had to call in a serviceman to fix his own monitor receiver when trouble developed.

The two-way radio communication stations used on boats, airplanes, and other mobile equipment provide more examples. Failure of just one tiny part in the radio receiver can put one of these stations out of action just as effectively as failure of the largest part in the station's transmitter.

The fundamental principles *which make a radio receiver work* also apply to television, transmitters, test instruments, and all other radio apparatus. Receiver parts and circuits work exactly like the corresponding parts and

Photo by F. C. Wilkinson

Courtesy General Electric Co.

Radio men use receiver servicing techniques for all types of radio equipment. Thus, the method which the man at the left is using to repair a modern all-wave superheterodyne receiver will apply equally well to the television transmitter being serviced by the man at the right.

circuits you find in all other types of radio equipment, wherever you may be—in the radio room of an ocean liner, at the radio controls in a transport air liner, at the sending key of a forest fire lookout station, in the control booth of the public address system at a huge football stadium, or in any of the broadcast and short-wave radio stations throughout the world.

Once you learn how to repair radio receivers by using modern professional servicing techniques, you will have the foundation training for operating and repairing practically any other piece of radio apparatus.

FIG. 1. This modern superheterodyne receiver is used as an example throughout this Lesson.

Preview of This Lesson

In this Lesson, you imagine that you have in front of you the table model receiver pictured in Fig. 1. It is an average modern receiver, using the latest *superheterodyne* circuit (pronounced *SOO-pur-HET-ur-o-DINE*, and often abbreviated as *superhet* or *super*). With the aid of special illustrations, you learn about the parts in this receiver and their general purposes, just as if the set were right in front of you in your own home.

Starting with the front of the receiver, you learn what each control knob does and how it is used. The meanings of the printed numbers and scales on the receiver tuning dial are clearly explained. You find out what to do when a customer loses one or more of the front-panel knobs or controls.

You remove the "works" (the *chassis,* pronounced *SHASS-iss*) from the receiver cabinet, then examine in turn each of the parts on top of the chassis, including the radio tubes, the loudspeaker, the output transformer, the gang tuning condenser, and some new parts which you take up for the first time here. In the same way, you study the many smaller parts which are located underneath the chassis.

Throughout this Lesson, the practical viewpoint is stressed. You learn a great deal about how a part is made, what it does, how it can fail or give trouble, and how it is repaired or replaced.

Radio Map of a Superhet

Your study of this Lesson will be much easier if you first get a general idea of what a superheterodyne circuit is. You are already familiar with the other common type of receiver circuit —the t.r.f. circuit, so it will be particularly interesting to find out why the superheterodyne can "run circles" around a t.r.f. receiver of the same size.

Figure 2 is the "radio map" which gives you the facts about the circuit arrangement of the superheterodyne receiver used as the example for this Lesson. As you can see, the first stage in our receiver is the *MIXER-FIRST DETECTOR*. It receives two signals:

1. The desired modulated r.f. carrier signal, which is produced in the receiving antenna by radio waves.

2. The r.f. signal, which is self-generated in the *R.F. OSCILLATOR* stage in such a way that its frequency is exactly 456 kc. higher than the carrier frequency of the desired incoming signal.

Now comes the action which makes the superhet so different from a t.r.f. receiver. The mixer-first detector combines its two incoming signals to give an entirely new signal called the *i.f. signal.*

The new modulated i.f. carrier signal in this receiver (and in many other superheterodyne receivers) *always* has a carrier frequency of exactly 456 kc. (This value is the difference between the frequencies of the r.f. signal and the incoming carrier signal.)

Strictly speaking, we should call this new signal the *modulated intermediate frequency carrier signal,* because it still has the original audio signal modulation. Since you are going to work with radio men, however, you will undoubtedly want to talk their own language, and say "eye ef signal" just as they do.

The frequency of the i.f. carrier signal is *in between* the r.f. carrier frequency and audio frequencies. This is why the new signal is called an *intermediate* frequency signal.

After the carrier frequency of the desired incoming signal has been changed to 456 kc. by the mixer-first detector, the resulting i.f. signal is fed into the *I.F. AMPLIFIER.* There it receives a tremendous amount of amplification, because an i.f. amplifier stage which works at *only one* carrier frequency is many times more effective than an amplifier stage which must work at many different frequencies. (In a t.r.f. receiver, you know, the r.f. amplifier stages must handle any carrier frequency which the listener tunes in.)

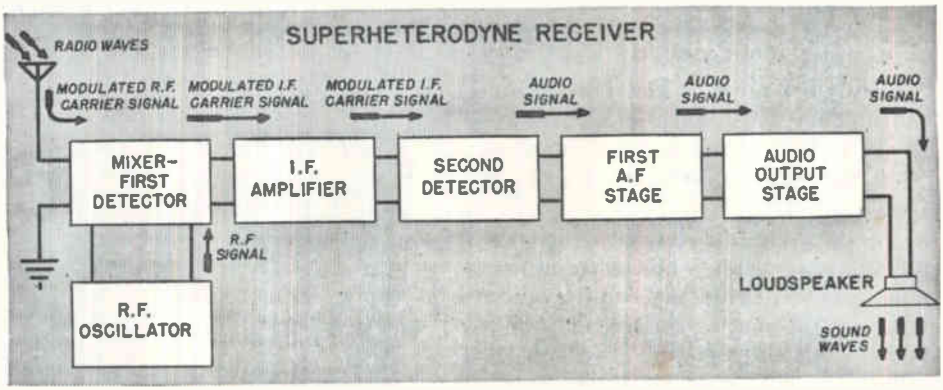


FIG. 2. Arrangement of stages in the superheterodyne receiver used as an example in this Lesson.

The strengthened i.f. signal enters the *SECOND DETECTOR.* This stage separates the audio signal from the i.f. carrier signal, and also gets rid of the i.f. carrier since it is no longer needed. The second detector thus gives us the audio signal we have been working for all this time.

The audio amplifier and loudspeaker, following the second detector of this super, are exactly like the audio amplifier and loudspeaker of a t.r.f. receiver. Thus, the audio signal gets one boost in strength from the *FIRST A.F. STAGE,* and gets another boost from the *AUDIO OUTPUT STAGE* before being fed to the *LOUDSPEAKER.* Here the audio signal is changed into *SOUND WAVES* which are the desired radio program.

You See How Radio Men Work. After becoming thoroughly acquainted with the various parts in this receiver, you will see how radio servicemen go about locating and repairing trouble in the receiver.

Once the trouble is located, the defective part is easily replaced or repaired. It is in finding the cause of the trouble that a complete knowledge of the purposes and actions of radio parts counts.

Front-Panel Parts

Control Knobs. The general arrangement of the controls on this receiver is typical of that used in most modern receivers, and is shown in Fig. 3.

To turn on this set you turn the *volume control* knob clockwise until a click is heard. This turns on the power pack, by completing the circuit for the power cord which goes to a wall outlet.

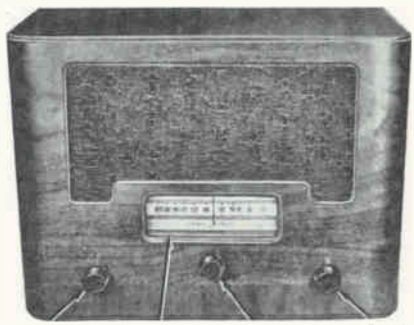
Further clockwise rotation of this knob increases the volume of loudness of the program coming from the loudspeaker.

When you tune in a station with the *tuning control* knob, you are doing two things: *1.* Rotating the gang tuning condenser to the correct setting for reception of the station; *2.* Moving a pointer to the position on the tuning dial at which the frequency of the station is indicated.

The *tone control* knob allows you to change the tone of the sound coming from this receiver, by reducing the strength of higher audio frequencies. The lower audio frequencies will then predominate, and give a mellow bass tone which emphasizes drums, large bass horns, and men's voices.

On some receivers, it is also possible to set the tone control to reduce the strength of only the *lower* audio frequencies. The high frequencies of violins, cornets, bells, and women's voices will then be emphasized. Tone controls are provided because people's tastes differ regarding tone just as much as tastes differ regarding food, clothes, or almost anything else.

Tuning Dial. It is common practice among receiver manufacturers to mark the tuning dial in kilocycles, with the last zero in the frequency value omitted. The dial shown in Fig. 3 is an example of this practice. If you add a zero to each number printed on this dial, the numbers represent *frequency in kilocycles.*



ON—OFF AND VOLUME CONTROL | TUNING DIAL | TUNING CONTROL | TONE CONTROL

FIG. 3. Front view of the modern superheterodyne receiver used as an example throughout this Lesson.

Radio station frequencies are usually expressed in kilocycles for convenience, so the term *kilocycle* (abbreviated *kc.*) is one which you should remember. (One kilocycle is equal to 1000 cycles.)

The tuning dial shown in Fig. 3 extends from 550 kilocycles to 2000 kilocycles, hence our superhet receiver covers the entire *broadcast band* and certain police bands just above the broadcast band.

Replacing Control Knobs. When a Radiotrician encounters a receiver having a broken or missing control

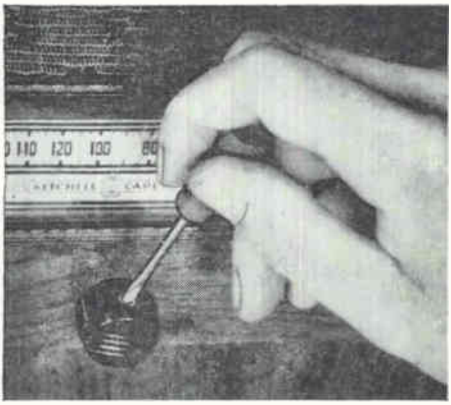


FIG. 4. Loosening the set screw of a receiver control knob with a small screwdriver. Some knobs may have two set screws.

knob, he will first try to obtain a new knob exactly like those already on the set.

If an exact replacement knob is not available, he will secure an entire set of new knobs, having a design and color which will harmonize with the finish of the receiver cabinet.

Removing the Chassis

In order to get a good look at the radio parts in our receiver, we will have to remove the *chassis* from the cabinet. The chassis includes the metal *chassis base* and all parts mounted on this base.

Removing Control Knobs. We first loosen the tiny set screw in each control knob, using a small screwdriver as illustrated in Fig. 4, then remove the knobs.

Sometimes knobs are held in position by stiff flat springs inside the knobs, instead of screws. These knobs are removed by pulling firmly. If it is difficult to get a good grip on a small knob, slip a handkerchief between the knob and the cabinet, and pull on the ends of the handkerchief.

Removing Chassis Screws. Next, we use a medium-size screwdriver to loosen the two wood screws which fasten the chassis base to the bottom of the receiver cabinet, as illustrated in Fig. 5.

In some receivers, the chassis is fastened with bolts which pass through the bottom of the cabinet. These are removed with either a screwdriver or a socket wrench, depending upon the type of bolt head employed, after turning the receiver on its side so that the bottom of the cabinet is accessible.

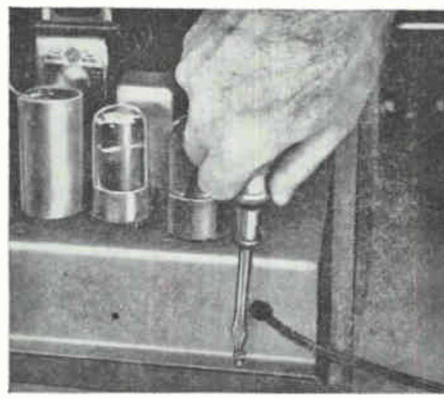


FIG. 5. Using a medium-sized screwdriver to remove the chassis hold-down screws at the back of our superheterodyne receiver.

The chassis-removing procedure just described applies to practically any radio receiver, so let's repeat it here as a practical radio servicing rule: *To remove the chassis from the cabinet of a radio receiver, first take off the control knobs, then remove the chassis hold-down screws or bolts.* If the chassis will not come out yet, look for additional hold-down screws around the dial and loudspeaker.

Radio and Television Receiver Tubes

Now we can slide the chassis out from the back of its cabinet. When this is done, all of the parts on top of the chassis base are clearly visible, as shown in Fig. 6. Study this view for a few minutes, to become familiar with the positions of the tubes and the labeled large parts.

Before you can understand how parts work together in radio circuits, and before you try to locate defective parts, you should have a general idea of how these radio parts look, how they are built, and how they act on signals and circuit currents when operating properly. Therefore, we concentrate upon radio parts in this Lesson, starting with tubes.

The five tubes in our superheterodyne radio receiver are all on top of the chassis base, and are easily recognized even though one of them is almost completely enclosed in a metal shield.

Tube Shields. First of all, we'll take off that metal shield and see what the hidden tube looks like. We remove the clip from the top cap of the tube, then pull the shield straight up with one hand as shown in Fig. 7.

Yes, there's just an ordinary radio tube inside this shield, a type 6K7

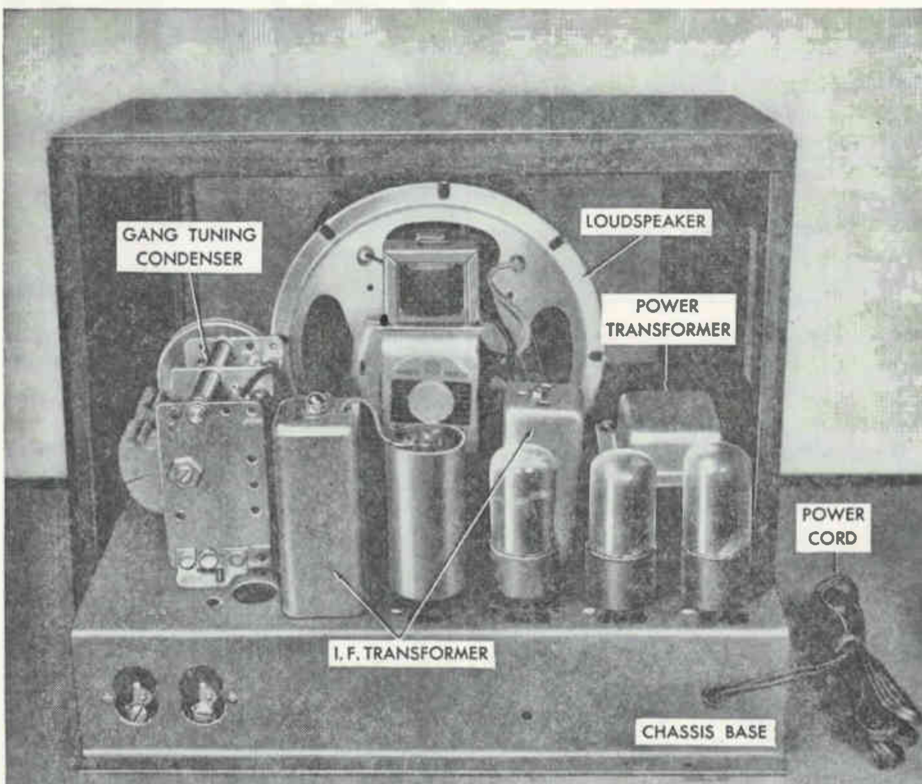


FIG. 6. Rear view of our superheterodyne receiver, with the chassis almost out of the cabinet.

tube serving in the i.f. amplifier stage. It's an important tube, for it receives extremely weak desired signals and boosts them a tremendous amount. But undesired signals would get this same amplification if they got into this tube circuit, so we must use the metal *shield* to protect the tube electrodes from stray fields (stray radiated signals) of other parts. Without a shield, the set would probably squeal at each station as you tuned across the dial.

Tube Bases. The tubes in this receiver all have *octal* bases, which means that each one can have as many as eight prongs. Some of the tubes require all eight prongs for connecting purposes, either because the tubes have extra grids or because two or more sets of electrodes are combined in one tube.

When a tube requires less than eight connections to its socket, some of the prongs are omitted during manufacture without changing the positions of the others. Thus, the 6X5 rectifier tube taken from our set and shown in Fig. 8 has only six prongs.

Tube Numbers. Each of the tubes in our receiver has an identifying num-

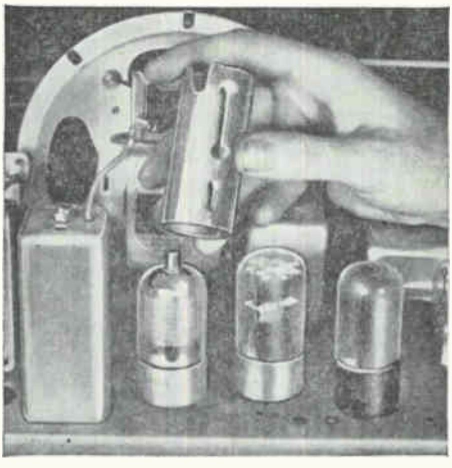


FIG. 7. Removing the shield from a tube.

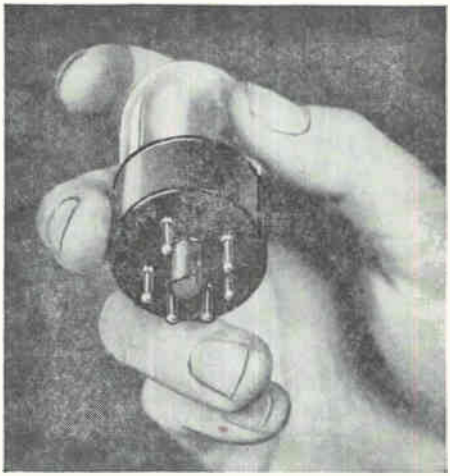


FIG. 8. This is what you see when you remove a 6X5 tube from a receiver and look at its base.

ber of its own, printed right on the glass envelope or on the base of the tube. Furthermore, each tube is intended for a particular socket on the chassis base of this receiver. Since an octal-base tube will fit in any octal-base socket, the sockets must be identified in some way so as to make sure that the correct tube will be placed in each socket.

Socket Markings. The number of the tube intended for each socket has been clearly printed on the chassis base of our receiver, as indicated in Fig. 9.

Sometimes tube sockets themselves are marked. More often, however, there are no markings anywhere near the sockets. Instead, there is a diagram attached to the chassis or the inside of the cabinet, showing which tube goes in each socket.

In a few sets, there will be no markings at all. You can either mark all the sockets yourself before taking out the tubes, or take out only one tube at a time for testing.

Removing Tubes. To remove a tube for testing or replacement, pull

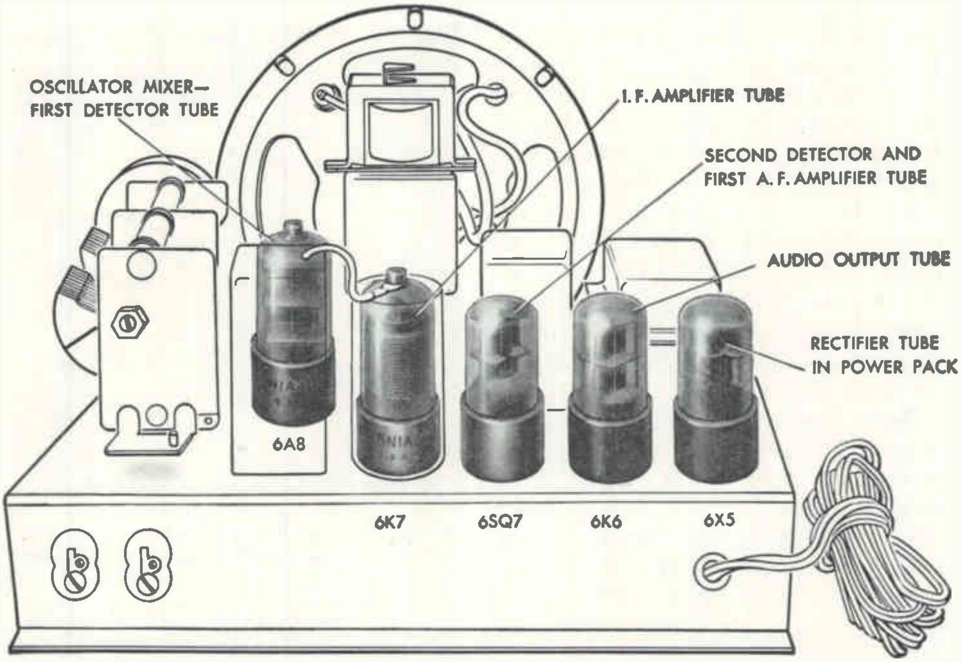


FIG. 9. This is the back of our superheterodyne receiver chassis showing the tubes.

it straight up while wiggling it slightly from side to side. Tube sockets are purposely made to grip tube prongs tightly, so as to provide good electrical contact and prevent tubes from bouncing out during shipment of a receiver. Thus, it may take quite a bit of force to pull out a tube.

Here is a practical tip which may prove very useful when you are trying to remove a tube from a crowded corner of a radio chassis. While pulling and wiggling the tube with your right hand, insert a screwdriver under the tube base with your left hand and twist the screwdriver so as to pry up the tube. Of course, the receiver must be turned off when this is done, for otherwise the screwdriver might short some power supply circuit and cause damage.

Tubes Get Hot. All radio tubes heat up when in operation, but some types of tubes get much hotter than others.

The tubes used in battery and portable receivers stay the coolest. All-metal tubes, on the other hand, sometimes get so hot in normal use that you can actually burn your fingers on them.

The tubes in our superheterodyne receiver all use glass envelopes, which in some cases get almost as hot as metal envelopes. Allow a minute or so for the tubes to cool before attempting to remove them, or use a handkerchief or piece of cloth to protect your hand when removing hot tubes.

This precaution applies particularly to the audio output tube and the rectifier tube in a receiver, for these two tubes usually get the hottest. The reason is that the audio output tube has a higher plate current than any other tube except the rectifier tube. As a matter of fact, the rectifier tube handles all the plate and grid currents drawn by all the other tubes in the receiver.

Testing Tubes. When a receiver

comes into a radio service shop for repair, tubes are usually the first things which the serviceman checks. He removes the tubes from the chassis and tests them, one at a time, in a special tube-testing instrument like that shown in Fig. 10.

For each tube, he first adjusts the tester controls according to a tube chart furnished with the tester, then plugs the tube into a socket on the tester. If the meter in the tester indicates BAD, the tube is defective.

Although tube testers have a number of different sockets and controls, they are really quite simple to use once the operating instructions are carefully studied. There is no need

FIG. 10. Radio men use tube testers like this to test tubes.

for you to secure a tube tester yet, however—in fact, you will not need one until you are doing a considerable volume of radio service work.

How Tubes Fail. How do radio tubes go bad? Three common reasons are a burned-out filament, low emission, and shorted electrodes.

Burned-Out Filament. The filament in a radio tube is normally operated at red heat or even brighter. The thinnest parts of the filament wire get the hottest. The intense heat eventually causes the filament wire to melt and break open at a thin spot, causing complete failure of the tube.

When the meter pointer in the tube tester does not move at all from its position at the lowest end of the BAD region, the serviceman knows the tube has a *burned-out filament.*

Low Emission. Another common cause of radio tube failure is aging of the chemical coating on the **cathode.** This chemical coating gives off electrons when heated by the filament. As the coating wears off during use, fewer and fewer electrons are given off, and the total electron flow from cathode to plate through the tube is correspondingly reduced.

Eventually, the number of electrons given off or emitted is so much reduced that the tube can no longer do its full job in the receiver. Radio men then say that the tube has *low emission.* A tube tester would indicate that the tube was BAD.

When a serviceman encounters a tube which has low emission, he discards it and puts in a new tube.

Shorted Electrodes. Another type of radio tube failure is *shorted electrodes* inside a tube. Changes in temperature may cause an electrode to sag out of position enough so that it touches a nearby electrode inside the tube. We then say that the tube has shorted electrodes. Thus, the filament may touch the surrounding cathode and cause a *short.*

Practically all tube testers have a separate red light on the panel of the instrument. This red light glows whenever any two of the electrodes are shorted together. When this light glows, the radio man knows that he will have to replace the tube anyway, so he ordinarily does not bother to figure out which electrodes are touching.

More About Tubes. You will learn a lot more about radio and television tubes later in the Course in a Lesson devoted entirely to tubes.

Above-Chassis Parts

Although other superheterodyne receivers may look quite different from the one chosen for our example in this Lesson, all superheterodyne radio and television sets use the same fundamental principles of operation and similar groups of ordinary radio parts. Corresponding parts in radio or television sets may look different, but their important purposes and actions will be quite similar.

The Loudspeaker

Let us consider the loudspeaker next, for it is the largest radio part in our receiver, and has the actual job of changing the final strong audio signal into the sound waves of a radio or television program.

Electrodynamic Loudspeaker. As you previously learned, a modern dynamic loudspeaker has only three important parts: A diaphragm or *cone*, a *voice coil*, and a *magnet*.

In the loudspeaker used in our superheterodyne receiver, an electromagnet provides the magnetic field, and consequently the loudspeaker is known as an *electrodynamic loudspeaker*. The coil of the electromagnet is called the *field coil*.

The direct current required by the field coil is obtained from the power pack of the receiver. An electrodynamic loudspeaker will therefore have two extra wires, going from the field coil to the proper power pack terminals underneath the chassis. The field coil and its leads can be seen in Fig. 11, which shows the loudspeaker all by itself on the chassis of our receiver.

Through its connection to the power pack, the field coil also does an important filtering job, about which you will learn more later when you study power packs.

How It Works. When an audio signal current is sent through the *voice coil* of our electrodynamic loudspeaker, this voice coil produces a varying magnetic field which reacts with the constant magnetic field of the field coil.

The two coils thus alternately attract and repel each other. The field coil electromagnet cannot move because it is attached to the frame, so only the voice coil moves back and forth. Since the voice coil is attached

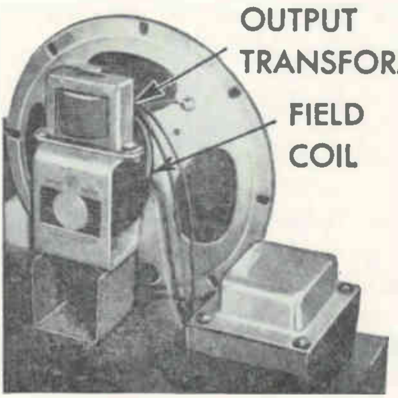
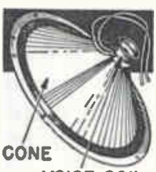


FIG. 11. Here's a close-up view of the loudspeaker in our superhet receiver.

to the cone, the cone likewise moves the surrounding air back and forth, producing the sound waves of radio programs.

Damaged Cone. When the stiff paper cone of a loudspeaker is accidentally torn, or when it becomes warped or cracked due to aging, radio programs no longer will sound natural, and will sometimes be accompanied by buzzing or scratchy sounds.

When a Radiotrician encounters a damaged cone, he either replaces the entire cone-voice coil assembly with an exact duplicate replacement assembly obtained from the set manufacturer or a radio parts distributor, or installs an entirely new loudspeaker. Curiously, with small loudspeakers it is often cheaper and more satisfactory to put in a new loudspeaker than to replace or repair a damaged cone.



Off-Center Voice Coil. One common loudspeaker trouble is an off-center voice coil. This coil moves in and out in a very small air gap between the pole pieces. Slight warping of the cone or slight shifting of the various parts of the loudspeaker throw the coil off center in the air gap, and the coil then rubs against the pole pieces.

When the voice coil is off center, radio programs will sound distorted on the loud bass notes which are present when a man talks or sings, but will probably be perfectly clear for women's voices, which have few low notes. You may hear a rubbing sound when you push the cone in and out with your fingers after the set is turned off.

When the voice coil is properly centered, you should be able to move it in or out without having the coil rub against the pole pieces between which it moves.

Practically all of the older loudspeakers and even a great many modern loudspeakers have provisions for recentering the voice coil. These loudspeakers will either have one screw inside the voice coil or several screws arranged around the outside of the voice coil. When these screws are loosened, the voice coil can be moved a small distance sidewise in any direction for recentering purposes.

With the screws loose, small narrow strips of celluloid or cardboard are inserted between the inside of the voice coil and the central iron core of the loudspeaker to provide automatic centering. The screws are then tightened, after which the centering strips can be removed.

There is a growing trend toward permanent fastening of the voice coil to the loudspeaker frame. The loudspeaker used in our superheterodyne receiver is an example of this, and its voice coil cannot economically be recentered by the radio serviceman. If for any reason the voice coil gets off center, the loudspeaker can be returned to a loudspeaker cone manufacturer or a radio supply firm for installation of a new cone-voice coil unit, or the entire loudspeaker can be replaced.

Open Field Coil. A broken wire (usually due to corrosion) is about the only trouble encountered in the field coil of an average electrodynamic loudspeaker. The trouble usually occurs at one end of the coil, at the point where the flexible insulated field coil lead is connected to the enamel-covered coil wire. If the trouble is at the outer end of the coil, it can often be repaired after removing the outer layer of insulating cloth from the coil.

When the field coil opens up and

the break cannot be repaired, it is sometimes possible to remove the defective field coil and install a new one. In many of the smaller modern loudspeakers, however, the core of the field coil is permanently anchored in position during manufacture, making it impossible to remove the field coil. The entire loudspeaker must then be replaced.

Replacing a Loudspeaker. After a receiver has been in use for three or four years, the paper used in its cone becomes quite brittle, and this appreciably affects the tone quality of the loudspeaker. The installation of a new cone or a new loudspeaker will usually provide a definite improvement in tone quality, with a corresponding increase in customer satisfaction with your work.

When replacing a loudspeaker with an exact duplicate replacement unit obtained from the receiver manufacturer or a radio supply house, all you need to be careful about is the connections. Make a rough sketch showing the terminals to which the voice coil and field coil leads of the old loudspeaker were connected, and use this as your guide for connecting the leads of the new loudspeaker.

The Output Transformer

The small radio part mounted on top of the loudspeaker in Fig. 11 is the *output transformer*. Its job, as you know, is to transfer audio signals from the audio output tube of the receiver to the loudspeaker in such a way that the loudspeaker gets the low-voltage, high-current signal it requires for most efficient operation.

Construction. The output transformer has two coils of wire, wound one over the other on an iron core. The primary coil contains many turns of fine wire. The secondary has fewer turns but uses heavier wire. The primary coil is connected to the output of the receiver, while the secondary coil is connected to the voice coil of the loudspeaker.

Open Coil. A break in either of the coils of wire in the output transformer will cause failure of a radio receiver. When such a break occurs, the serviceman says that the output transformer is *open*, and replaces the entire transformer. If the old transformer is held in place with rivets, he either drills out the rivets or cuts off their spread-out ends with side-cutting pliers. There are usually only four connections to unsolder, so this is a fairly simple service job. Either rivets or nuts and bolts can be used for mounting the new transformer.

Once the trouble has been isolated to the audio output stage by professional servicing techniques, the output transformer can be checked by two simple ohmmeter measurements, one across each winding.

The Gang Tuning Condenser

In Fig. 12 is a clear illustration of another highly important large part in our superheterodyne receiver, the *gang tuning condenser*. It has two sections, which work with the two r.f. coils located underneath the chassis. A tuning condenser is never used by itself; it is always used with a coil, and *tunes* the coil to a particular frequency. You will find this interesting situation many, many times in radio and television—different parts acting together to produce results which the parts could not give separately.

One gang tuning condenser section is connected to an r.f. coil in the input circuit of the mixer-first detector input, and tunes the r.f. coil to the frequency of the desired incoming signal. The other gang tuning condenser section is connected to the r.f. oscillator coil in the oscillator circuit, and tunes

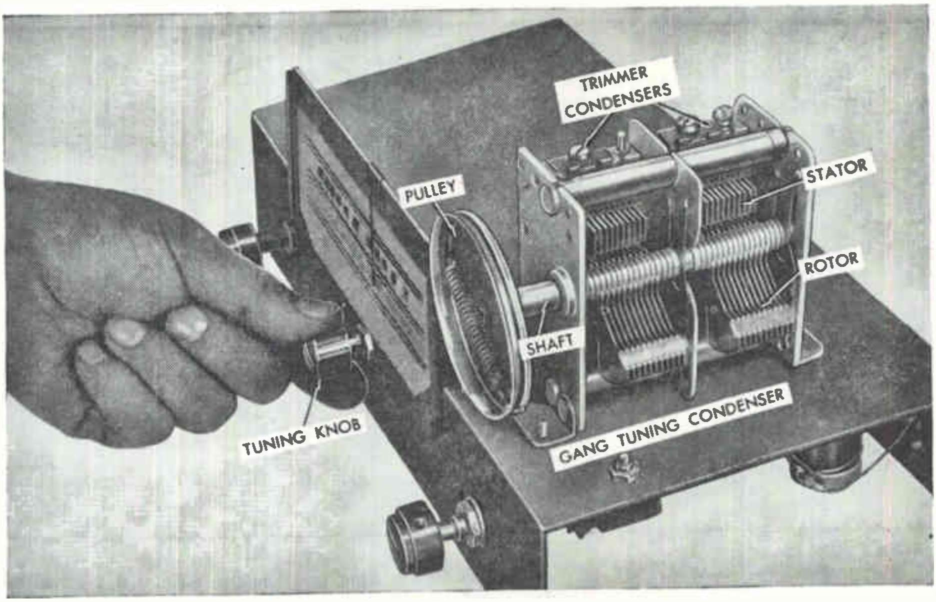


FIG. 12. View of the gang tuning condenser in our superheterodyne receiver, with important parts identified.

this coil to a frequency exactly 456 kc. higher than the desired incoming carrier frequency.

Rotor and Stator. Each section of our gang tuning condenser in Fig. 12 has two important parts:

1. A *rotor*, which in this particular unit has eleven aluminum plates. Both rotors are mounted on the same condenser shaft.

2. A *stator*, which consists here of ten aluminum plates mounted on but *insulated* from the condenser frame.

The rotor of each tuning condenser section *rotates*, but the stator of each section is stationary, staying in the same position all the time.

How the Capacity Varies. When the shaft of the gang tuning condenser is turned in one direction, the rotor plates go farther in between the stator plates, without ever touching the stator plates. This increases the electrical size or *electrical capacity* of each tuning condenser section.

Turning the shaft in the opposite direction brings the rotor plates out from the stator plates, reducing the electrical capacity of each section.

It is this change in the electrical capacity of each gang tuning condenser section which tunes the receiver to different stations. In later Lessons you will learn exactly how this is done.

Dial Cord. The tuning control knob in our superheterodyne receiver is quite some distance from the gang tuning condenser shaft, as you have probably noticed already in Fig. 12. Now, what makes the tuning condenser shaft rotate when we turn the tuning control knob? Also, what makes the dial pointer move to the correct dial number for the station whose program is coming from the loudspeaker?

Figure 13 shows the answer—simply a length of braided dial cord and a few pulleys. The cord runs around a small pulley on the tuning control knob shaft, around a large pulley on the gang

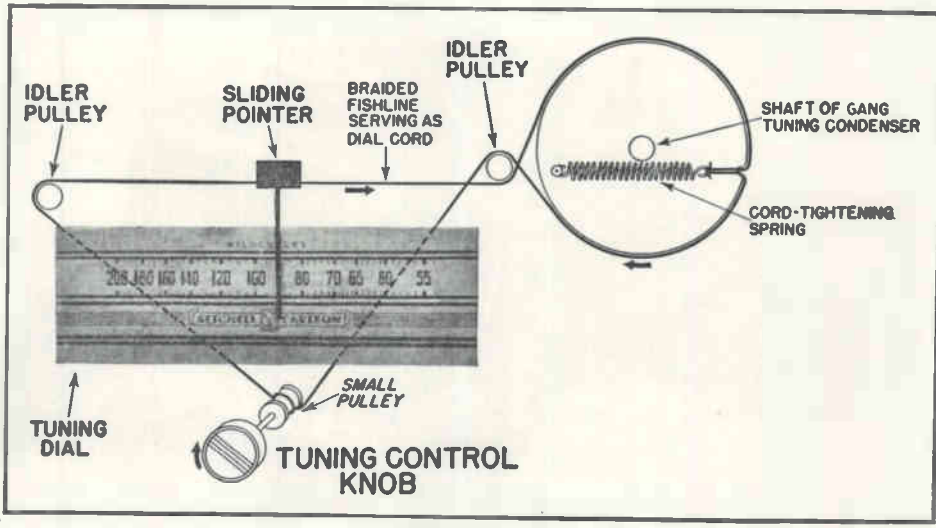


FIG. 13. This diagram shows how a length of fishline is used to make the pointer slide over the tuning dial and make the gang tuning condenser rotate when the tuning knob is turned.

tuning condenser shaft, and around two idler pulleys. A spring inside the large pulley keeps the cord tight.

The pointer is attached to the dial cord at the position shown. When you turn the tuning control knob in a clockwise direction, the sliding pointer moves to the right along the tuning dial, and the gang tuning condenser shaft turns in a clockwise direction.

The average radio set owner never sees this cord-and-pulley system, because it is at the front of the chassis, and cannot be seen when the chassis is in its cabinet. For this reason, a radio serviceman will usually be called even for a mechanical trouble such as a broken dial cord.

Restringing a Dial Cord. The diagram in Fig. 13 also gives you the necessary information for restringing the dial cord of our superheterodyne receiver. After removing the old dial cord, tie one end of the new cord to the spring, bring the cord entirely around the system exactly as shown in the diagram, then tie the other end of the cord to the spring and cut off surplus cord.

Now tune in a local station whose frequency you know, then push the pointer over the cord at the frequency number of this station. There are spring clips behind the pointer for gripping the cord. If restringing is properly done, the pointer will now move to the correct dial number for whatever station you tune in.

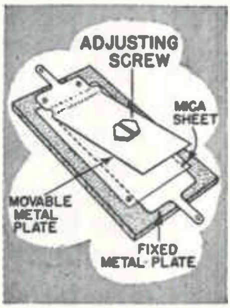
Bent Rotor Plates. Defects in a gang tuning condenser are generally easy to locate and repair. For instance, one of the rotor plates may become bent so that it touches an adjacent stator plate. This shorts one of the tuning circuits, and the receiver no longer plays. In other cases, the short is only momentary, and causes noise in the loudspeaker as the receiver is tuned.

Sometimes you can hear the condenser plates scraping against each other if you listen closely while turning the tuning control knob. The remedy simply involves straightening the bent plate with a putty knife or a thin-bladed screwdriver.

Trimmer Condensers

On top of each section of the gang tuning condenser is a small adjustable device known as a *trimmer condenser*. The purpose of these two trimmer condensers is to take care of any small differences which might exist between the two sections of the gang tuning condenser.

When the two tuning condenser sections are correctly matched by adjusting the "trimmers," both sections will automatically be tuned correctly for reception of a desired station when the tuning dial pointer is at the station frequency.



Construction. Each trimmer condenser consists of one fixed and one movable metal plate, separated by a sheet of *mica*, an insulating material. Tightening the adjusting screw brings the movable plate closer to the fixed plate, and thus increases the electrical size or capacity of the trimmer. Loosening the screw reduces the capacity of the trimmer.

The construction of a trimmer condenser is so simple that this unit rarely becomes defective. Correct adjustment is the chief problem of the radio man when working with the trimmer condensers in a receiver.

Adjustment. Although the actual adjustment of a trimmer condenser with a screwdriver or wrench is an extremely simple job, considerable knowledge of radio servicing techniques and radio fundamentals is necessary in order to know when and how much to turn the screwdriver or wrench during the alignment procedure. This is another highly practical technique which you are going to learn in the NRI Course.

I. F. Transformers

Also on top of the chassis base of our superheterodyne receiver are two parts which look like square metal cans. Through the two holes in the top of each can, we can see adjusting screws if we look carefully. These screws are fairly reliable identifying clues which tell that the parts are *i.f. transformers*. The square cans are simply *shields* which protect the inner coils from the effects of stray electric and magnetic fields. These shields also keep the fields of the coils from affecting other parts.

Construction. Figure 14 shows what you would see if you removed a few nuts, then lifted up the square shield of one of the i.f. transformers. Inside this shield are two small coils mounted on a wood rod. Above the coils are two trimmer condensers, one connected across each coil. These are the trimmer condensers which you adjust with a screwdriver through the holes in the top of the shield during alignment of the receiver.

What I. F. Transformers Do. When the gang tuning condenser and its coils are adjusted or tuned to a desired incoming carrier signal, these parts cannot always keep out undesired signals having different frequencies. I.F. transformers are much more selective, however.

The only signal which can get through a properly adjusted i.f. transformer without serious reduction in strength is the one whose carrier frequency is the i.f. value of the receiver (456 kc. in this case).

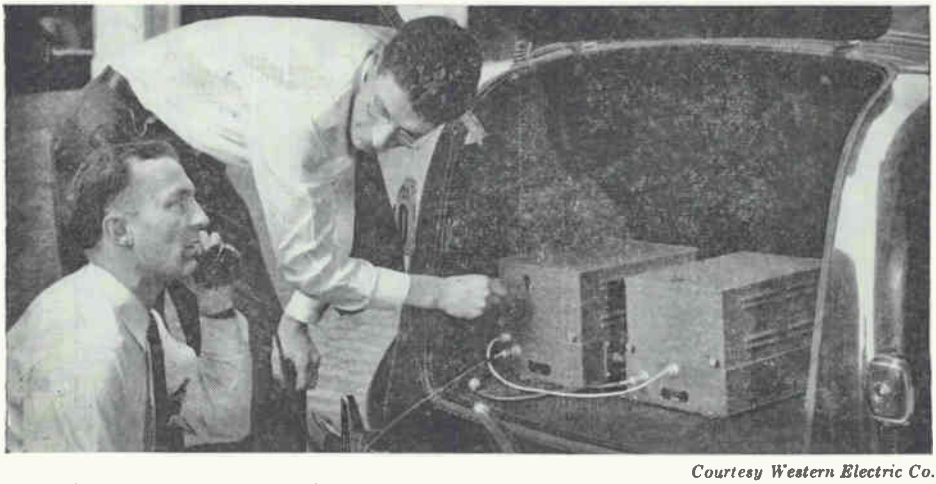
FIG. 14. This is what you see inside the i. f. transformer when you lift the metal shield can.

The oscillator-mixer-first detector automatically changes the carrier frequency of the desired incoming signal to the i.f. value, but changes undesired signals to other frequencies which cannot get through. One i.f. transformer transfers the desired signal from the mixer-first detector to the i.f. stage, and the other i.f. transformer transfers the desired signal from the i.f. stage to the second detector.

Open Coils. The coils in an i.f. transformer are made from small-size insulated copper wire. This wire sometimes breaks as a result of vibration or jarring, strains set up by changes in temperature, corrosion at soldered joints, or swelling of the coil form in damp weather. Any break in the coil wire interrupts the signal circuit, thereby causing complete failure of the receiver. If the break is at a joint, it can sometimes be repaired by soldering. If not, a new i.f. transformer must be installed.

Sometimes a connection may be weakened by corrosion without being completely open. This defect can cause loud crackling noises in the loudspeaker as the connection opens and closes at irregular intervals.

These are just a few of the many receiver troubles which cannot be seen by examining the parts. A systematic



Courtesy Western Electric Co.

The radio man at the right is adjusting a trimmer condenser in the transmitter unit of a two-way mobile police radio set while the other man listens to the effect of the adjustment with a headset plugged temporarily into a test jack on the transmitter.

and efficient trouble-locating procedure such as you learn in the NRI Course is absolutely necessary for locating defects like open i.f. transformers.

Power Transformer

We now have only one device left to consider above the chassis base of our superheterodyne receiver. This is the *power transformer*, a large and heavy unit located at the right of the loudspeaker when looking at the back of the chassis. Since all of the leads of this radio part are located underneath the chassis, however, let us postpone its study until we turn the chassis base upside down.

Under-Chassis Parts

Turning the chassis of our superheterodyne receiver upside down, as in Fig. 15, we find that most of the actual wiring and practically all of the small radio parts are underneath. As a result, the bottom of the radio chassis may look complicated to you now.

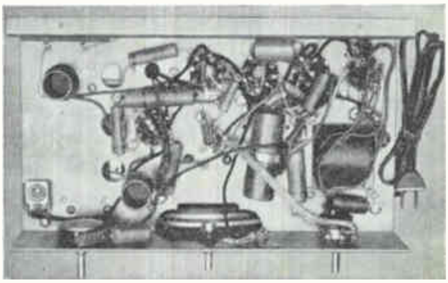


FIG. 15. When you turn the chassis of our superheterodyne receiver upside down, this is what you see. A radio man doesn't care how complicated a set looks underneath its chassis, however, because he looks only for certain parts or circuits and disregards all the rest.

Don't let this worry you, however. A radio man never has to figure out all at once what every single part under the chassis is doing. When he works underneath the chassis, he is looking for one particular circuit or part, and disregards all the other parts.

In this section, you will see a number of under-chassis views, each with only certain groups of parts showing. These views really represent what the trained eyes of a radio man might see as he works on the chassis.

Soldered Joints

Poorly soldered joints between groups of wires or between wires and terminals are a possible cause of receiver failure, but bad joints are just about the easiest defects to repair.

There are over 75 soldered connections which can go bad in our superheterodyne receiver; a television set will probably have at least 300. A loose joint can cause annoying crashing sounds to be heard with the radio program from the loudspeaker when the receiver is jarred, or can momentarily affect receiver performance in other ways.

Servicing Technique. Here is how you could go about locating a bad joint. Take the chassis out of the receiver cabinet and set the chassis upside down in such a way that you can see all of the joints under the chassis. Now take a stick of wood and push against each of the joints or leads in turn under the chassis while the receiver is in operation and tuned to a station.

If you hear the crashing sound from the loudspeaker as you move one of the joints or its leads, you know that the joint is loose and should be resoldered. A joint can be loose and defective even though it looks good, because it takes only a very small separation between wires to cause trouble.

After you learn a bit more about radio fundamentals and servicing techniques, you will become able to tell which section or stage has a defective joint, and will then have to check only the joints in that section.

Resistors

A careful count reveals that there are nine small carbon resistors mounted underneath the chassis of our superheterodyne receiver. The construction of one of these resistors is shown in Fig. 16.

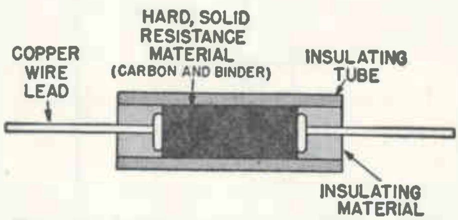


FIG. 16. Inside story of a carbon resistor. The two wire leads (pronounced LEEDS) make contact with the ends of the resistance material.

Each resistor is in a current-carrying circuit. The current flowing through a resistor produces a voltage drop across it. This voltage drop controls voltage and current in various ways both in the d.c. supply circuits for tubes and in the circuits which transfer signals from tube to tube.

Resistor Color Code. Carbon resistors are by far the commonest of all resistors used in radio and television equipment. Each resistor is marked with rings of color which tell the electrical size in ohms just as accurately as would printed values. You will be shown later how to read the color rings on resistors.

Resistor Troubles. A resistor can fail because of a break in one of its leads, usually inside the resistor or at the point where the wire lead enters the body of the resistor. A crosswise crack in the carbon resistance element can also cause failure of a resistor. In both cases, the radio man says that the resistor is *open*, for the break or crack blocks electron flow through the resistor.

Locating a Bad Resistor. A defective resistor can always be located by making tests with servicing instruments, chiefly with an ohmmeter.

Burned-Out Resistors. Resistors also become defective due to overheating, which occurs when an excessively large current flows through the resistor.

Overheating may cause the resistor to open up or change its electrical value, but radio men will simply say that the resistor has *burned out*. Such a resistor can usually be spotted at a glance because its colors and markings are blackened by the heat. A blackened resistor is not necessarily defective, however; it may have been overloaded at some time, but not enough to cause failure.

Condensers

Four different types of condensers are to be found underneath the chassis of our superheterodyne receiver—*paper* condensers, *electrolytic* condensers, *mica* condensers, and *trimmer* condensers. The illustration in Fig. 17 shows all of these condensers.

In basic electrical action, all four types of condensers are alike, in that they all control voltage and current in signal and supply circuits. The chief differences in condensers occur in the method of construction and in the electrical sizes.

Paper Condensers. The condenser used more than any other type in radio equipment is the *paper con-*

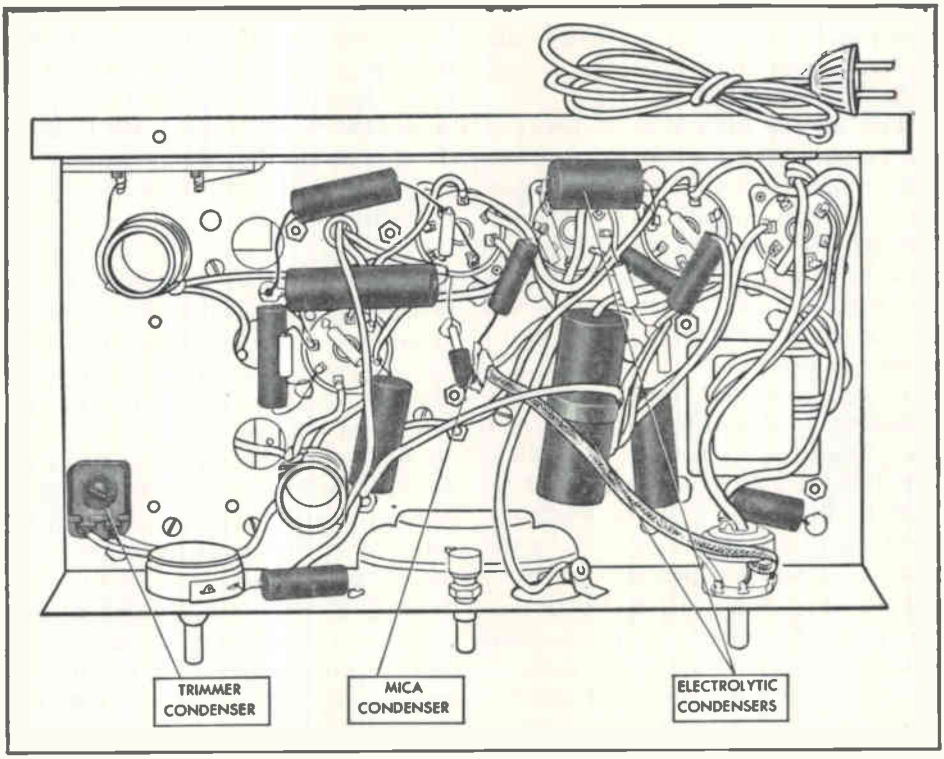


FIG. 17. This shows the condensers underneath the chassis of our superhet receiver. The condensers not marked are paper condensers.

denser. This name comes from the fact that the material used for insulation inside the condenser is waxed *paper.* The construction is shown in Fig. 18.

Loose Leads. A poor connection between a foil strip and one of the wire leads is a common cause of trouble in a paper condenser. A defect of this nature can sometimes be located by wiggling the body of each condenser under the chassis while the receiver is turned on. The defective condenser will usually cause a change in loudspeaker volume when this is done.

Shorted or Leaky Condensers. If the waxed paper insulation between the two foil strips of a paper condenser fails completely (becomes

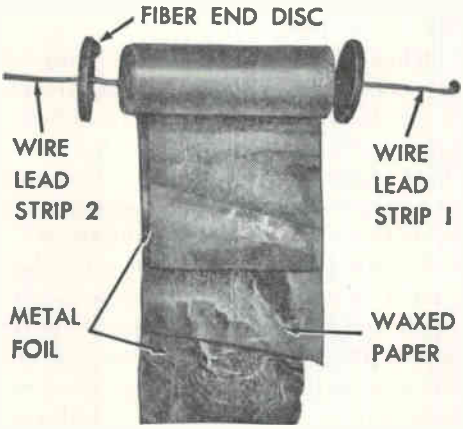


FIG. 18. This photo shows you what's inside a paper condenser. Two long strips of metal foil separated by strips of waxed paper are rolled together, with the two foil strips projecting from opposite ends of the roll and making contact with the two wire leads. The cardboard housing and fiber end discs keep out moisture.

punctured, so that the metal strips touch each other through a small hole in the paper), the condenser is said to be *shorted.*

Just as the high voltage between the points of an auto spark plug can burn a hole through a sheet of paper, so can high voltage burn a hole through the insulation of a paper condenser. This paper insulation weakens with age, so that eventually the normal circuit voltage is sufficient to short the condenser.

If the insulation becomes *partly* defective, so that a few electrons can flow from one strip to the other through the paper, the condenser is said to be *leaky.* Simple measurements with an *ohmmeter* will locate shorted or leaky paper condensers.

Capacity. Since one entire Lesson of your NRI Course is devoted to condensers of various types, the manner in which condensers are rated according to electrical size and working voltage need not be taken up in this Lesson. Now we just want to make a general acquaintance with the different kinds of condensers, so let's pass on to the next type.

Electrolytic Condensers. Two of the condensers in our receiver are of a special type known as *electrolytic condensers* or simply *electrolytics.* These condensers look much the same as paper condensers, and are made in a similar manner except that there is no paper between the rolled-up aluminum sheets. Instead, the sheets are separated by a moist chemical paste which produces an *insulating film* on the aluminum sheets through *electrolytic* action. (A scientist would explain that electrolytic action occurs when an electric current is sent through chemical materials.)

Leaky Electrolytics. Electrolytic condensers are common causes of radio receiver trouble, for the pasty chemical material spoils with age, reducing the effectiveness of the insulating film. Radio men say that the condenser has then become *leaky*, because the insulating film allows electrons to *leak through* the condenser when they should be held back.

Connections. The large electrolytic condenser in this receiver is really two electrolytic condensers combined in one housing. Three insulated leads, colored red, black, and blue respectively, come out of one end of the cardboard housing.

The leads are colored for two reasons, to distinguish between the two sections of the condenser and to indicate the correct polarity of connections. An electrolytic condenser will work as a condenser only when connected in a certain way. Correct connections are designated by calling one lead *positive* and the other *negative;* the positive lead must go to the positive terminal of the circuit. In our large electrolytic condenser, the black wire is the negative lead for both sections of the condenser. The red wire is the positive lead for one condenser section, and the blue wire is the positive lead for the other section. This information is marked on the condenser housing.

It is common practice to combine two or more electrolytic condensers in one housing in this way. A careful radio man always makes a rough sketch of connections before removing an old condenser, to reduce chances for errors when connecting the new unit.

Mica Condensers. There is only one *mica condenser* in our receiver. It is a tiny unit encased in molded brown Bakelite, and located just about in the exact center underneath the chassis. (See Fig. 17.) The mica con-

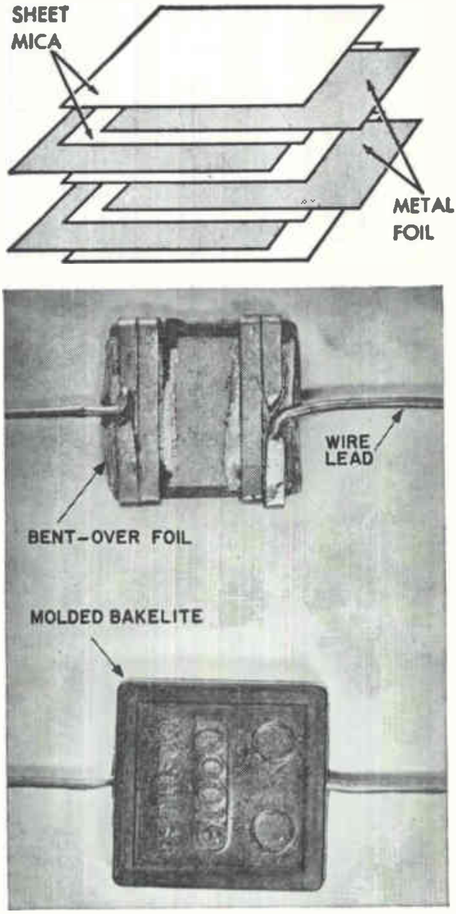


FIG. 19. How a mica condenser is made.

denser gets its name from the fact that sheet *mica* is used as the insulation between the metal plates. The construction is shown in Fig. 19.

Possible Troubles. Mica condensers seldom fail in use, but are more costly than paper condensers. Occasionally a wire lead may break at the point where it enters the Bakelite body of a mica condenser. The break may not always be visible, but can be located by wiggling each of the mica condensers in turn while the receiver is in operation. When a defective condenser is moved in this manner it affects the loudness of the sound coming from the loudspeaker.

The mica insulation can fail because of moisture or excessively high voltages. Adjacent metal plates then touch each other, causing a *shorted* mica condenser. A simple ohmmeter test will reveal this trouble once the defective condenser is located.

Trimmer Condenser. As you can see in Fig. 17, there is only one trimmer condenser mounted underneath the chassis. This unit is constructed very much like the trimmer condensers already studied.

Just as with the other trimmer condensers in this receiver, the chief problem is *knowing how* to make the simple screwdriver adjustment which is required during alignment of the receiver.

This particular trimmer condenser is technically known as the *oscillator padder,* because it is connected in series with the tuned circuit of the oscillator. You will learn later that this trimmer is adjusted to make the tuning dial readings more accurate at the low-frequency end of the tuning dial.

R. F. Coils

There are two *r.f. coils* (radio frequency coils) under the chassis. Each r.f. coil has the basic construction shown in Fig. 20, in which there are two windings placed side by side on a waxed cardboard or Bakelite coil form. These windings may either be in a single layer as shown in Fig. 20,

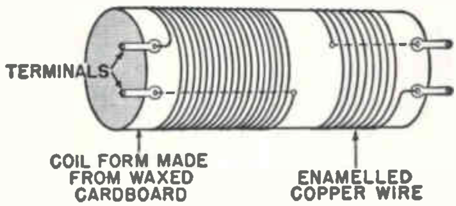


FIG. 20. Construction of an r.f. coil.

in many layers wound one over the other in a criss-cross manner as they are on one of the coils in this receiver, or even with one coil wound right over the other.

One of the r.f. coils is known as the *antenna coil*, because it has a direct connection to the antenna terminal of the receiver. Its job is to transfer the incoming modulated r.f. carrier signal from the antenna circuit to the grid circuit of the mixer-first detector tube.

The other r.f. coil is known as the *oscillator coil*, because it is a part of the tuned circuit of the r.f. oscillator.

These r.f. coils work hand in hand with the two sections of the gang tuning condenser to let only the one desired carrier signal get through the receiver.

R.F. coils have much the same troubles as i.f. transformer coils. Thus, they may have broken wires or poor connections at terminals. Sometimes adjacent turns of wire may touch each other and cause shorted turns. When a radio man finds that an r.f. coil is defective, he invariably replaces the coil with a new one, because it is difficult to make satisfactory repairs with the very fine wire used in winding these coils.

Power Transformer

When you see a large, heavy unit like that in Fig. 21 on top of the chassis of a radio receiver, you can be sure it is the *power transformer*.

All connecting wires for the power transformer in our receiver are underneath the chassis. The wires have various colors for purposes of identification.

Construction. A power transformer consists of a number of separate coils of insulated wire, wound one over the other on a core made from thin strips of soft steel stacked together.

Purpose. The power transformer in a radio or television set transforms the a.c. power line voltage to the various higher and lower a.c. voltage values which are required by the tubes in the receiver. Since a television set has more tubes and circuits, the transformers used must be larger to supply the additional power required without getting too hot; but their construction will be the same.

Possible Troubles. A number of defects in receiver circuits can place an *excessive load* on the power transformer. Overloading causes excessive heat which damages the insulation between the windings.

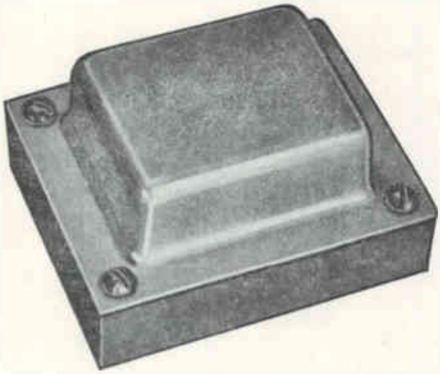


FIG. 21. The power transformer in a radio set is a heavy, bulky unit. It is covered with a metal cap for two reasons, to protect prying fingers from the high voltages that exist in the coils of wire inside, and to prevent the magnetic effects inside from escaping and interfering with other parts.

When the insulation on the wires or between the coils of a power transformer loses its insulating qualities because of heat, adjacent turns touch each other and cause a short circuit. This allows more current to flow, and produces still more heat. The condition becomes worse and worse. Eventually the trouble becomes so bad that the wire in the transformer

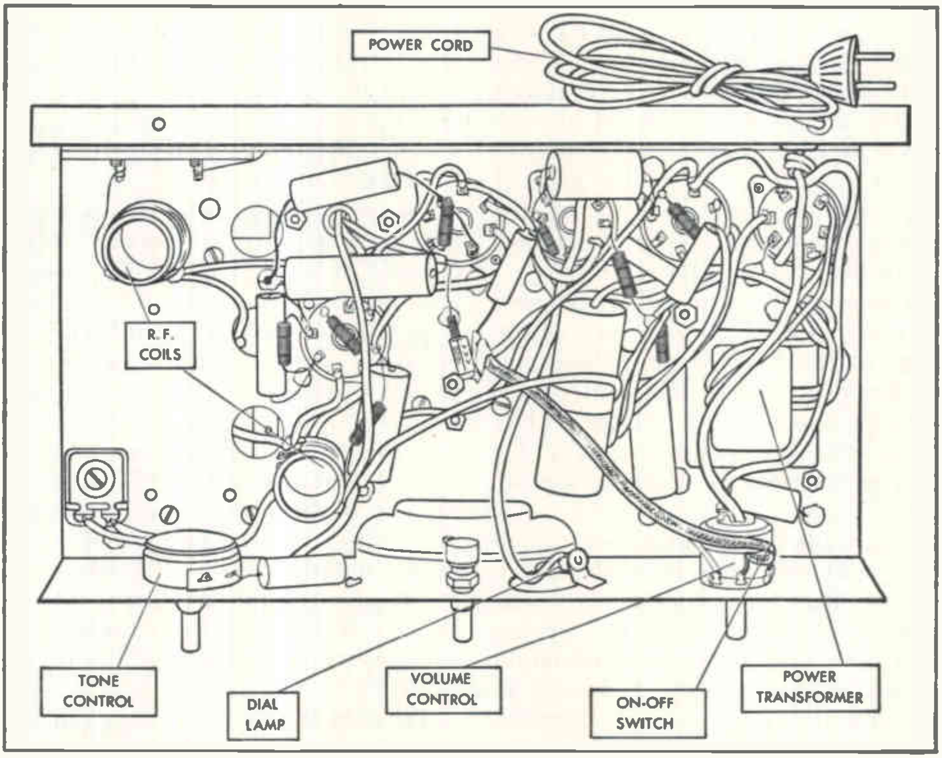


FIG. 22. Additional under-chassis parts of our superhet receiver are identified in this view.

melts and opens up at some point, causing complete failure of the receiver.

A radio serviceman often relies upon his nose to tell him when a power transformer is bad. Failure of this part is usually due to the overheating just described. The resulting smell of burned insulation is easily recognized, hence a radio man suspects the power transformer first of all whenever he encounters this strong, unpleasant odor of burned insulation.

An ordinary break in one of the wires inside a power transformer is rather rare, and yet may happen occasionally. Either voltmeter or ohmmeter measurements at the power transformer would reveal this trouble. Poor connections at the power transformer terminals would have a similar effect.

Defective power transformers are replaced rather than repaired. The replacement offers no difficulty if you make a careful diagram of the original connections before disconnecting the damaged transformer.

Other Under-Chassis Parts

As you can see in Fig. 22, there are still quite a few parts underneath the chassis of our receiver which have not yet been taken up. Most of these are highly important parts which often require attention by a radio serviceman, so a brief study of each will be well worth while.

Power Cord. One trouble which

occasionally baffles even the most expert radio man because of its very simplicity and obviousness is a *defective power cord.* This cord, shown in Fig. 22, serves to connect the receiver to an a.c. power line. The cord has a standard wall outlet plug at one end, and the two leads at the other end connect to two points underneath the chassis of the receiver.

The most likely places for trouble to occur in a power cord are at the plug, at the receiver connection, and at the point where the cord passes through a hole in the chassis. Examine all these places carefully for poor connections or damaged insulation.

The rubber used in a power line cord ordinarily lasts only about five years. Therefore, whenever you encounter an old receiver having brittle or cracked rubber insulation on the power line cord, it is best to install a new cord. The replacement job is quite simple, as it involves the resoldering of only two connections.

Always examine the power cord plug carefully whenever you work on a receiver, to make sure that there are no loose strands of wire which might eventually touch the opposite terminal of the plug and cause a short which would blow the fuses in the house. Tighten the screws in the plug if they are loose.

On-Off Switch and Volume Control. As you already know, a single control knob serves for both of these parts. The on-off switch is mounted at the back of the volume control. The switch is connected in series with one of the power cord wires, so that it can open the power supply circuit.

The on-off switch rarely gives trouble. About the only thing you need watch for is a poor connection at either of the two switch terminals.

The volume control is definitely a trouble-maker, however, in any radio receiver. In this set, it is in the circuit of the second detector, and governs the strength of the audio signal, which is fed into the first a.f. stage by the second detector.

The volume control in this receiver is a type of variable resistor which consists of a strip of carbon resistance material, and a rotating contact arm which sweeps over the carbon material. The contact arm can be set to make contact at any desired point along the resistance material.

If the carbon material in a volume control wears away through repeated use, or if the contact arm becomes loose, we have the equivalent of a poor connection. The radio man says the volume control has become *noisy,* because a noise is heard from the loudspeaker every time the control is adjusted.

The only remedy for a noisy volume control is replacement with a new volume control. It is usually customary to order a new switch at the same time, since the two are furnished as a single unit.

If you make a rough picture diagram of the connections to a defective volume control before removing it, you should have no trouble in making connections to the new unit. Even experienced servicemen follow this procedure, to reduce chances for mistakes.

Shielded Wire. One of the leads going to the volume control in our receiver is enclosed in a tube of braided wire which serves as a shield. This shield is necessary to prevent that particular wire from being affected by stray electric and magnetic fields around the chassis. Without this shielded wire, the set might have an annoying squeal or hum.

Tone Control. The tone control circuit in this receiver consists of a variable resistor connected in series with a condenser in the audio output stage. The condenser side-tracks the higher audio frequencies, and the variable resistor determines *how much* the higher frequencies will be side-tracked or suppressed. This variable resistor thus controls the *tone* of the program coming from the loudspeaker.

The tone control resistor is less likely to cause trouble than the volume control, but the two parts are similar and do have the same types of trouble.

Dial Lamp. Mounted behind a hole in the front of the chassis is a small socket containing a *dial lamp*, also known as a *pilot lamp*. This lamp illuminates the tuning dial when the receiver is turned on, and thus also serves to indicate whether or not the receiver is turned on. The dial lamp in our receiver requires a voltage of 6.3 volts, the same as the filaments of the tubes in the set. The lamp is therefore connected in parallel with the tube filaments.

There is only one wire connection to the dial lamp and to each tube filament, because the circuit to the other terminal is in each case completed through the metal chassis. This arrangement is common practice in radio sets, and is illustrated in Fig. 23.

A dial lamp has about the same life as an ordinary electric light bulb in a home, and hence requires replacement occasionally. The easiest way to insure getting the correct new lamp is to take the old bulb to the radio supply store and ask for a similar new bulb.

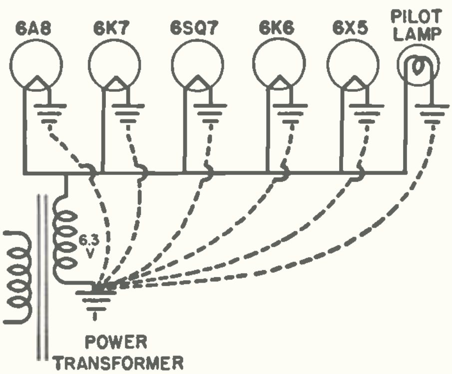


FIG. 23. Filament circuit, with dotted lines indicating the connections that are completed through the chassis of the receiver. All tube filaments and the pilot lamp require 6.3 volts, and the transformer secondary provides this voltage.

When ordering a dial lamp by mail from a catalog, select one having the same type of base, the same voltage rating, and the same color of glass bead inside the lamp as that in the original. The color of this glass bead is a clue to the current required by the lamp.

In some receivers, the color of the glass bead is unimportant, but in others the wrong pilot lamp can definitely cause tubes in the receiver to burn out, as you will learn later.

Tube Sockets. The five tube sockets on the chassis of this receiver are of modern design, and rarely if ever give trouble. However, on older sets you will occasionally encounter tube socket contacts which do not grip the tube prongs tightly enough. If it is impractical to tighten the socket clips sufficiently, a new socket must be installed. The installation of a new tube socket should offer no difficulty to you even right now, if you make a careful sketch showing how connections were made to the various terminals of the old socket before you remove it.

When sockets are riveted to the chassis, they can be removed by drilling out the rivets. The new socket can be mounted with bolts and nuts or with new rivets.

Conclusion. Remember that failure of a radio and television receiver is due to some simple breakdown in one or more of its parts. The breakdown is purely mechanical, such as a broken wire, a defective terminal, or parts touching each other. Usually the breakdown can be seen if you go to the trouble of taking the defective unit completely apart.

Of course, it is impracticable to take apart every unit in a receiver when hunting for trouble. You won't have to do this, because the knowledge of how radio parts work in circuits and the radio servicing techniques you learn in the NRI Course will enable you to locate defective parts speedily with simple test instruments. In some cases, you will even be able to spot the guilty part by noting the manner in which an ailing receiver is operating.

Radio Receiver Servicing Techniques

If you have twelve identical radio receivers all with the same trouble, and give these receivers to twelve different radio servicemen for repair, the chances are pretty good that each man will use *a different method* for locating the trouble!

This is an entirely normal condition, because radio servicing techniques depend a great deal upon the amount of training and experience a man has. All twelve men will undoubtedly find the trouble, but some will find it much faster than others, because their methods are more efficient.

To illustrate some of the methods which could be used to find trouble in a receiver, let us imagine that you have a defective receiver for repair.

Check of Performance. All servicing methods start with a thorough check of performance, to see just how the radio receiver is misbehaving. Oftentimes this check gives valuable clues to the source of trouble.

To make a performance check, you plug the receiver power cord into a wall outlet, make antenna and ground connections if the set does not have a built-in aerial, then turn on the receiver and attempt to tune in stations. You note how the volume control, the tone control, and any other controls affect performance. Your training and experience have taught you to pay particular attention to unusual squeals, noises, or hum, because each tells its own story of trouble.

Testing Tubes. Since bad tubes are common causes of trouble in receivers and since tubes are easily tested, your next step is a test of each tube in the receiver. Tubes should be tested at some point in the servicing procedure anyway, so this might as well be done first of all since it is so easy.

A beginner might prefer to check the tubes later if he didn't have a tube tester, for he would usually have to take the tubes to some reliable store for testing.

An expert serviceman might be able to figure out where the trouble is just by listening to the receiver, and clear up the trouble before making a routine check of the tubes. In the great majority of cases, however, you will find that tube testing comes first on the serviceman's list of trouble-hunting techniques.

Your aim in servicing is to narrow down the trouble first to a section of the receiver, then to a stage, and finally to just one circuit and to a particular part in that circuit.

The average superheterodyne receiver can be divided into six sections for servicing purposes. The *preselector* section includes all circuits between the antenna and the mixer-first detector. The *frequency converter* section includes the local r.f. oscillator stage and the mixer-first detector stage. The *i.f. amplifier* includes all i.f. stages and i.f. transformers. The *second detector* is just one stage. The *audio* section covers everything following the second detector, including the loudspeaker. The *power pack* section includes the rectifier tube and its associated parts.

Sometimes an experienced, properly trained serviceman can tell the section containing the trouble just by listening to how the receiver is misbehaving. If the faulty section has more than one vacuum tube stage, he then makes simple tests which isolate the defective stage.

Other servicemen prefer to start right in with tests which locate the defective stage. Let us select just two of these tests now, and see how you would carry them out.

Circuit Disturbance Test. For a dead receiver, the simple circuit disturbance test is one of the fastest and most effective of these tests for locating the defective stage. It is carried out by introducing an electrical disturbance in each tube circuit in turn while the receiver is turned on.

You start at the audio output stage (next to the loudspeaker) and work backward through the stages when carrying out the circuit disturbance test. The disturbance which you introduce causes a click or thump in the loudspeaker when all the stages between the point of disturbance and the loudspeaker are good, but no click is heard when you arrive at the defective (dead) stage.

The electrical disturbance for this test can be inserted in a stage by removing a tube momentarily, by touching the top cap of the tube if there is one, by removing and replacing the top cap, or by shorting the grid of the tube momentarily to the cathode of the tube.

Since you must go from tube to tube in a definite order if a circuit disturbance test is to be effective, one requirement for making this test is the ability to identify the various tubes on top of the chassis.

Stage-Isolating Procedure. For some receiver troubles, such as low volume, you introduce a test signal in one stage after another, working toward the antenna. Again the loudspeaker tells when you have come to the defective section or stage, because the introduced signal will increase in volume for good stages but not when you move through the defective stage. For each other type of receiver complaint, there are one or more professional techniques for tracing the trouble.

Locating the Defective Part. Having located the defective stage in our ailing receiver, you could now follow the practice of some servicemen and begin testing the parts in the defective stage, one after the other. This eventually locates the defective part, but it can take a lot of valuable time.

A professional radio serviceman, however, would make additional general tests which gradually narrow the trouble down to a particular circuit in the stage. Then, by testing only a few radio parts at the most, he would locate the defective part in the quickest possible time.

It is in locating the defective stage and circuit that we find such a great variety of servicing techniques. There is no one technique which can be considered the best for all jobs; each has its own advantages, and will work best in a particular job.

Television Servicing. A television receiver has a sound section and a sight section. The procedures for servicing the sound section are identical to those used for the radio receiver. The fundamental principles used in these procedures will also be shown, later in the Course, to have special applications for use in servicing the sight (video) section of the television receiver.

Short Cuts. After years of experience in radio servicing, a man learns to associate certain ailments and symptoms of a receiver with definite defects. He can then take short cuts through the general servicing procedure which bring him more rapidly to the defective part. One important requirement for taking any short cuts, however, is a thorough knowledge of radio fundamentals. Unless these are thoroughly mastered, radio and television servicing becomes an unprofitable guess-and-try proposition.

Guess-Work Won't Pay. If you consider how many different tubes, resistors, coils, condensers, transformers, connections, and other parts there are in a radio receiver, and remembering that there are several times as many in the television receiver, the folly of expecting to service receivers simply by testing one part after another without thinking becomes clearly evident.

Looking Ahead

Having now completed the groundwork for your study of radio and television, you are ready to add to your knowledge of how radio parts work and what they do.

In the next Lesson you will study different types of resistors, and learn how they are used in practical radio circuits to control voltage and current. The two following Lessons will cover coils and condensers in the same thorough manner.

This next group of three Lessons will thus complete your knowledge of three important parts used in radio circuits.

Lesson Questions

★ **LESSON NUMBER FOUR** ★

Try your hand at answering these examination questions if you wish, but DO NOT send in your answers for grading. You can understand why we feel obliged to reserve the full time of our instructors for our students and graduates.

1. If there is no set screw on the control knob of a receiver, how would you remove the knob?

2. Why is a shield placed around one of the tubes in our superheterodyne receiver?

3. Name three ways in which radio and television tubes commonly fail.

4. If a radio receiver sounds distorted, and you can hear a rubbing sound when you push the loudspeaker cone in and out with your fingers, what is the trouble?

5. You are tuning a radio receiver towards one end of the dial. The set suddenly goes dead as you tune, and all you can hear is the noise caused by the gang tuning condenser plates scraping against each other. How would you correct this trouble?

6. State briefly the purpose of the small trimmer condensers which are mounted on top of the gang tuning condenser.

7. What type of meter is ordinarily used to locate shorted or leaky paper condensers?

8. What happens to a power transformer when you overload it by drawing too much current from it?

9. How many connections must be unsoldered in order to disconnect the power cord of an a.c. superheterodyne receiver like that studied in this Lesson?

10. At what stage do you start, when using the simple circuit-disturbance test in a dead receiver?

THE VALUE OF COURTESY

A recent survey showed that people complain more about discourteous clerks than about any other fault a business could have. In fact, many people pay extra at higher-priced stores just to get the courtesy and respect they feel entitled to.

Regardless of whether you work for someone else or have a radio business of your own, plain ordinary courtesy can bring many extra dollars to you.

Courtesy becomes a habit if practiced long enough. Be courteous to everyone—to members of your family, to those who don't buy from you, even to the very lowest persons who serve you—then you can be sure you'll be courteous when it really counts.

Give your courtesy with a smile. There is an old Chinese proverb which says, "*A man who doesn't smile shouldn't keep a shop.*" And you're keeping a "shop" even if you are selling only your ability and knowledge to an employer. A friendly smile is itself courtesy of the highest type, bringing you unexpected returns in actual money as well as friendship.

J. E. Smith

SERVICING ELECTRIC TOASTERS

9AA

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

ESTABLISHED 1914

STUDY SCHEDULE NO. 9

For each study step, read the assigned pages first at your usual speed, then re-read slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each step in this same way.

☐ **1. Introduction .... Pages 1-3**

This section will give you an over-all view of toasters and their servicing.

☐ **2. Toaster Types .... Pages 4-10**

The various types of toasters which the serviceman is apt to encounter and the theory of their operation are discussed here.

☐ **3. Non-Automatic Toasters .... Pages 11-14**

Specific servicing data for several models of these somewhat obsolete, but still often encountered, toasters are given here.

☐ **4. Semi-Automatic Toasters .... Pages 14-15**

Here is a set of servicing instructions for a typical semi-automatic toaster.

☐ **5. Automatic Clock Timer Toasters .... Pages 15-17**

Operating and servicing instructions for a single slice Toastmaster Mode 1A2-1A4 and a Sun Chief Series 623 are included in this section.

☐ **6. Flexible or Stove Timer Automatic Toasters .... Pages 18-30**

There are probably more of this type of automatic toaster than any other. Instructions for four typical models are given here.

☐ **7. The Automatic Combination Clock Timer Thermostatic Switch Toaster .... Pages 30-36**

Servicing the Westinghouse Model TO-521, a typical toaster of this type, is discussed in this section.

☐ **8. Answer the Questions at the end of the Lesson.**

☐ **9. Start studying the next Lesson.**

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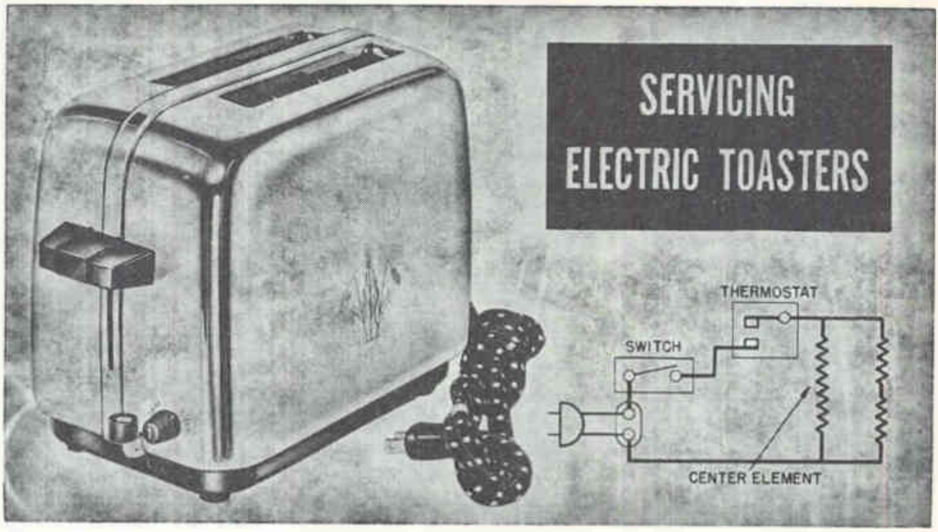


Practically every household in the United States that has electricity uses an electric toaster. It is probably one of the most popular appliances in use in the home today and will continue to be as long as toast and coffee are breakfast staples.

Toasters are among the simplest electrical appliances. A heating element, or elements, produces the intense heat needed to toast the surfaces of a slice of bread, which is placed in close proximity to it. In its simplest form an electric toaster consists merely of a frame which supports the heating element and a rack which supports the bread which is to be toasted.

Elements are made of Nichrome ribbon wound on mica sheets or nichrome coils suspended on suitable supports. In an earlier lesson, we described the resistance wires used in heating appliances. Nichrome is the trade name of an alloy heating wire consisting of 80% nickel and 20% chromium. Other alloys are used for heating elements and are available under different trade names. All contain nickel and chromium as their basic materials.

The first simple toasters consisted of the heating element and suitable doors mounted upon a metal frame. They have developed from the single-element manually operated type of many years ago to the fully automatic pop-up types, which are now the most popular. Today's models have added auxiliary equipment to make them fully automatic as well as modern in appearance.

The auxiliary equipment includes a timing device, which may be either a clock or a thermostat, and a thermostatic compensator to get the same color toast consistently, from either a hot or cold (just switched on) toaster. It also includes a mechanical means of raising the toast without throwing it out of the toaster when the cycle of toasting has been completed.

A device known as a dashpot is used to prevent a rapid rise in the pop-up toaster. This consists of a

Photo above, courtesy Nelson Machine and Mfg. Co.

small piston-like mechanism which is linked to the carriage or the bread rack of the toaster. As the carriage is raised by considerable spring pressure, the piston is forced into a small cylinder and builds up a pressure. This pressure is released rather slowly, thus dampening the speed of the carriage in its upward movement.

Most home toasters are designed for one or two slices of bread at one time. However, larger ones are available for commercial use, although it isn't likely that you will have occasion to service one, unless you decide to expand into the commercial field.

In this lesson we will learn to service the more popular types, of which the two-slice toaster predominates. As a matter of fact, non-automatic and single-slice toasters are in little demand today. However, so many have already been sold, because they are cheap, that you will undoubtedly be called upon to service them sooner or later.

A moment's thought will show that the electrical system of a toaster is not very complicated, and little time should be taken to determine the cause of failure. In the non-automatic toaster either the elements burn out, or the electrical connections become loose or broken. Loose connections will cause the terminal to turn blue with the heat produced at the point of poor contact.

In automatic toasters these difficulties will also be found with the addition of poor or broken contacts in the thermostatic switch mechanism. The major part of your toaster repair work will be of a mechanical nature, consisting of repairing or replacing bent, broken, or worn parts, as well as cleaning and polishing.

If a burned-out heating element or broken connection cannot be easily seen, you will use your tester for locating the fault.

The tools required for toaster repair are few, although a very few require special tools. The following should be sufficient:

- Pliers
- Hand files
- Small drill
- Allen wrenches
- Small and medium size screwdrivers
- Polishing equipment
- Philips Screwdriver

Other tools that might speed your work would be:

- Set of small socket wrenches
- Small riveting tool
- Tool for making springs (coil type)
- Nichrome ribbon or wire
- Splicing sleeves
- Motor driven grinder

We have suggested nichrome wire or ribbon in case of delay in getting a new heating element from the toaster manufacturer. Patched-up heating elements should be discouraged because they often overheat, and are short-lived. However, sometimes a customer can be satisfied by a temporary repair while waiting for the replacement unit to arrive.

Mending Sleeve. A mending sleeve can be used to repair a break in an open coil or ribbon heating element. The mending sleeve is merely a length of hollow metal tube with fairly soft walls so that it can be flattened or crimped between the jaws of a pair of gas pliers. The two ends of the heating element to be repaired are straightened and inserted into the tube, one from each end. The tube is then crimped over the element by means of a pair of gas pliers. This will not make a permanent repair, and it should be remembered that if a heating element breaks in one place, it is probably weak somewhere else and so before too long the same trouble will occur again.

For this reason you should emphasize to your customer that the repair is at the best only a temporary one and, if the same fault recurs, he will be likely to be charged for the same job again, plus the cost of any new parts. However, the mending sleeve does make it possible to repair elements in old appliances for which it is impossible to obtain replacements.

To a certain extent, toaster repairs can be made without completely disassembling the toaster. This is something that will vary with each individual toaster and can generally be determined by observation. After working on toasters for a while, the experience you will have gained will make your observation more effective and you will be able to go much faster in your work without wasting time on unnecessary disassembly.

In all appliance repair work, and this is especially true with toasters, it is most important to observe the order of parts when disassembling. This can save you many hours on reassembly. Until you get quite a bit of first hand experience, you should study each toaster closely until you feel that you understand the function and action of each part. Very often you will think that there are a lot of little pieces that have no value. This is not so. Each part serves a particular purpose.

It may be that there are much simpler methods of accomplishing a certain action, but keep in mind that toaster manufacturers are very competitive and patent ownership will often dictate the methods used in various manufacturer's products.

Thus far we have discussed toasters in general and mentioned the tools required for servicing, as well as others that would speed your work. Now we will get into more detail on toasters.

Toaster Types

The list at the end of this lesson shows 20 manufacturers of toasters currently producing. Many of these have been making toasters for many years. Thus, you can see that there is a great variety of types, sizes, and shapes which you are apt to be called upon to service.

There is no need to describe all these toasters, so we will discuss the representative types of toasters. In some cases two or three of a type will be described because of major differences in their operation.

In most cases the information given in this lesson will be adequate to enable you to repair all makes of toasters. However, occasionally you will come across an unusual model, which has what we call a "trick" method of disassembly or assembly. If you are faced with the job of repairing such a toaster, you should write to the factory service station to obtain manufacturer's service sheets. It may happen, in the case of an older model, that the company is no longer in existence, or that service sheets are not available. If this should happen to you, the best policy is to proceed very slowly before attempting to dismantle any parts in case you damage any irreplaceable ones! Remember that it is very seldom necessary to use any amount of force in disassembling relatively delicate electrical equipment.

The following sections present servicing information on various non-automatic and automatic electric toasters. Quite obviously it is impossible to present servicing information on *every* toaster in production. Nevertheless, by carefully selecting the models, we are able to give you very good general instructions for all and specific instructions for the most popular models.

1. **Non-Automatic.** This toaster is completely manually operated. The elements are "on" as long as the toaster is plugged in, and the bread is inserted or removed by opening the toaster door. In very old models the bread has to be turned by hand to toast both sides. In later ones, opening the door and closing it again turns the bread over.

2. **Semi-Automatic.** This toaster is similar in operation to the non-automatic, but shuts off the current automatically. Some give a bell signal or turn *off* a small glow lamp to tell when the toast is ready. A simple spring motor provides these signals.

3. **Automatic Pop-Up.** This toaster will toast the bread, shut off the current, and raise the toast to where it can be reached by the finger tips. In general, there are four types of automatic pop-up toaster.

a. *Clock timer.* This toaster, when it first came on the market, had a simple clock timer with a speed control knob. Later an auxiliary speed control actuated by a bi-metal strip was added to act as a heat compensator.

b. *Flexible or stove type timer.* The object of the flexible or stove type timer is to compensate for voltage variations and heat storage in the toaster. These toasters are so designed that the same amount of heat is supplied to each batch of toast irrespective of the temperature of the toaster. For example, if the toaster has already been used and is still hot, the controlling mechanism will utilize this accumulated heat for toasting the next batch of bread. Furthermore, if the voltage supplied to the toaster is below normal, this mechanism will keep the current on for a longer time to provide enough heat for the proper toasting process. If the voltage at the toaster terminals is above normal, then the toasting time will be less.

c. *True thermostat type.* This toaster has the thermostat located very close to the bread, where it obtains exactly the same amount of heat as the bread. It is timed to break the circuit and release the carriage when a measured amount of heat has been produced.

d. *Combination type.* This is a combination of a and c. An adjustable clock timer works the pop-up mechanism while a thermostat placed very close to the bread controls the electrical circuit.

All these toasters will be described in detail in the following section, which gives specific servicing information on each type.

Never probe around inside a toaster with a metal object. Not only do you run the risk of getting a shock, or of causing a short circuit between the various sections of the heating elements and the case of the toaster, but also, even if the power is not on, you may damage the relatively delicate heating element wires. In any case, *never* attempt to do any work on the toaster until it has been disconnected from the electrical outlet. If it is necessary to have power on the toaster while observing a test operation, be very sure you know just what you are doing. Do not attempt to make any changes in the test until the plug has been removed from the outlet.

THE ELECTRIC CIRCUITS

The electric circuit of a toaster is probably the simplest part of toaster servicing. It is very similar to the circuits encountered in electric irons. Fig. 1 illustrates the three basic circuits which you will find in servicing toasters. At A of this figure, the simplest circuit, which is used in non-automatic toasters, is shown. This consists of nothing more than a plug, cord, terminals, and a single heating element.

The single heating element is used in non-automatic toasters, because the user must turn the toast over to toast both sides of it. Therefore, only one element is necessary. Servicing the electric system of the non-automatic toaster consists of inspecting and testing the four parts involved, making point-to-point continuity tests, and replacing or repairing parts found defective.

At B in Fig. 1, a circuit which is used in many automatic and semi-automatic toasters is shown. It differs from the circuit shown at A in that it has added a switch and two more heating elements. The switch will be turned on when the desired darkness lever or knob is set in the case of the semi-automatic toaster, or when the handle is pulled down on the automatic pop-up type toasters. On both of these types, when the toast is done, the switch will be automatically opened. The two additional elements make it possible to toast

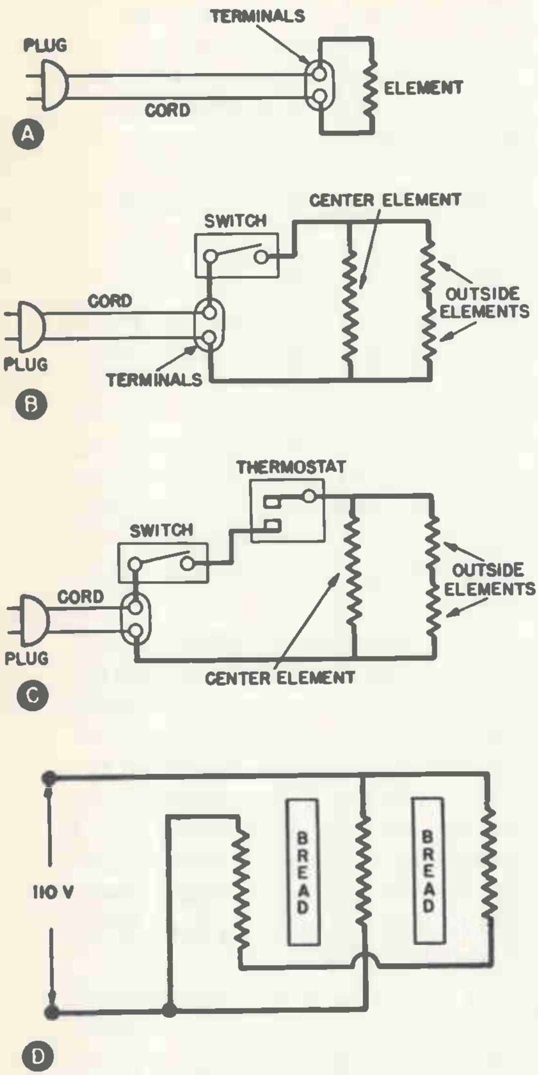


FIG. 1. Three basic toaster circuits.

both sides of two slices of bread simultaneously. The center element is connected across the total 110 volts supply, while the two outside elements which are of lower wattage are connected in series and then across the 110-volt supply. From Fig. 1D you can see that the center element must heat one side of both slices of bread, while the two outside elements each heat only one side of a single slice of bread. Therefore, it is obvious that the center element must produce more heat, and consequently must be of higher wattage and consume more power. If each of the outside elements were of the same wattage as the center element, one side of each slice of bread would be burned before the other side was even brown. In some toasters you may find that the outside elements are connected directly across the 110-volt supply, just as the center element is. But in this instance, the outside elements will be of lower wattage and higher resistance than the center element. You may also find toasters with four elements, all connected across the full voltage.

In Fig. 1C, a circuit which is found in many automatic toasters is illustrated. This differs only from the circuit shown at 1B in that it has, in addition to a switch, a thermostat. The switch in this circuit will be turned on by lowering the handle, which allows the bread to go into the toaster, and turned off either by a clock mechanism or by a thermo mechanism device utilizing a bi-metal strip. When a switch controlled by a timer is used, and a thermostat is added, it is possible not only to vary the color of the toast, but also to vary the degree of hardness, or moisture, contained in the toast. If the timer is set for a relatively short duration of toasting time and the thermostat is set so that the full heat will be on throughout that time, then you will get toast that is crisp on the outside but soft on the inside. At the other extreme, one could set the timer for a long duration and the thermostat for minimum heat, and obtain toast that was light but dry all the way through. Toasters which use this feature in conjunction with the automatic pop-up feature are probably the most completely automatic toasters available.

While the electric circuits of these toasters appear to be very simple, and trouble shooting for electric troubles is accomplished by simple point-to-point continuity checks, the mechanical systems employed are sometimes both complicated and delicate. For this reason, a larger portion of this lesson is devoted to instructions for mechanical disassembly, assembly, and adjustment.

MECHANICAL DEVICES

Before you begin to study the individual toasters, it is necessary that you have a knowledge of the theory of operation of some of the mechanical devices used in them. Therefore, we are going to illustrate and describe the operation of the mechanical devices that you will meet in servicing toasters. None of the illustrations or descriptions given in this section is an exact duplicate of a part used in any specific toaster. They are simply drawn and described so that they may be easily understood. However, if in this section you get a good fundamental knowledge of the theory of operation behind each individual device, you will have little or no difficulty understanding the more complex combinations of the devices used in the toasters.

Clockwork Mechanisms. Watches and clocks, except electric ones, operate on the gradual release of energy that is stored in a spring when tension is placed on it. If an ordinary coil spring which has been wound tight is suddenly completely released, the spring will immediately uncoil, and the energy that was stored in it will be rapidly dissipated. You may, as a youngster, have taken an old watch or clock apart just to see what made it tick, and, after reaching a certain point in its disassembly, had the main spring suddenly release and spread the various parts far and wide. Obviously, this sudden release of energy is useless in any sort of timing device, so we use what is known as an escapement mechanism to control the release of energy from a spring.

In any watch or clock, the escapement mechanism controls the release of the energy contained in the spring so that it revolves a large gear at a very slow rate of speed. This rotary motion is then transmitted through a system of other gears to the various hands of the clock. Much the same thing happens in the clockwork timers used on toasters, except that there is not a complicated system of gears. There is usually a much simpler mechanical device operated by the slowly released tension on the spring.

The Escapement Mechanism. Fig. 2 illustrates a simple escapement mechanism. It consists of a wheel, which the spring tends to turn in the direction indicated by the arrow, and a balance which is pivoted at point A. As the wheel attempts to turn in the direction indicated by the arrow, the action of a tooth on the left hand pawl will force that side of the balance to move in an upward direction. When the left hand side of the balance moves up, the right hand side is forced down, and the right hand pawl will prevent the wheel from moving more

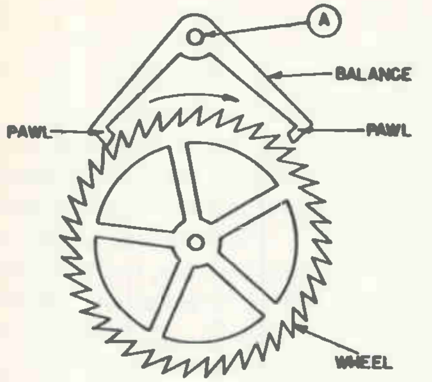


FIG. 2. A simple escapement mechanism for controlling the release of energy from a spring.

than the distance from one tooth to the next. The left hand pawl then drops down between the next two teeth, and the right hand side of the balance rises, allowing another tooth to pass the right hand pawl before the left hand pawl is again forced up by the next tooth. Thus, the balance is continually rocking back and forth, allowing the spring to uncoil only one tooth at a time.

The speed at which the balance arm rocks back and forth, and thus the speed of rotation of the wheel, can be varied by placing various degrees of spring tension against the rocking motion of the balance arm, or by varying friction against any of the rotating parts of the clockwork mechanism.

When clockwork mechanisms are used in toasters, the spring is wound or tensioned when a lever is set which controls the time that the mechanism is to run and, consequently, the darkness of the toast, or, in the case of automatic pop-up toasters, when the lever which lowers the bread into the toaster is depressed. The rotary motion produced by the spring and controlled by the escapement mechanism is used to operate either a cam or a rack and pinion arrangement which will shut off an electrical switch when the spring has unwound to a predetermined point. In addition to cutting off the current to the toaster, the cam or a rack and pinion may be used to release a mechanical latch which will allow the toast to pop-up when done.

Cam. Fig. 3A illustrates the use of a cam to operate an electric switch. When the spring is wound, the cam will rotate in a clockwise direction until what is now the upper end of the detent is in contact with the top blade of the switch, forcing the switch to remain closed until the detent has rotated far enough in a counter-clockwise direction to allow the upper spring blade of the switch to rise and break the electrical contact. Thus the length of time that the toaster circuit would remain energized would be determined not only by the speed at which the clockwork mechanism operated but also by the length of the detent on the cam. The simple switch shown here consists merely of two spring blades with contacts on one end and separated by an insulator at the other end with electrical connections made under the holding screws.

Rack and Pinion. Fig. 3B illustrates the use of a rack and pinion assembly to operate the same type switch as was shown at A. In this arrangement, instead of rotating a cam, the clockwork mechanism rotates a gear or pinion, which is meshed with a rack. The rack is nothing more than a bar with teeth in one side. This mechanism is shown in the position it would assume after the clockwork mechanism had been wound. As the clockwork mechanism rotates the pinion in a clockwise direction, the rack moves to the left until it allows the switch spring to move far enough to break the electrical contact. The mechanical coupling between the rack and the metal switch parts, of course, would have to be insulated, or a ground would occur in the electric circuit.

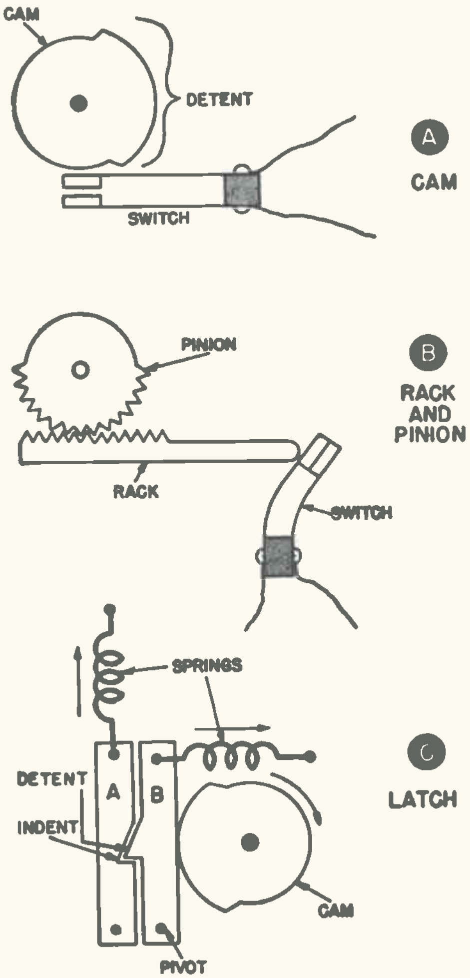


FIG. 3. How a cam can be used to operate a switch, A; B, a rack and pinion used to operate the same type of switch; C, a cam-operated latch mechanism.

Latch Mechanism. Fig. 3C illustrates a cam-operated latch mechanism, but this mechanism could be just as easily operated by a rack and pinion arrangement. Latch mechanisms are used extensively where the pop-up feature is used in a toaster. When the handle which lowers the bread into a toaster is pushed down, the spring in the clockwork mechanism is wound, the cam rotates in a counter-clockwise direction, and bar A is forced down. The detent on the cam forces bar B to the left, forcing the detent on bar B into the indent on bar A as shown. As the clockwork mechanism unwinds, the cam rotates in a clockwise direction as indicated by the arrows. There is spring tension on the two bars as indicated by the arrows, but as long as the detent on bar B is in the indent in bar A, bar A will be held down. When the cam has rotated far enough in a clockwise direction, its detent will no longer be bearing on bar B, and the spring attached to bar B will pull it to the right, pulling the detent out of the indent. The spring attached to bar A will pull it up and pop up the toast.

Similar, but more complicated, latch mechanisms are used in toasters which utilize the action of a bi-metal strip for timing, rather than that of a clock mechanism. You must bear in mind that you will probably never see any of these mechanisms duplicated exactly as shown in these illustrations, because the illustrations are greatly simplified to give you a clearer understanding of their theory of operation.

Bi-Metal Blade. Fig. 4 illustrates a type of bi-metal blade or strip used in some toasters to operate a mechanical timer. You are already

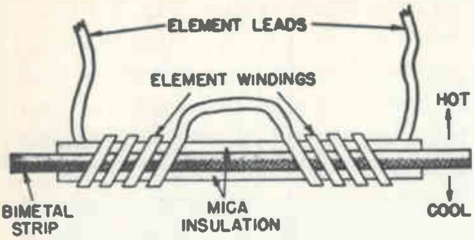
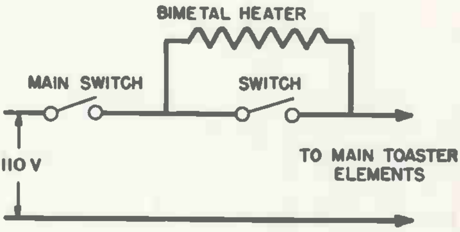


FIG. 4. A bi-metal strip used to operate a mechanical timer.

familiar with the operation of the ordinary type of thermostat in which the bi-metal blade is actually a part of a switch, but in this application, although the blade is used to operate a mechanism which both operates a switch and pops up the toast, it is not actually a part of the switch and no current flows through the blade. The strip is heated by an element which is wrapped around it, but in some cases the heat of the toaster elements is added to the heat from the element wrapped around the strip, thus speeding up the timing operation if the toaster is too hot.

The bi-metal strip is used for timing in the following manner. The strip is mounted at the center and both ends are free to bend when it is heated or when it cools. By restricting the movement of one end, it is possible to increase or decrease the movement of the other. When the toaster is energized by pushing down the bread-lowering lever, current flows through the heating element wound around the strip, and the strip bends in an upward direction. When it moves up, one end of the strip will operate a latch mechanism which closes a switch, cutting the element out of the toaster circuit. The latch mechanism is so arranged that it also sets up another latch which, when the bimetal cools and bends in the opposite direction, will be released, shut off the current to the toaster elements, and pop up the bread. The length of time that it takes for one end of the bi-metal to bend up, shut off the switch and bend down on the cool-off cycle can be varied by adjusting the gap in which the other end of the strip bends back and forth. A smaller gap will result in more rapid action at the other end.

With the foregoing information on basic circuits and mechanical devices used in toasters, you are now prepared to go into a more detailed study of the various types of toasters. As you study the rest of this lesson, look for variations of the circuits and mechanisms which we have described here. You will not find exact duplicates of these circuits and mechanisms, but you will find applications of them in which the theory remains the same.



Schematic diagram showing the element which heats the thermostat bi-metal strip.

Non-Automatic Toasters

The two-slice non-automatic toaster consists of one, and sometimes two, heating elements mounted in the center of the toaster. The doors on either side are hinged at the bottom, and swing out from the top and downward to the horizontal position. Bread is placed on the doors, which are then closed, thus bringing one side of each slice of bread close to a heating element. When one side is toasted, the door is opened manually. The base of the door pushes the bottom edge of the bread outward, letting this edge slide down the length of the door to the top edge. Thus, when the door is closed again, the bread has been turned over and the other side is now against the heating element.

The doors are usually operated independently by small knobs on the ends. A spring common to both doors normally holds them closed tightly. You will encounter some toasters with doors which are connected by a linkage so that both doors will operate by the movement of either one. Some of these toasters also have an indicator lamp or a glow coil to show that the current is on.

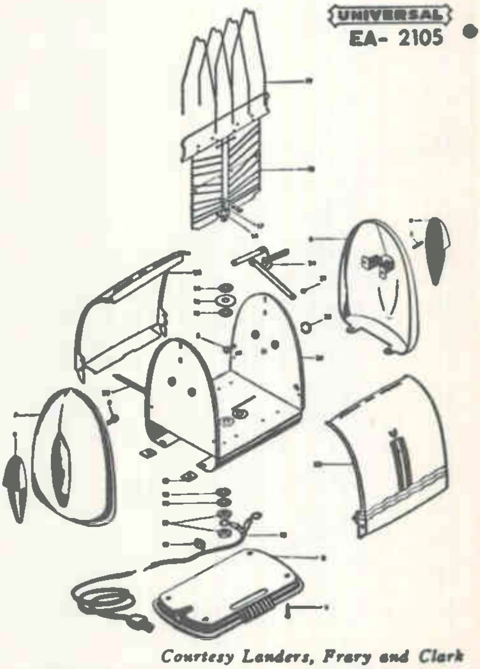
Although one of the earliest of the electric toasters, this type is still being sold because it is very cheap. There is comparatively little to go wrong with these toasters; the main complaint is usually a burned-out heating element. Since there are no thermostats or switches in the heating circuit, repairs are generally confined to replacing the element or, if a replacement cannot be obtained, rewinding it.

Fortunately these elements are fairly well standardized and a glance through the wholesaler's catalog will almost certainly indicate a suitable replacement heater.

UNIVERSAL NON-AUTOMATIC TOASTER, MODEL EA2105

This toaster is rated at 500 watts for use on 110-120 volt ac or dc. It draws 4.5 amperes when operating at this voltage. The heating elements are in series and have a total resistance of 26 ohms.

Operation: When the bread holders are in the open position, they should remain in this position without springing back to the closed position until moved by the operating handle, No. 4 in Fig. 5.

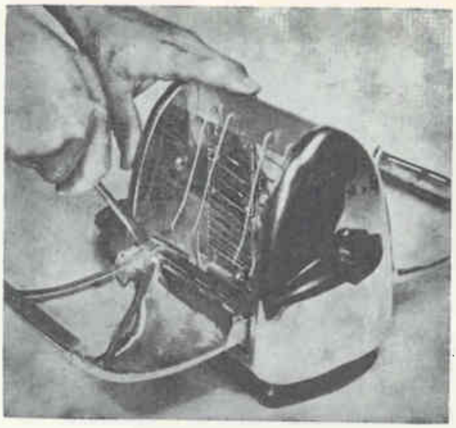


Courtesy Landers, Frary and Clark

FIG. 5. An exploded view of the Universal non-automatic toaster, Model EA2105.

The bread holders (22) should close by themselves when they have been moved by the operating handle to an upright position. They should hold reasonably firm in the closed position, and should not fall open if the toaster is jarred.

The bread holders and body are finished in rust resistant chromium, and mottled bakelite is used for the handles and base. When replacing self-tapping screws in these parts, be careful not to strip the threads, or make the holes too large. If this should happen, plastic wood can be used to fill the holes, which can then be retapped.



Courtesy Landers, Frary and Clark

Removing bread holder from Universal EA2105.

Servicing Procedure. With a small Allen wrench, remove the single set screw holding the operating handle to the door operating shaft (24). With the toaster inverted, remove the four screws on the bottom side of the base, and remove the two hex nuts holding the terminal leads. Remove the base and cordset.

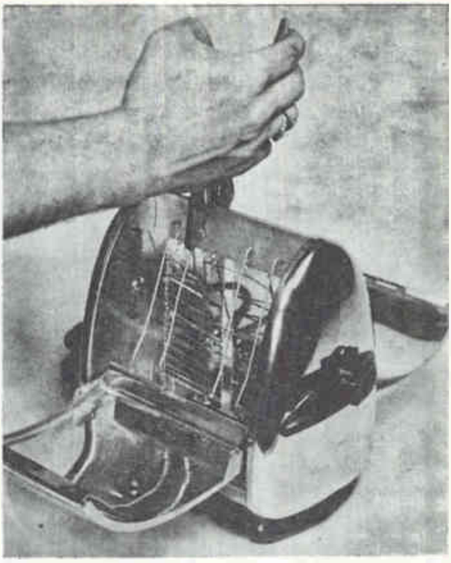
Courtesy Landers, Frary and Clark

Removing body ends on the Universal EA2105.

The two body ends may now be removed. Two screws from the inside hold each of them in place. Also, the stationary handle (9) may be removed by unscrewing two screws. In replacing the body ends, take care to fit the flange on the body *inside* the body ends.

To disassemble the unit and support assembly, the two terminal screws must be completely removed. By gently bending back the two tabs on either side of the support, the unit and support can be detached from the body sides. Be careful not to break off the tabs.

The bread holders are riveted and, after carefully filing or drilling out the rivets, they may be removed. First, remove the bread holder spring and then pry the bread holder out from the body rivets. The operating lever must be filed, or drilled, to detach it from the bread holder. This lever connects the two doors to the operating handle through a linkage.



Courtesy Landers, Frary and Clark

Straightening guide rods in Universal EA2105.

The doors and guide rods (19) are the only components of this toaster which may require adjustment. The bread guide rods may be straightened by using pliers. If the bread holders do not shut tightly, the lever arms should be bent to adjust them as necessary. Take care to prevent friction or rubbing between the mechanical parts.

Many other toasters of the non-automatic type are still in use. Most of them are of the type in which the doors are opened manually by means of small plastic knobs on the top ends.

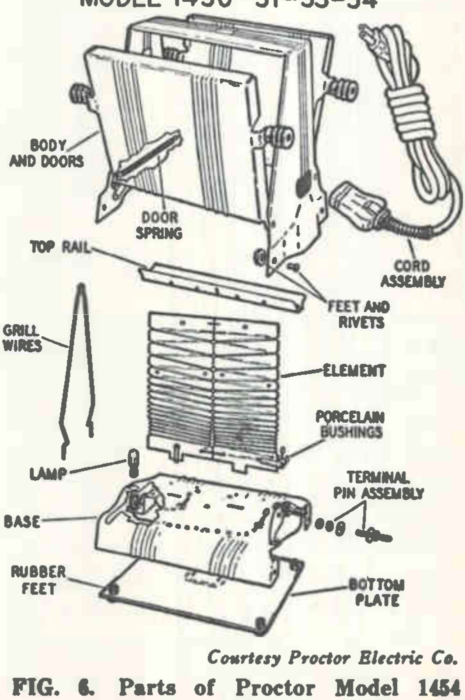
These toasters are very simple to understand and their disassembly is reasonably obvious. Your main difficulty will be encountered where rivets are used, rather than nuts and screws. In such cases, you should carefully drill out the rivets and replace those you remove with small nuts and bolts. Be careful to use the correct size to avoid interference with the proper functioning of the toaster. Be very sparing with lubricants. If too much is used, the toaster will smoke and the bread will taste of oil!

PROCTOR ELECTRIC CO. NON-AUTOMATIC TOASTER, MODEL 1454

This toaster has a detachable cord-set and an indicator light in series with a single element. It toasts one side of two slices of bread simultaneously. Power consumption is 500 watts at 110-120 volts ac or dc.

Servicing Instructions. If the toaster will not operate, test for an open circuit. Look for loose or broken connections. If the indicator lamp fails to light when toaster is operating, remove from socket and check. Fig. 6 shows the parts of the toaster. To disassemble it, proceed as follows:

MODEL 1450-51-53-54



Courtesy Proctor Electric Co.

FIG. 6. Parts of Proctor Model 1454 non-automatic toaster.

Remove the bottom plate from the toaster and then remove the four corner rivets holding the base to the body. Open the doors and ensure that the top rail, which supports the top of the element, is not fastened to the body top at the corners.

With the doors still open, raise the body, thus separating it from the base and the element. Remove the four grill wires projecting through the base. Remove the terminal nuts and washer from the element and lift it out.

The doors and door knobs are held in place by rivets. The door spring spans the space between the two doors and hooks on to a door at each extremity.

The lamp bracket assembly is held in place by bent tabs, or sometimes with rivets as in the terminal pin bracket. Nuts and washers hold the terminal pins onto the bracket.

On reassembly, substitute small screws and nuts in place of any of the rivets that have been removed.

Semi-Automatic Toasters

The semi-automatic toaster is quite similar to the non-automatic type. This toaster will sometimes have a clock-type timer that turns the current on, and winds the clock movement when the operating lever is pushed down.

At the end of the timing cycle, it disconnects the heating element circuit and stops clicking, thus indicating that the toast is done.

Another type of semi-automatic toaster will energize a small magnetic coil when the circuit is closed. This holds a small steel ball above a bell. When the thermostat breaks the electrical circuit, the magnet is de-energized and the ball falls, striking the bell and signaling that the toast is done.

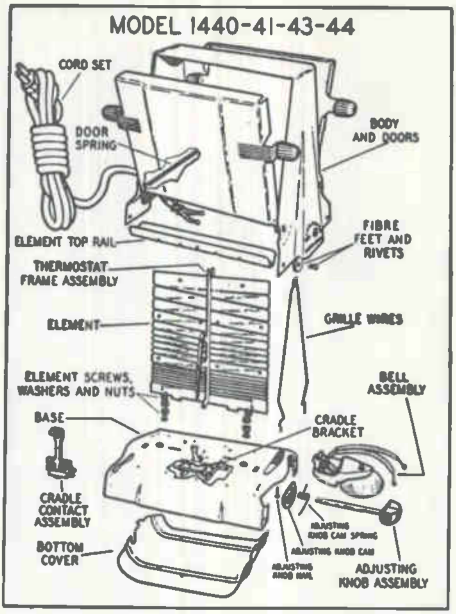
You may find a third type of toaster which has an indicator lamp in the circuit across the element. This lamp will go off when the electrical circuit is opened, indicating that the toast is done.

This toaster is not classed as automatic because it lacks the pop-up feature when the toasting cycle is completed. Such toasters generally have a control knob which allows the operator to adjust for light or dark toast.

PROCTOR ELECTRIC CO. MODEL 1440-41-43-44

This semi-automatic toaster, shown at Fig. 7, incorporates a time-control plus a magnetic coil, steel ball, bell signal as described above. The bread must be turned over and removed by hand just as it is in non-automatic toasters.

Operation. The user places one slice of bread in each door and closes the doors. Then she turns the adjusting knob from the off position to one of the numbers from 1 to 8, depending on the degree of darkness desired in the toast. Turning the knob adjusts the cradle contact assembly so that the contacts are closed, completing a circuit through the contacts, the



Courtesy Proctor Electric Co.

FIG. 7. The Proctor Model 1440 toaster.

element, the bell coil, and back to the other side of the line. As soon as this circuit is complete the electromagnet on the bell assembly lifts the steel ball from the bell, and the element begins to heat. As the element heats, the bi-metal strip that is mounted at the center of the element bends and pushes against the roller at the top of the cradle contact assembly. Adjusting the knob has positioned the contact assembly so that when the toast has reached a certain degree of brownness this bi-metal strip will cause the contacts to open. When the contacts open the circuit, the electromagnet in the bell assembly releases the steel ball and it strikes the bell, signaling that that side of the toast is done. The operator then opens and closes the doors, which turns the toast over, and starts the whole process again until at the second sounding of the bell the toast is done on both sides.

Disassembly. From Fig. 7 you can see that the assembly and disassembly of this toaster are relatively simple, and with the aid of this diagram should be obvious upon inspection of the toaster. The same general instructions as have been given for non-automatic toasters of similar construction will apply to this one.

In all of the previously described toasters, both non-automatic and semi-automatic, you may sometimes have difficulty in obtaining replacement parts because of their age and the fact that they are obsolescent. Because of this, you may have to omit semi-automatic features when repairing such toasters in order to make the toaster operate at all. This is easily done by makeshift means, or by bypassing or shunting the timers, glow coils, or indicator lamps as necessary.

Automatic Toaster—Clock Timer

Toasters under this classification are usually single or two-slice types. A control knob is linked to a small governor mechanism controlling the speed of the clock timing mechanism. Pushing down the control lever until it is latched starts the toasting cycle by closing the contacts, and energizes the heating element.

At the end of the clock mechanism

cycle, the circuit is broken, the carriage release lever is tripped mechanically, and the toast pops up.

More recent models of this type toaster have a bi-metal arm positioned near the bread, and extending back towards the clock mechanism. In one make of toaster, this arm, when cool, acts as a brake on the clock mechanism, thus making its cycle longer.

In another type, the arm makes a direct adjustment on the length of the winding stroke on the flywheel of the clock mechanism. In either case, it acts, to a certain extent, as a compensator for either a hot or a cold toaster.

TOASTMASTER SINGLE SLICE MODEL 1A2-1A4

This toaster, shown in Fig. 8, is a single-slice type, with a clock timing mechanism. Later models of this toaster have a bi-metal compensator which increases the speed of the clock when heated.

The toaster is equipped with a speed control knob governing the clock timing. It has an operating lever, which lowers the toast into the well and at the same time closes the electrical contacts to start the toaster.

Servicing Procedure. The bottom cover and four legs are a single unit, and may be removed by unscrewing the two knurled nuts from the bottom. Remove the two set screws holding the operating handle to the shaft and the very small bolt holding the control knob to the adjusting shaft.

With the toaster inverted, you will find six ears, or tabs, projecting through the base plate. Gently straighten the tabs and turn the toaster upright. This will prevent the guide wires from falling out as the

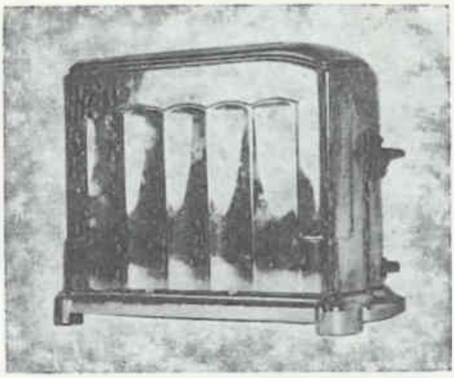


FIG. 8. The Toastmaster Model 1A2-1A4. One-slice toaster.

cover is removed. Raise the cover enough to detach the cordset leads from the terminals and remove the cord from the cover. Continue to raise the cover, guiding it clear of the operating lever.

To remove the elements, loosen the nuts on the long spacer bars passing through the length of the toaster on the top sides, lift the sliding baffles upwards and disconnect the leads from the elements. Remove the ten guide rods resting in the well, remove the horseshoe clip from the vertical shaft projecting through the top frame, and remove the single screw holding one end of the top frame in position. Either element may now be raised up out of the well.

At this point, any parts of the operating mechanism or the contacts may be removed without difficulty. The clock mechanism is also on the control end of the toaster and is clamped in position by a bracket on the top mounted with two screws. After removing the bracket, work the clock upwards until it is clear of the base plate well.

Later models of the toaster are equipped with a compensator. This bi-metal is pivoted from the center bottom of the toaster adjacent to the two heating elements, and is supported on a bracket mounted by screws on each side of the underside of the frame.

There is an adjusting stop about halfway along the bi-metal strip. The end of the bi-metal, when heated, operates a lever extending out from the clock. This lever changes the length of the stroke on the flywheel of the clock, thus shortening or lengthening its timing cycle.

FIG. 9. The Son Chief series 623 automatic toaster.

SON CHIEF SERIES 623 TOASTER, FIGURE 9

This is another clock type automatic pop-up toaster with a bi-metal blade near the toasting well that contacts a lever speeding up the clock mechanism.

Servicing Procedure. Both the operating lever handle and the control knob may be pulled off their respective shafts. The bottom cover of the toaster is removed by taking three hex nuts off the stud bolts passing through it from the frame of the toaster. The porcelain collar through which the cord passes is held in place by a spring clip, which can easily be removed with pliers.

The clock and switch mechanism is mounted on the bottom of the toaster base, and held in place by three screws. Disconnect the terminal leads from the bottom by removing the two hex nuts and washers.

For servicing any of the operating levers or replacing any elements, it is necessary to remove the side and cover of the toaster. This is held in place by four tabs extending from the sides and bent around the bottom of the frame. Straighten these tabs and unwrap the cover from the toaster.

Four screws hold the body of the toaster to the bottom of the frame. Two of these screws (on the control end) also hold the element guide bracket. The other ends of the elements are held in place by their terminal bolts held in place by hex nuts on the bottom of the toaster.

The bi-metal compensator assembly is held by one screw near the bottom center of an outside element.

Because the skeleton of the toaster is rather flimsy after the body has been removed, care must be taken when handling it. Also, note very carefully the relationship of the parts during disassembly.

Positioning the bi-metal strip is the only adjustment on this toaster. For lighter toast, pivot it away from the speed lever arm, and for darker toast, move it closer. Make adjustments with the control knob set about at the midpoint, so your customers will have as wide a range as possible in either direction.

Automatic Toaster—Flexible or Stove Type Timer

In this type of toaster, the thermostat (bi-metallic strip) contains its own heating coil, which is connected in series with the main heating element of the toaster.

When the main contacts are closed, the thermostat coil, being in series with the elements, heats the bi-metal and causes it to bend. At the end of this cycle, the auxiliary switch closes, shunting the coil out of the circuit. As the bi-metal cools and returns to normal, it trips a lever to break the element circuit and releases the carriage, thus raising the bread.

Some toasters of this type also have a "stay-warm" lever to prevent the toast from popping up when it is done.

KNAPP-MONARCH TOASTER NO. 22-501

This toaster requires 115 volts, 1060 watts ac only and is equipped with a control knob and bread carrier handle. It is shown in Figs. 10A and 10B. When the bread carrier handle (28) is pushed down and latched, it closes the main contacts (104 and 105), allowing current to flow through the main elements as well as the heater ribbon (89) located just beneath the bi-metal (65). The heat from the ribbon causes the bi-metal to curve downward towards the upper spring blade (107).

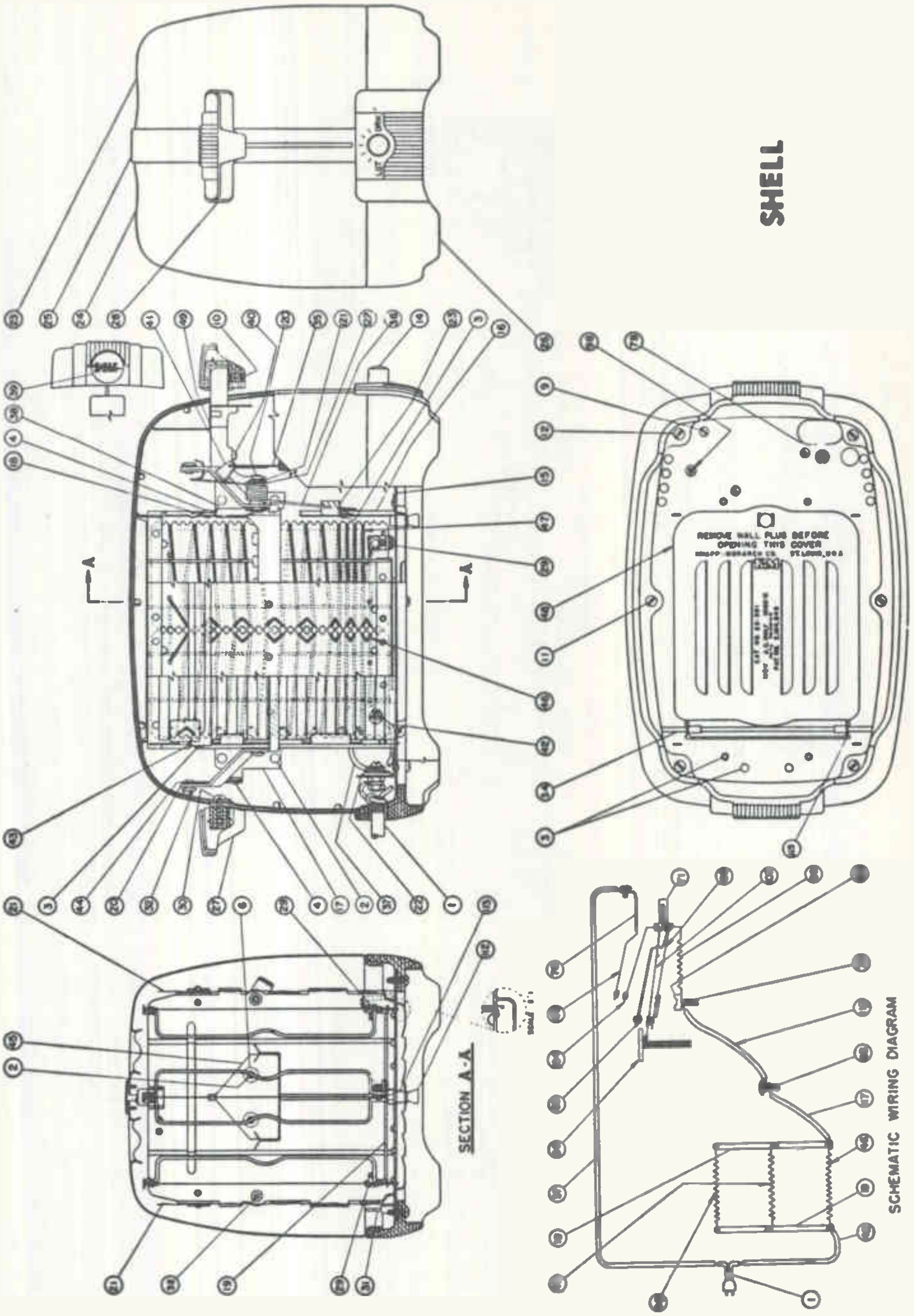
This blade is tensioned upward against the adjustable cool-down limit screw (98). The lower spring blade (108) is also tensioned upward with slightly less tension, thus making contact with the upper spring blade (107).

During the downward movement of the bi-metal, it makes mechanical contact with the upper spring blade, forcing both the upper and lower spring blades downward. Finally, a small magnet on the lower spring blade is attracted by a permanent magnet (90) placed beneath it on the magnet bracket (67). This provides a positive action in opening the contact between the upper and lower spring blades, creates an electrical contact between the magnets, and shunts out the heater ribbon.

The bi-metal then starts its cooling cycle and moves upward until contact is broken with the upper spring blade, which is stopped by the "cool-down" limit screw. Now the current must pass through the "hair-pin" bi-metal (71) which causes the quick release of the bread carrier and ends the cycle. The "hair-pin" bi-metal is in the circuit only long enough to release the carrier, generally for a few seconds.

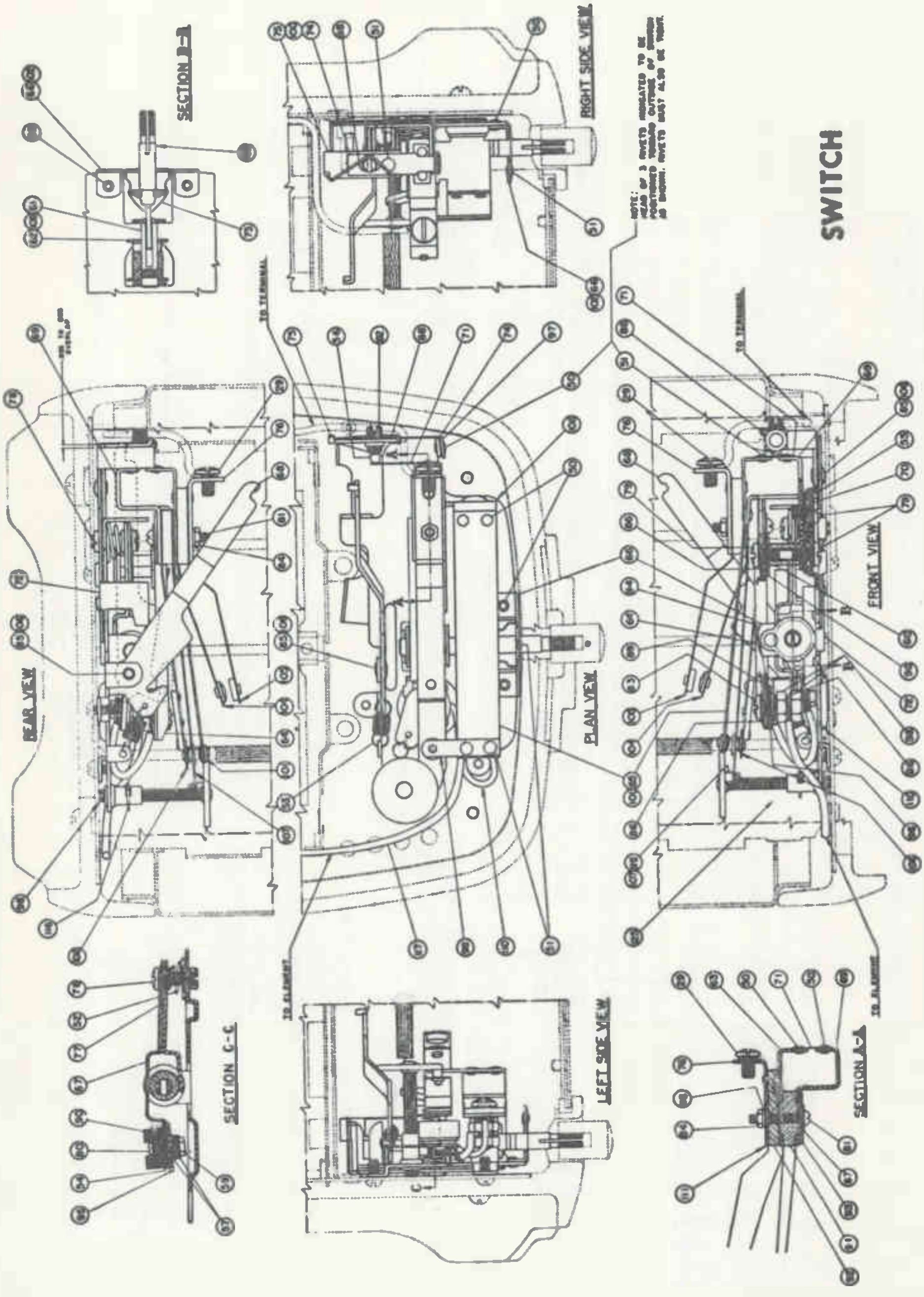
Servicing Procedure. The toaster is disassembled in the following manner. First, remove the single set screw from beneath the carrier handle and remove the handle. With the toaster upside down, remove the six screws passing through the base into the base plate.

Slide the cord into the base a few inches and raise the base far enough to clear the cord end, then slide it off the control knob and lift off.



Courtesy Knapp-Monarch

FIG. 10A. The Knapp-Monarch 22-501 automatic toaster.



Courtesy Knapp-Monarch

FIG. 10B. View of thermostat and switch used on the Knapp-Monarch 22-501 toaster.

With the toaster still inverted, raise the entire assembly out of the toaster shell. You will note, there are three heater elements, the center one being common to the inside surface of each of the two slices of bread. To remove the center element, invert the toaster frame and take out the single screw on each of the two bus bars (19) connecting the three elements together, and raise the element and its guide rods out through the top.

To remove the two outside elements, first invert the toaster and squeeze the split tabs together. These double tabs are located on the ends of the outside elements passing through the base plate. Now place the toaster upright, and slide the outside baffles (21) upward and out. Unscrew the four screws connecting the extremities of the two bus bars with the elements. The elements and guide rods may now be lifted out.

The switch assembly may be removed by disconnecting the lead wires (117) and removing three screws from beneath, which hold it to the base plate. The heater box (64) may be removed by straightening one ear and removing a single screw. This allows you to replace the heater ribbon (89).

Further disassembly of the toaster is of a mechanical nature and requires the removal of numerous rivets. These hold the end plates and the bread rack carrier assembly together. The method and order of their disassembly is apparent from visual examination.

Adjustments to this toaster are rather numerous. There is a control knob for light and dark selection, and two adjusting screws in the bottom; one controls the "cool-down" limit adjustment and the other the magnet bracket.

With the toaster plugged in, push down on the lower spring blade until the permanent magnet holds it down. This will energize the hair-pin bimetal which should release the carrier in from 2 to 5 seconds.

If it does not, it should be adjusted so that the latch escapement (75) overlaps the latching lever (68) by its own width—approximately 1/32 inch. There is an adjusting screw for this. Proper adjustment of this toaster cannot be made without actually trying it on two or three rounds of bread. For adjusting for darker toast, the screws should be turned clockwise.

Reassembly is done in the reverse order.

UNIVERSAL AUTOMATIC TOASTER EA-2601

This toaster requires 1150 watts at 110-120 volts, ac only, and is equipped with a different type of compensator for obtaining uniform toast. This is a two-slice toaster which is operated by putting in toast and pushing down on the operating lever handle. There is a somewhat smaller knob beneath this lever which is also depressed with the same stroke. This is the bread rack knob.

When the hand pressure has been released from the operating lever, it will immediately rise, and the bread rack knob will remain in its downward position. This knob may be raised at any time for inspection of the bread.

The control knob is located beneath the bread rack knob, and controls the speed of the clock mechanism which is variable from 20 to 120 seconds to select the color toast desired.

When the operating lever is depressed, the switch contacts close and remain so, until the toast has popped up. There is a bi-metal strip inside the toaster, which is linked to a small brake on the timer balance wheel; when the bi-metal is heated up, it lifts the brake from the balance wheel and the timing cycle begins.

In this way, with the toaster at room temperature, there will be about a 50-second delay in the clock starting the timer action. With a hot toaster, the timing action might start immediately. Although the elements are always heating after the control lever has been pushed down, there may not be any audible ticking until a short time later.

When the clock reaches the end of its timing cycle, a trigger mechanism breaks the electrical circuit and releases the bread rack, which is forced up by spring pressure.

Servicing Procedure. In order to disassemble this toaster, refer to Fig. 11. Remove the set screws from the operating lever handle, the bread rack knob and the indicator knob and lift off these pieces. Invert the toaster and remove the four base screws and the two cord strain relief screws from the base, and lift it off.

Spread the body cover of the toaster and raise it over the control arms, then lift off the two side panels. Remove the two nuts holding the cord to the terminals. To remove the heating elements of the toaster, disconnect the unit leads from the terminals. Straighten the four lugs of the unit support plates extending through the bottom frame, and straighten the lugs of the unit and bread support assemblies extending through the upper support plates. Any desired unit may be removed.

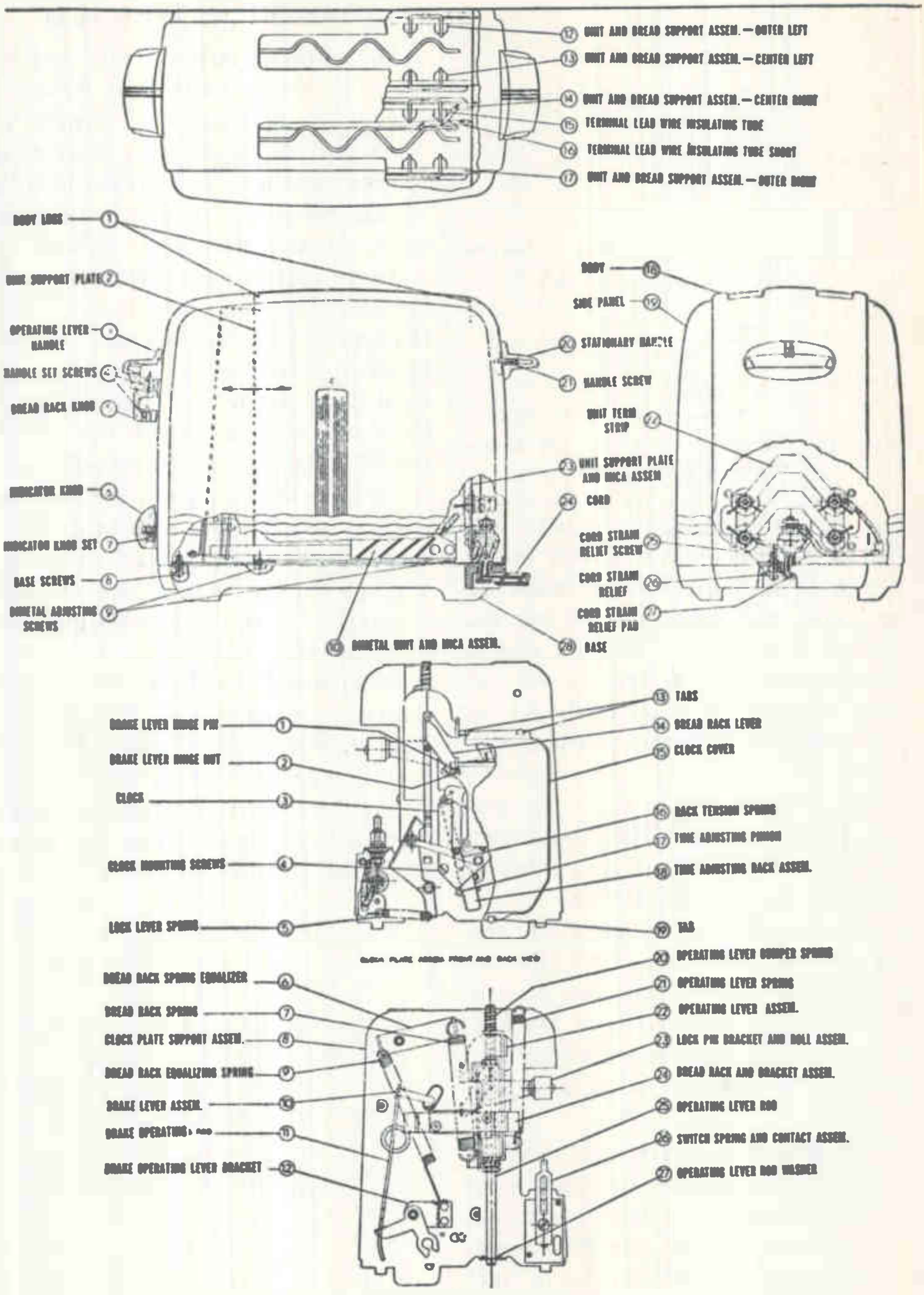
Straighten the three tabs projecting through the clock cover, move the bread rack lever a little to the left and pull the clock cover from the frame.

There are three clock mounting screws and a brake lever hinge nut to be removed before pulling out the clock mechanism. If the clock mechanism is electric, as it is in some models, it will be necessary to remove the terminal leads. If it is necessary to remove the mechanical controls of the operating mechanism, straighten the tabs holding the clock plate assembly to the unit support plate and crumb tray, and lift out the entire assembly, disconnect the bread rack spring and the operating lever springs. Great care must always be used when bending tabs for removal of parts. If any are broken off, reassembly will be difficult.

A small snap ring, or sometimes a small screw, located on the top of the clock plate, holds the vertical operating lever rod in place. After removal of the ring, pull the rod out through the bottom of the plate. Observe carefully the order of parts mounted on this rod to make reassembly easier.

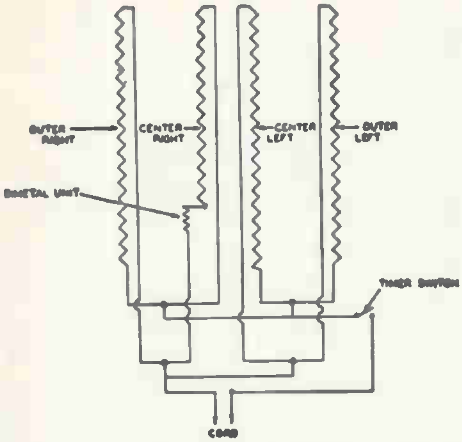
To remove the bi-metal, first disconnect the lead wires coming from the center unit and the bi-metal assembly, then remove two screws, one from each end, and remove the single screw holding the bi-metal assembly to the center right unit.

Adjustments for this toaster are as follows. Starting with a cold toaster, the bi-metal should be adjusted so that within 35 to 50 seconds after the



Courtesy Landers, Frary and Clark

FIG. 11. The Universal Model EA-2601 automatic toaster.



Courtesy Landers, Frary and Clark

FIG. 12. Electrical connector for a mechanical clock timer.

current is turned on, the bi-metal will release the brake on the clock mechanism. This adjustment is made by loosening the screw on the moving end of the bi-metal support and it can be reached from beneath without any disassembly. There should be no rubbing or binding of this bi-metal.

The clock running time should be from 10 to 50 seconds when the control knob is set on LIGHT, and from 1 minute 45 seconds to 2 minutes 30 seconds when set on DARK.

The bi-metal should never be bent, as this will put it out of adjustment. Make sure that the movable contact is fairly well centered with the stationary contact of the switch for best results. This may be bent until centered.

Electrical Connections. As in practically all toasters, the lead wires are of nickel and insulated with asbestos, covered with spun glass braid.

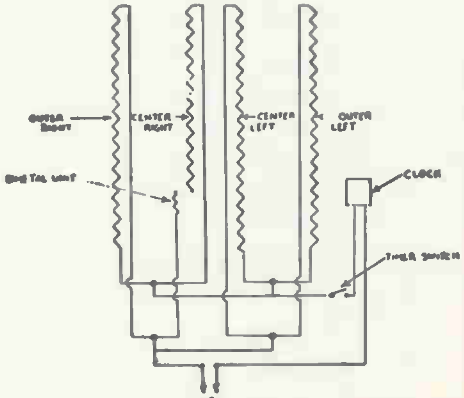
Electrical connections for a mechanical clock timer are shown in Figure 12, and for an electrical clock timer in Figure 13.

TOASTMASTER DOMESTIC TOASTER, MODEL 1B14

The bi-metal strip on this toaster, Fig. 14, has a small coil wrapped around it. This auxiliary element is connected in series with the main heating elements. This results in both voltage compensation (for low supply voltages) and heat compensation.

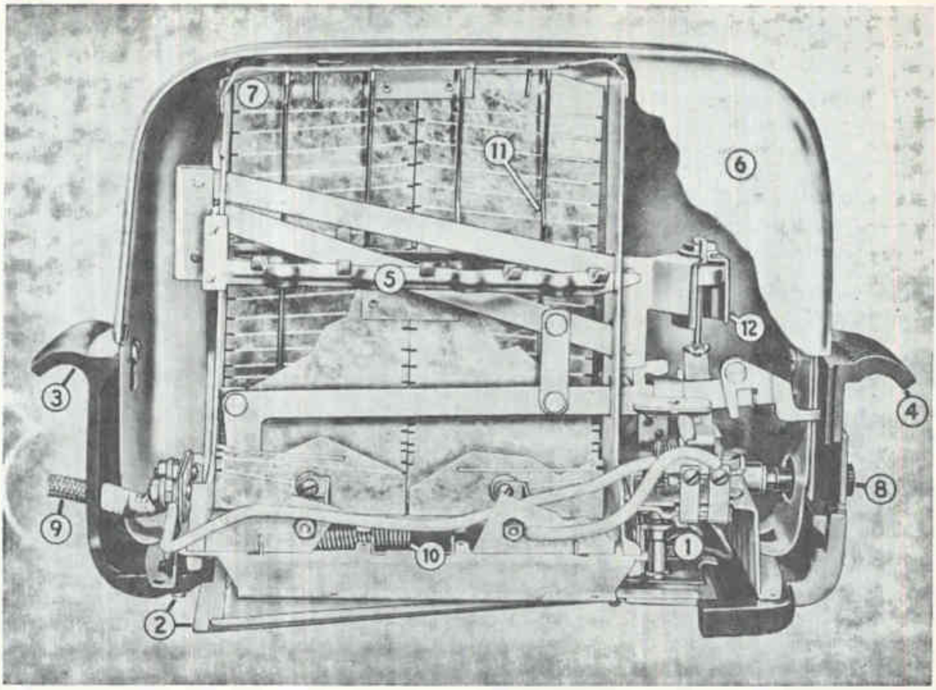
As the carriage is pushed down and latched, the main contacts close and the toasting cycle is started. As the bi-metal heats up, it bends inward until it reaches a point where it trips the shunt lever which cuts the coil of the bi-metal out of the circuit, and the release lever drops in the path of the bi-metal. The bi-metal then starts cooling and bends outward, tripping the release lever, opening the electrical circuit and releasing the carriage.

Servicing Procedure. To remove the case of this toaster, first remove the single set screws from both the operating handle and the timing knob. Invert the toaster, unlatch the crumb tray, and remove the two crumb plate attaching screws.



Courtesy Landers, Frary and Clark

FIG. 13. Electrical connections for an electrical clock timer.



Courtesy McGraw Electric Co.

FIG. 14. The Toastmaster Model 1B14 automatic toaster: (1) timer assembly; (2) undercover; (3) handle; (4) operating handle; (5) carriage; (6) shell; (7) element; (8) timer adjustment; (9) cord; (10) spring; (11) guide wire; (12) damper.

Now remove the four self-tapping screws from the four corners of the bakelite base. There are five other screws holding the bakelite base to the toaster base which should *not* be removed at this time.

Now turn the toaster upright and work the case off by gently rocking it back and forth, guiding the cord into it. If the toaster is not upright, the guide rods will fall out. You will note that the operating lever can be tilted upward so the case will clear it.

The outside element must be removed before the inside element can be removed. First remove the bread guide wires and then remove the hex nuts located at the bottom of the outside elements. After the screws have been removed, press the top of the elements inward until they can be raised up through the bread slots. Now remove the bus bars holding the center elements in place, and remove them upwards through the bread slots. Notice that the elements fit into small slots at the base of the toaster and that the side of the element on which the wire is wrapped faces the bread. The ampere rating of the outside elements is greater than that of the inside elements. Ratings are stamped on the top of the center elements; be sure to replace elements in the proper places.

To remove the switch and trip lever assembly, remove the two screws holding this to the base. The upper switch assembly is held in place with two rivets which may be replaced by nuts and screws on reassembly.

The lower switch assembly is also riveted, but this must be re-riveted on reassembly; therefore, unless you have facilities for riveting, exercise discretion in removing it. The trip lever assembly is removed by working from under the base, spreading the horseshoe washer open, and sliding it off the main trip lever pin. Any of the parts can now be replaced.

The operating time of this toaster is 1½ minutes for the heat-up time of the bi-metal. The cool-off cycle should be complete in another ½ minute.

If further adjustments are needed, try to get a copy of the manufacturer's service bulletin. Some adjustments affect more than one operation.

GENERAL ELECTRIC CO. TOASTER 159T77 AND 179T77

This toaster, Fig. 15, is quite similar in operation to that of the Toastmaster. In addition, it is equipped with a stay-warm device, which is operated by a single lever on the control end of the toaster. It prevents the carriage from rising when the toasting cycle is completed, keeping the toast warm as long as heat remains in the toaster wells.

This toaster has two escapement triggers. The slightly lower one holds the carriage down and holds the main circuit on. When the stove or coil of the bi-metal is shunted out of the circuit, this trigger is released, allowing the latch bar to rise very slightly to the second trigger, which is released at the end of the cool-down cycle of the bi-metal.

Removal of Chassis. Remove the set screw from the bottom side of the handle and slide off handle. Pry off the name plates on both ends of the toaster by inserting a small screw driver between the left end on the nameplate and the slot.

Two end shell screws and a hex nut underneath the top shell hold it in place. Lift it off. If the bread guide wires are not to be removed, wrap an elastic band around them, otherwise lift them out before inverting the toaster.

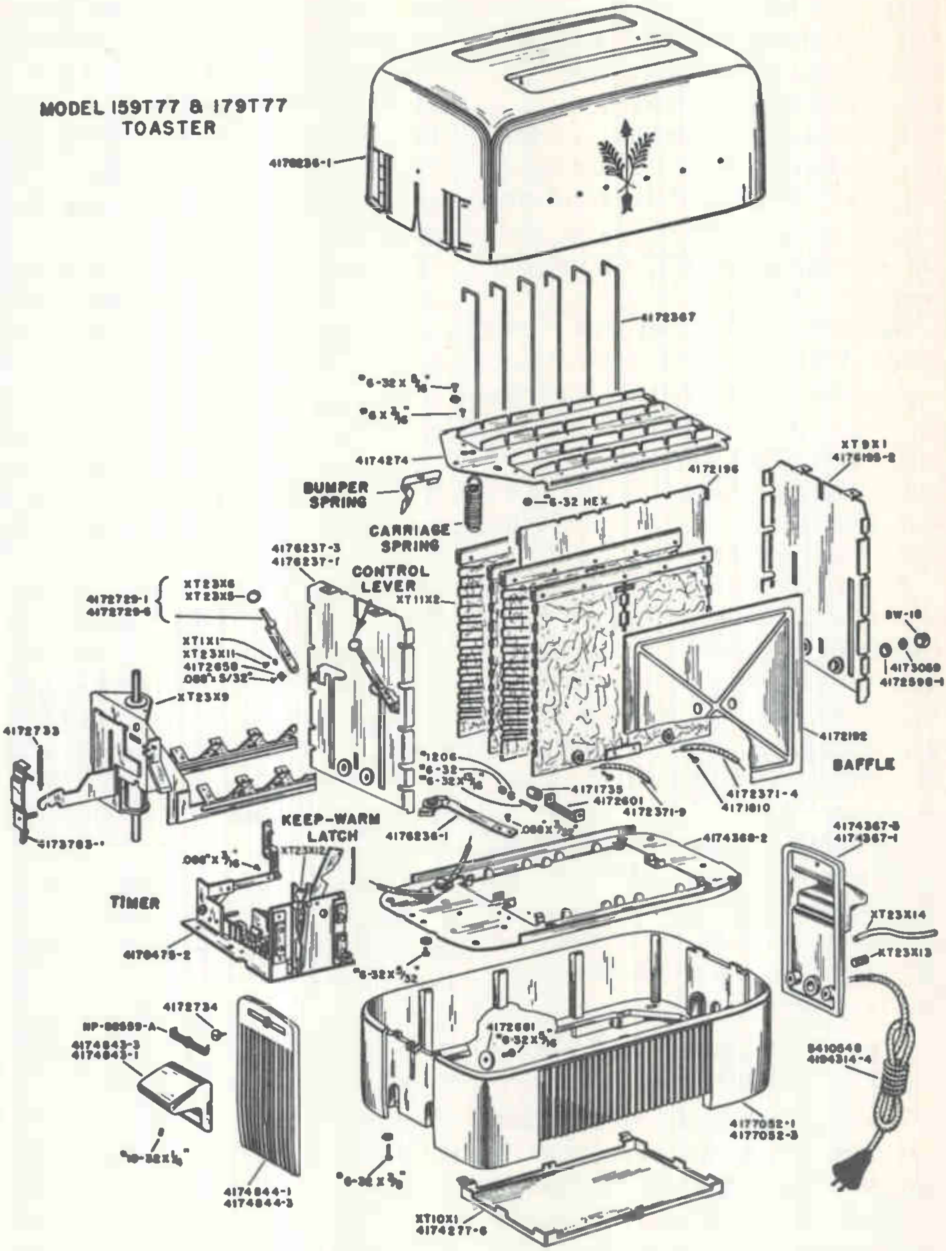
With the toaster inverted, remove the five base screws and lift the chassis off the base by raising the back end and feeding the cord into it.

Removal of Timer. First remove the chassis and then the terminal connection screws holding all leads to the timer. Pull the keep-warm latch from the control lever. Remove the split type rivet holding the control lever and the calibrating link of the timer together. Now invert the toaster and remove the two screws from the bottom that hold the timer to the base.

Removal of Carriage Assembly. Remove the chassis and the bread guide wires as previously described. Remove the carriage spring, the top and bottom center post screws, and the bumper spring. Move the carriage mechanism forward and pull out the center post, then pull the carriage out, taking care not to damage the units.

Observe carefully the order of disassembly of the parts, so you will not be confused on reassembly.

Removal of Heating Elements. Remove the chassis and lift out the baffles (reflectors). At the bottom of



Courtesy General Electric Co.

FIG. 15. The General Electric automatic toaster Model 159T77 and 179T77.

each of the outside elements, remove the two terminal screws and push the carriage in the down position so you can push the top of the outside elements towards the bread well, and lift them out of the frame.

To remove the inside elements, first remove the center bus bar connectors, and push the top of the elements towards the bread wells. Again with the carriage down, lift out the elements.

Removal of Cordset and Base Ends. With the chassis removed, disconnect the cordset terminals at the back end of the base. Remove the strain relief knot and pull the cord out. The base ends are held in position with two screws going through from inside the base.

Adjustments. There are numerous adjustments necessary for proper operation of this toaster. It is recommended that you procure instruction sheets from the manufacturer before you attempt adjustments other than the cool-down adjustment screw and the control dial.

The other adjustments include the clearances of various latch bars and triggers in relation to each other. Adjustments are made by bending and close tolerances, for which data sheets are necessary.

PROCTOR ELECTRIC CO. MODEL 1467A

In this toaster, shown in Figs. 16A and 16B, the bread lifter knob is depressed, latching the controls in the control box. The thermostat near the element makes contact with the permanent contact point, and the movement of a crank assembly allows a spring to slide a jam plate along a latch bar.

The flow of current through a hot wire makes it expand, allowing the jam plate to slide still farther along the latch bar. When the toasting cycle has been completed, the thermostat breaks the circuit, and the hot wire contracts, pulling back on the pivot yoke and jam plate, disengaging the latch keeper and releasing the bread lifter spring.

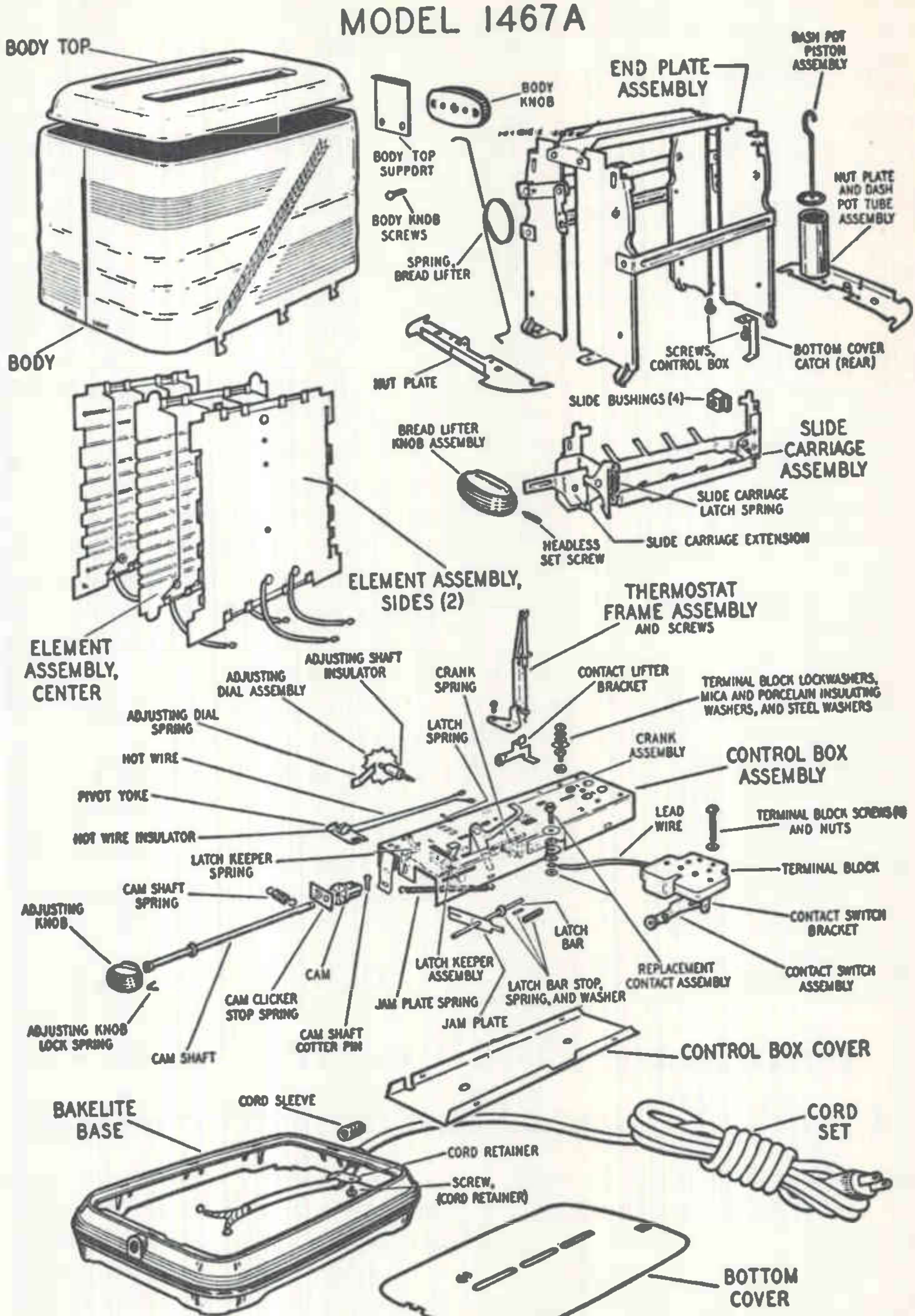
Movement of the rising carriage releases the control elements and springs put them in position for the next cycle.

If the toaster is still hot from previous toasting, the slight heat retained in the thermostat operates the cycle more rapidly and maintains the proper color of the next batch of toast.

Servicing Procedure. With the toaster inverted, remove the crumb tray and squeeze the control box cover, then lift it off. Disconnect the cord leads by removing the two hex nuts, remove the cord retainer screw, and remove the cord sleeve and remove the cord by pulling it out through the base.

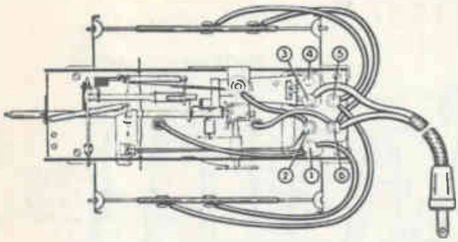
Straighten the cotter pin on the adjusting knob cam, turn the knob to the mid-point, and remove the pin. Then remove the knob, cam shaft, the cam clicker stop spring, the contact lifter bracket, and the cam shaft spring.

Straighten the body tabs and set the toaster upright. Remove the set screw from the bread lifter knob and pull off this knob. Lift the body of the toaster and strike the base downward with the hand. If prying is necessary, *take care not to damage the body*. This will separate the base from the body.



Courtesy Proctor Electric Co.

FIG. 16A. The Proctor Model 1467A automatic toaster.



Courtesy Proctor Electric Co.

FIG. 16B. Wiring of Proctor Model 1467A.

After disconnecting and straightening the element and thermostat leads from the terminal block, take out the four control box screws that go into the end plates and lift out the control box assembly. It will be necessary to slide this away from the thermostat location. The control box contains all the operating mechanism of the toaster.

The elements are held in place by metal tabs or rivets, but are easily reached with the control box removed. The outside elements may be replaced without removing the control box. All elements are guided into channels formed by tabs.

In order to remove the carriage rack assembly, the bread lifter spring and dash pot must be disconnected. Then the nuts placed on each end of the bottom of the toaster frame are removed by removal of their retaining screws.

This toaster is adjusted by turning the adjusting dial, which is under the control box, until it will toast to the degree indicated by the adjusting knob. Bread test this toaster with the adjusting knob on medium. If toast is not done just right, turn the adjusting dial (not knob) in the direction indicated on the control box cover.

To test the compensation, run a series of three slices through the toasting cycle. If this does not produce toast that is the same each time, the compensator blade may be bent slightly nearer or farther from the bread. Never let the blade come beyond the guide rods.

If large adjustments are necessary, replace the thermostat.

Note: This toaster is connected in series-parallel. The outside elements are in series with each other, making both inoperative if either fails. The outside elements are then connected in parallel with the inside element. (See Fig. 1D.)

Automatic Combination Type— Clock Timer, Thermostat Switch

WESTINGHOUSE MODEL TO-521 TOASTER

This is a two-slice automatic toaster. If a single slice is to be toasted, place it in the well that is so marked. Set the control knob at LIGHT, MEDIUM, or DARK, depending upon how the toast is desired.

The carriage is pushed downward by a lever until it latches, beginning the cycle of operation. A clock timing mechanism releases this carriage, which will pop up when the toast is cooked. This time is predetermined and should complete its cycle in from 90 to 105 seconds.

The thermostat of this toaster is placed adjacent to one of the heating elements and will be subject to exactly the same heat as the bread. Therefore, after a definite amount of heat has been supplied, the thermostat will break the circuit, regardless of the time remaining on the timer.

Adjustments of the control knob will vary, depending on the thickness. texture, or freshness of the bread used.

This toaster is of the compensating type, which means that it will give approximately the same color toast, whether the toaster is hot or cold.

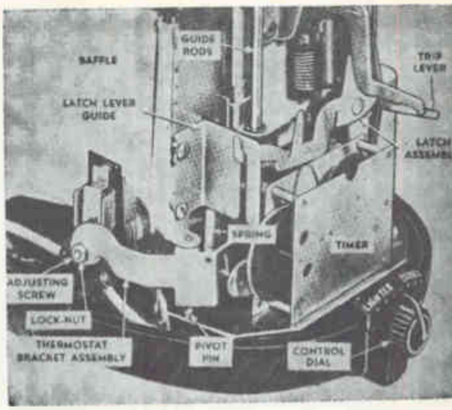
SERVICING

The carriage handle is removed by pressing it down far enough to clear the fixed portion and removing the set screw from the side. The outer casing must be removed to remove the two casing handles.

The handle on the carriage side is held on by two screws. One from inside the casing, and the other from without. The handle opposite the carriage side may be removed by removing the self-tapping screw from inside the casing.

Outer Casing. Remove the carriage handle and turn the toaster upside down to remove four sheet metal screws in the base, and then turn it right side up again. Lift the casing off at an angle so that the carriage lever is the last part cleared. While the casing is off, check for proper clearance of wires and thermostat movement, see Fig. 17.

Baffle. The baffle is a heat shield and is held in place by a speed-clip. Remove the carriage handle and the outer casing, and then turn the control dial to the darkest position. By turning the speed-clip a quarter turn,



Courtesy Westinghouse

FIG. 17. The outer casing of the Westinghouse toaster model TO-521 has been removed to show the thermostat, timer, and latch assemblies.

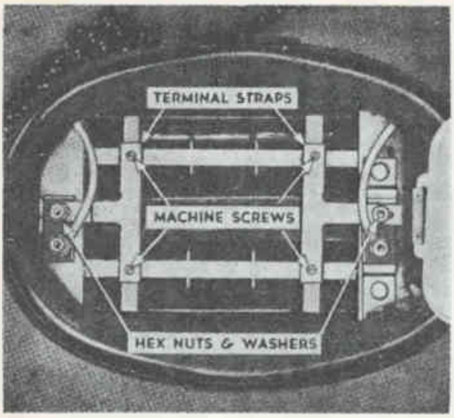
you can lift it off easily, and the baffle may be lifted off.

Observe the position of the baffle in order to replace it correctly. Check clearance of parts adjacent to the baffle.

Toaster Base. Remove the carriage handle, the outer casing, the baffle, and pull out on the control knob to remove it. Remove the screws holding the end supports to the base. After lifting up the frame, slide it up the control shaft until it clears the base.

Turn the frame upside down and remove the terminal leads held in place by two hex nuts and washers, Fig. 18. Remove the cord from the base after unwrapping the leads and then straighten the lugs of the hinge holding the bottom cover, and remove the cover from the base.

Cord. Open the bottom cover and disconnect the cord leads by removing the two hex nuts. Cut the plug end off the cord and pull the cord through the inside of the toaster. If the cordset is to be replaced, it is best to use



Courtesy Westinghouse

FIG. 18. Underneath view of Westinghouse TO-521.

a cord with a detachable plug to avoid further disassembly of the toaster. The cord terminals and binding make it difficult to put the cord through the hole from the outside.

Heating Elements. With the toaster set upside down, open the bottom cover, Fig. 18. Remove the four machine screws that will be found on the ends of the two terminal straps. Remove these screws as well as the two hex nuts, one holding each terminal strap to the frame. The elements may be lifted out of their slots.

The outer elements have a higher wattage rating than the inside elements. These may be identified by inspecting the screw holes at the bottom of the elements. The holes of the inside elements are tapped and those for the outside elements are not.

In replacing the elements, be sure that they have slight play in all directions. If not, they will buckle when heated and the toast will have dark and light spots.

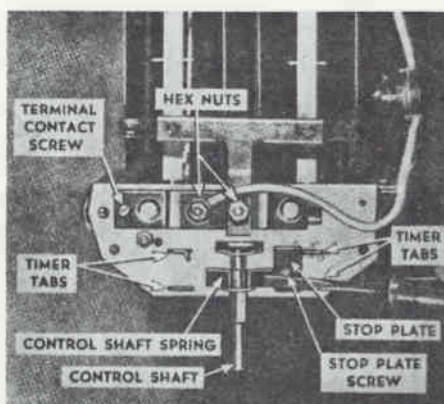
Timer. Remove the outer casing and the baffles, free the base from the control shaft, then turn the frame upside down, Fig. 19. Remove the stop plate screw and stop plate, which are on one side of the control shaft tension spring. Remove this tension spring by relieving tension on the shaft and pushing it towards the left.

Pull out the control shaft, straighten the tabs coming through from the timer, and place the frame in an upright position. Slide the timer to the right to clear the supports and then move it away from the front support, rotating it until it clears the latch assembly.

The latch assembly will come out with the timer when it clears the carriage and the lever guide.

Contact Terminal Assembly. Follow the instructions under TIMER until the frame is inverted, then remove the two hex nuts and washers from the contact terminal assembly at the control end of the toaster.

Remove the single screw holding the contact assembly to the frame. Remove the two machine screws holding the tee-terminal to the terminal straps, and remove the tee. Remove



Courtesy Westinghouse

FIG. 19. Underneath view of Westinghouse TO-521 with outer casing and baffles removed.

the thermostat wire connection and slide the terminal contact out of the slot at the opposite end from its holding screw.

Contact Carrier. The carrier and contacts are attached to one another; therefore, if either needs replacement, both must be replaced. Remove the timer, latch assembly, and contact terminal assembly as previously described, and then lift out the two guide rods.

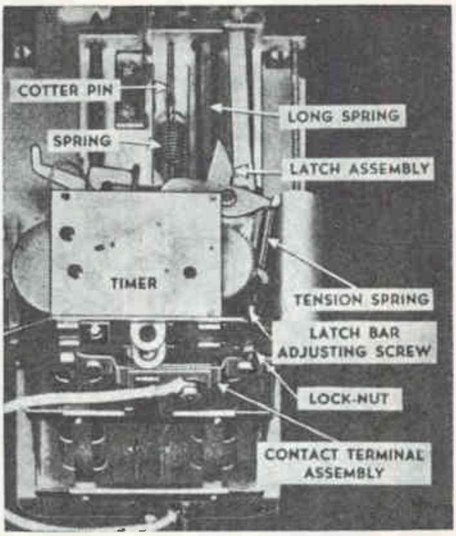
With a pair of pliers, remove the long spring, Fig. 20, connecting the carriage and the front support. With pliers, open the slotted opening in the contact carrier. This allows the spring and cotter pin to be removed.

Straighten the slotted opening and remove the carrier by lifting the carriage assembly with one hand while tilting the lower part of the contact carrier forward.

Guide Rods. Remove the outer casing and the contact terminal assembly as previously described. The guide rods can be removed by pulling up on the bottom of the rods. Make sure these rods ride freely when reassembled.

Carriage Assembly. Remove the contact carrier as previously described, and then straighten the tab on the dashpot to remove the shaft and washer. Carefully line up the carriage lifting bars with the cross slots of the toaster frame, and pull the carriage out through the slots. Remove the carriage springs and cotter pins.

Thermostat Bracket Assembly. As you will note, this is in one piece, Fig. 17, and is so placed that it is adjacent to the outside element on the side of the toaster marked SINGLE SLICE. To remove this assembly, remove the outer casing and the two screws holding the leads to the thermostat. With long nose pliers, remove the spring from the bracket assembly.



Courtesy Westinghouse

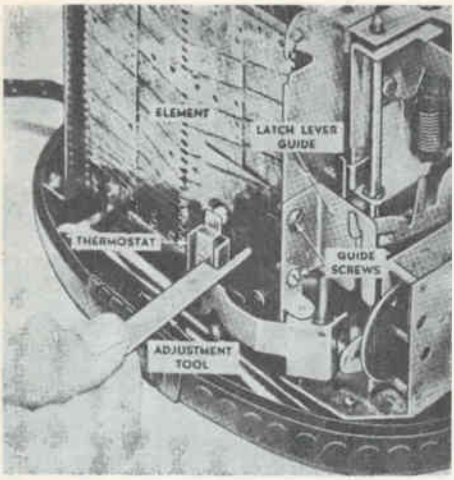
FIG. 20. Adjusting the contact carrier assembly.

This spring holds the bracket against the adjusting knob. Remove the two screws and washers holding the latch-lever guide and lift it off to release the bracket swivel pin which will drop through the bottom when the bracket is lifted.

Reassembly of the above groups is done in the reverse order.

Adjustments. The timer should be set to operate between 90 and 105 seconds. Adjustment can be made by turning the latch bar adjusting screw. One turn will make a difference of about 12 seconds.

The thermostat bracket assembly should be adjusted so that the outmost point of the bracket is 11/16 inch from the element, Fig. 21. This adjustment may be made by loosen-



Courtesy Westinghouse

FIG. 21. Adjusting the thermostat bracket assembly.

ing the latch-lever guide and moving it in the necessary direction to get this clearance.

The adjusting screw for thermostat calibration is held in place by a lock nut. Loosen the lock nut and turn the screw counter-clockwise to get darker toast and clockwise for lighter toast. If you cannot get the desired result with a rotation of 180 on the adjusting screw, the thermostat bracket assembly should be replaced.

SUMMARY

You have now passed another milestone in preparing for your career as an electrical appliance repair man. Electric toasters are so popular today that if you mention in front of your friends that you have learned how to repair electric toasters in your NRI Electrical Appliance Servicing course, you will probably get a job at once, or very shortly, repairing his or her faulty toaster!

Although you have encountered a number of new parts and mechanisms in this lesson on electric toasters, you have also learned that they all employ the same basic principles which you learned earlier in this course. Thus, a thermostat merely contains a heating element and a switch which is operated when the heating element has reached a certain temperature. A clock timer may be electric or mechanical; but in either case, after a certain time has elapsed, determined by the number of revolutions of a wheel and timer, a switch will open or close. Indicating devices such as pilot lights and simple bells employing magnets to raise steel balls (which are then dropped on to a bell resonator) are, as you have learned, very simply connected.

With the information you have learned in this course and the material we have given you on the many different types of electric toaster, you will have no difficulty in servicing just about any electric toaster brought in for service. Remember, if you should run up against a toaster whose construction is completely different from any described in this lesson, write to the manufacturer for service information before you begin to take it apart. But before doing this, sit down and study the unusual toaster very carefully and compare it with the many types illustrated in this lesson. The odds are, you will find that it combines the features of several of these, and, by carefully selecting the section from each toaster which applies to the strange model, you should have no difficulty in servicing it.

You may be wondering why there should be so many different ways of doing the same thing—such as measuring the time that the heat is on. In most cases, patents are the cause of the sometimes unorthodox, often unusual, methods of controlling the cooking time. In other words, in efforts to get around some controlling patents, designers achieve some rather fantastic devices at times!

NOTES ON ORDERING REPAIR PARTS OF TOASTERS

When you write to a toaster manufacturer, or any other appliance manufacturer for information or repair parts, be sure to include the following:

1. Description, model number and serial number.
2. Date of purchase by user if appliance is claimed to be within the guarantee period.
3. Nature of defect, cause of failure, or detailed complaint made by your customer.
4. Authorization to proceed with repairs if within guarantee period; or a request for estimate of cost of such repairs.
5. Shipping instructions for return of appliance.
6. Complete billing instructions.

In writing a manufacturer, or in returning appliances for repair, be sure your address is in the letter and on all packages. Transportation charges should be prepaid; of course, they may be legitimately passed on to your customer. Be sure that you have carefully packed all appliances or parts to prevent further damage.

Ordering Repair Parts. Many repair parts are not interchangeable in the various toasters. It is necessary, therefore, to furnish the following information if ordering replacement parts from large wholesale houses instead of the original manufacturer:

1. Make of toaster.
2. Model number of appliance for which part is required.
3. Quantity, part number and description of part.
4. SPECIAL NOTE: When ordering heating elements for toasters, give the markings on the old elements which are to be replaced: such as, 2.64 amp., 2.73 amp., 55-V, 315-W, etc. Also, state the position of the elements when facing front of toaster. EXAMPLE: On a two-slice toaster, the location of the elements would be as follows:

   (a) Left outside
   (b) Left center
   (c) Right center
   (d) Right outside

5. If the information requested in paragraphs 1, 2 and 3 is not available, return the used part as a sample.
6. Service transactions are usually handled on a C.O.D. basis, unless payment is made in advance. This practice is to expedite shipment and is in no way a reflection on customer's credit standing.

Now that you have read this lesson once, go over it and read it again very thoroughly, underlining any parts which seem to you to be particularly important. Remember that these lessons form a very valuable source of service information and should be kept conveniently at hand on your service bench.

When you are sure that you understand what is in this lesson, fill out your name, address, student number, etc., as requested on the lesson answer sheet and proceed to answer the ten questions to the best of your ability. Then mail it in to NRI.

TOASTER MANUFACTURERS

Bersted Mfg. Co.
Div. of McGraw Electric Co.
Boonville, Mo.

Camfield Mfg. Co.
14-102 Merchandise Mart
Chicago 54
Illinois

Capitol Products Co., Inc.
Winsted, Conn.

Chicago Electric Mfg. Co.
6333 West 65th St.
Chicago 38, Ill.

Dominion Electric Corp.
150 Elm St.
Mansfield, Ohio.

Dormeyer Corp.
(Toastmaker)
700 N. Kingsbury St.
Chicago, Ill.

General Electric Co.
Small Appliance Div.
1285 Boston Ave.
Bridgeport 2, Conn.

General Mills Home Appliances
(Betty Crocker)
Appliance Service Co.
1516 E. Lake St.
Minneapolis, Minn.

Knapp-Monarch Co.
(K-M)
3501 Bent Ave.
St. Louis 16, Mo.

Landers, Frary & Clark
(Universal)
New Britain
Connecticut

Lasko Metal Products, Inc.
(General) (United)
438 W. Gay St.
W. Chester, Pa.

Metal Ware Corp.
(Empire)
1700 Monroe St.
Two Rivers, Wis.

Nelson Machine & Mfg. Co.
Box 354
Ashtabula, Ohio.

Proctor Electric Co.
3rd St. and Hunting Park Ave.
Philadelphia 40, Pa.

Son-Chief Electrics, Inc.
Winsted
Connecticut

Stern-Brown, Inc.
(Superstar Toastrite, Superstar)
42-24 Orchard St.
Long Island City 1, N. Y.

Sunbeam Corp.
5600 Roosevelt Rd.
Chicago 50, Ill.

Toast-O-Lator Co., Inc.
10-23 Jackson Ave.
Long Island City 1, N. Y.

Toastmaster Products Div
McGraw Electric Co.
Elgin, Ill.

Westinghouse Electric Corp.
Electric Appliance Div.
Mansfield, Ohio

Lesson Questions

Be sure to number your Answer Sheet 9AA.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What part in an automatic toaster is not operating properly if the pop-up mechanism rises too rapidly and throws the toast out of the toaster?

2. What is the trouble if a connection on a terminal of a toaster turns blue?

3. If you repair a burned-out heating element with a mending sleeve, which should you tell your customer: (1) that it is a permanent repair, or (2) it is a temporary repair?

4. When dismantling a toaster, should you expect to have to pry some of the parts loose to get the toaster apart?

5. List the *three* general classes of toasters.

6. Name the *four* types of timing mechanisms used on automatic toasters.

7. Give two reasons why you should not probe around inside a toaster with a metal object.

8. Name the *four* parts found in the electrical circuit of the simplest toasters

9. What is an escapement mechanism used for in a timer?

10. What is the purpose of the bi-metal strip or blade found in some automatic toasters?

HOW TO DEVELOP CONFIDENCE

Self-confidence—an active faith in your own power to accomplish whatever you try to do—is a personal asset which can do big things for you.

One thing which builds self-confidence is a successful experience. Each lesson completed with a passing grade is a successful experience which will build up confidence in you.

Little successes are contagious. Once you get a taste of success, you'll find yourself doing something successful every day. And before you realize it, your little successes will have built up to that big success you've been dreaming of. So get the habit of success as fast as possible. Resolve to study every day, even if only for a few minutes.

Another confidence builder is a deep, firm faith in yourself—in your ability to get ahead. If you do believe in yourself and you are willing to back up this faith with good hard studying, you can safely leave the final result to itself. With complete confidence, you can look forward to an early success in Appliance Servicing.

Act as if you could not possibly fail, and you will succeed!

J. E. Smith

ANALYZING TYPICAL RECEIVERS

22B

RADIO-TELEVISION SERVICING

PIONEER HOME STUDY RADIO-TV SCHOOL

NRI

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

Study Schedule No. 22

☐ 1. **Introduction** .... **Pages 1-2**

☐ 2. **A Modern Five-Tube AC-DC Receiver** .... **Pages 3-7**

A stage-by-stage analysis of the type of radio most widely sold today is given.

☐ 3. **A Pre-War AC-DC Receiver** .... **Pages 8-15**

You will learn that pre-war ac-dc receivers did not differ much from present day ones, but you will see examples of what circuit variations there are.

☐ 4. **A Five-Tube AC-Operated Receiver** .... **Pages 15-23**

Here we study a set that uses a power transformer, and can therefore be operated only from an ac power line.

☐ 5. **A Four-Tube Superheterodyne** .... **Pages 24-26**

A brief analysis of a four-tube superheterodyne, showing how it differs from a five-tube set.

☐ 6. **A Four-Tube TRF Receiver** .... **Pages 27-29**

A brief analysis of a four-tube trf set.

☐ 7. **Answer Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

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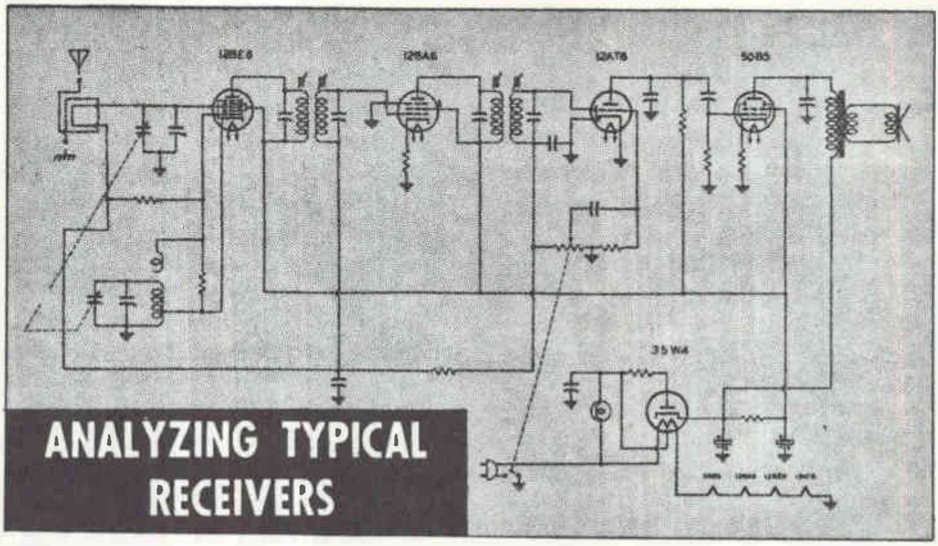


ANALYZING TYPICAL RECEIVERS

WHEN a service technician is repairing a radio or TV set, he seldom has to analyze the entire circuit. Usually the type of complaint will indicate which stage the defect is likely to be in. Once he knows that the defect is probably in one or two stages in a receiver he will then study those stages to see how they are supposed to work and to see what parts are likely to be causing the trouble.

However, even though a technician may not have to analyze the entire circuit when he is repairing a set, he should be able to do so, because each set he works on may have a defect in a different stage. For example, you might first repair a set having a defect in the audio system. The very next set might have a defect in the power supply, and the next set after that might have a defect in the mixer, the i-f, or the oscillator circuit. Therefore, you should be able to tell from a schematic diagram how the various stages work. You should be able to trace out both the dc circuits and the signal circuits and decide which parts are in each circuit.

Being able to analyze the schematic diagram of a receiver and determine how each stage works is chiefly a matter of understanding the individual circuits, and of getting practice in tracing out the schematic diagrams. You have already studied all of the circuits you are likely to encounter in a radio receiver. You have had some practice in tracing out the circuits on a schematic diagram. The purpose of this lesson is to give you additional practice in tracing out circuits, to show you a few new circuits, and also to give you practice in recognizing the various symbols used by manufacturers and the styles used in drawing schematic diagrams.

In studying the receivers analyzed in this lesson, you will also become familiar with some of the minor circuit variations fround in different receivers. We cannot cover in a single lesson all of the various circuits you are likely to encounter, but we will cover the most important ones.

We have selected diagrams that will familiarize you with various radio receiver types. We have reproduced each diagram just as the manufacturer shows it, so that you will become familiar with the various systems. These diagrams are stapled into the center of the book, so that you can remove them and refer to them easily. Carefully open the staples, remove the diagrams, and close the staples again.

Today, most of the table-model radio receivers manufactured are 5-tube ac-dc receivers. However, there are still a few receivers manufactured that operate from a power transformer, and millions of these sets made in the past that are still in use. You are likely to run into both types in service work.

Most of the tubes used in modern receivers are miniature tubes that are about three-quarters of an inch in diameter and between two and three inches high. However, there are still many receivers in service using the older, larger tube types. The tubes used in the receivers we have selected are typical of the tubes found in both old and new receivers; they are typical of the types that you are likely to receive for servicing. Learning to recognize some of these tube types will be a big help to you in service work. It will mean that you will be able to look at a receiver or at the schematic diagram of the set and immediately identify certain stages in the receiver from the tube types.

In reading the discussion of the various receivers in this lesson, take the time to refer to the parts and circuits on the schematic diagram whenever they are referred to in the text. This will give you valuable experience in finding parts and circuits on a diagram. You will get practice tracing out schematic diagrams. You will find that this is the type of experience that you need in order to become a top-notch technician. In many cases the dividing line between the top-notch technician who knows exactly what he is doing, and the mechanic who does repair work by trial and error, lies in the ability of the technician to read and analyze schematic diagrams, and the inability of a mechanic to do so.

Since most radios sold for home entertainment today are 5-tube ac-dc receivers, we will start our study of typical receivers with an analysis of a receiver of this type.

A Modern Five-Tube AC-DC Receiver

A schematic diagram of a typical modern five-tube ac-dc receiver is shown in Fig. 1 (in the center of the book). This receiver is called an ac-dc receiver, because it can be operated from either an ac or a dc power line. When it is operated from a dc power line, the power cord must be plugged into the power outlet with the polarity shown. When it is operated from an ac power line, it can be plugged in with either polarity. However, even when the set is operated from an ac power line, the side of the plug that connects to the on-off switch will connect to B– in the receiver, and the other side will connect through the rectifier tube to B+.

We will analyze this receiver by tracing out both the dc supply circuits and the signal circuits. In tracing out these circuits, we will point out anything unusual that has not already been covered in your lessons.

THE POWER SUPPLY

The rectifier used in this receiver is a conventional half-wave rectifier using a type 35W4 tube. This is a modern miniature tube designed for this type of use. As you have learned, in this type of receiver, current flows from one side of the power line to B–, through the various amplifier tubes in the receiver, and to the cathode of the rectifier tube. Current flows from the cathode to the plate of the rectifier tube whenever the polarity of the power line is such that the plate of the tube becomes positive with respect to the cathode. If the set is operated from a dc power line, the plate will always be positive. When the plate is positive, electrons will flow from the cathode to the plate, and then through the 39-ohm resistor in the plate circuit, that is marked 24. Some of the electrons will then flow through the pilot light marked 32, and some of them will flow through the section of the rectifier heater between terminals 4 and 6, back to the other side of the power line.

The filter network used to smooth the pulsating dc flowing through the rectifier to pure dc consists of a dual electrolytic capacitor marked 6 on the diagram, and the 1000-ohm filter resistor marked 23. A dual electrolytic capacitor is one having two separate capacitors in the same container. The 30-mfd capacitor, marked A, is the input filter capacitor, and the 50-mfd capacitor marked B is the output filter capacitor. In this particular receiver, since the negative leads of both sections of the filter capacitor connect to B–, a common negative lead is brought out of the capacitor. Two separate positive leads are also brought out. Thus, instead of having four leads, the capacitor has only three, because the negative lead is common to both sections. In replacing this capacitor there is no reason why you could not use a capacitor with separate positive and separate negative leads; you simply connect both the negative leads to B–. You could also use two separate capacitors instead of the dual capacitor.

While we are looking at the rectifier circuit, it might be well to look at the heater circuit. Notice that one side of the power line is connected directly to B–. The heater of the 12AT6 tube, which is the second detector and first audio stage in the receiver, is connected at the end of the string nearest B–.

We next have the 12BE6 converter tube and then the 12BA6 i-f tube. Each of these three tubes operates on a heater voltage of 12.6 volts. The number 12 preceding the letters indicates this. The 50B5 tube is the next tube in the heater string; the 50 preceding the letter B indicates that this tube operates with a heater voltage of 50 volts. The final tube in the heater string is the 35W4 rectifier tube, which operates with a heater voltage of 35 volts.

THE DC CIRCUITS

We can simplify the tracing of the dc circuits of the amplifier tubes by tracing these circuits more or less all at once. Remember that electrons will flow from B− to the cathodes of the tubes, through the tubes to the screens and plates, and then back to B+. Let's trace the cathode circuits of the four amplifier tubes from B− back to B+, first.

The cathode of the 12BE6 tube is connected to B− through part of the oscillator coil, 29. Notice the lead from the cathode goes to the tap on the coil, and one end of the coil is connected directly to B−. The cathode of the 12-BA6 tube connects to B− through the 120-ohm resistor marked 17; the cathode of the 12AT6 tube is connected directly to B−, and the cathode of the 50B5 is connected to B− through the 150-ohm resistor marked 22. Thus we see how electrons can get from B− to the cathodes of each of these tubes. Let's trace the plate and screen circuits to see how the electrons get back to B+.

Looking at the 12BE6 tube first, we see that the plate connects to the upper end of the primary winding of the i-f transformer, the screen to the lower end of the winding. The lower end is connected back to the positive side of the 50-mfd output filter capacitor.

The plate and screen of the 12BA6 tube also connect to the 50-mfd output filter capacitor; the screen directly, and the plate through the primary winding of the output i-f transformer. The screen of the 50B5 tube also connects directly to the output filter capacitor. The plate of the 12AT6 first audio stage connects back to the 50-mfd output capacitor through the 470K resistor marked 20 on the diagram.

Connected from the output filter capacitor back to the cathode of the rectifier tube is the 1000-ohm filter resistor, 23. All the B+ leads coming back to the positive side of the output filter capacitor connect to the cathode of the rectifier through the filter resistor.

Notice that the lead from the plate of the 50B5 tube does not connect to the 50-mfd output filter capacitor, but instead connects directly to the cathode of the rectifier and the positive lead of the 30-mfd input filter capacitor. We've seen this arrangement before; we'll explain it once again to be sure you know why it is used, and why using it does not result in excessive hum from the speaker.

The reason it is used is to avoid excessive voltage drop in the 1000-ohm filter resistor. The plate current of the 50B5 tube is quite high. In fact, in most receivers of this type the plate current flowing in the output tube will be higher than all the rest of the currents in the receiver combined. You will remember that the voltage drop across a resistor is equal to the product of the current flowing through it times the resistance of the resistor. Therefore, if the current through the filter resistor were too high, there would be an excessively high voltage drop across it, and the voltage available for the plates and screens of the tubes in the set would be quite low. We can reduce the current flowing through the resistor by bringing the plate circuit of the output tube back directly to the cathode of the rectifier tube.

Although you might think at first that bringing this lead directly back to the cathode of the rectifier tube would result in hum in the speaker, let's see why it doesn't. As you know, there is considerable ac superimposed on the dc at the output of the rectifier tube, which the filter resistor and the output capacitor are used to eliminate. However, the 50B5 tube is a beam power tube. (The schematic diagram shows the two beam-forming plates between the screen and the plate of the tube). One of the characteristics of screen-grid tubes, beam-powered tubes and pentode tubes is that the plate current depends very little on the plate voltage. It depends primarily on the screen-grid voltage and the control-grid voltage. Because the plate current depends very little on the plate voltage, a small amount of hum voltage at the plate of the 50B5 tube will cause little or no variation in the current flowing through the tube and through the primary of the output transformer. Since the transformer operates on current changes through the primary, there will be no hum current induced in the secondary winding.

THE SIGNAL CIRCUITS

Converter. The converter tube in this receiver is a 12BE6 tube, which performs the dual function of mixer and oscillator. You will remember that this tube has five grids and is called a pentagrid converter. The signal picked up by the antenna is fed to the No. 3 grid. The No. 1 grid is the oscillator grid, and the No. 2 grid is the oscillator plate. The No. 4 grid, which is connected inside the tube to the No. 2 grid, is the screen grid, and the No. 5 grid, the suppressor grid.

Notice that the antenna is a loop antenna. In most locations it will pick up enough signal to give satisfactory reception. However, the diagram shows a single turn wound around the loop. This actually consists of one or two turns of wire forming an additional winding on the loop antenna form. An external antenna and ground can be connected to this winding to provide better signal pickup. The ground should be connected only to this winding on the loop, which does not make any connection to the receiver chassis or any other part of the receiver and therefore creates no hazard. A ground should *never* be connected to the chassis of an ac-dc receiver.

The signal picked up by the loop is fed directly to the grid of the mixer section of the 12BE6 tube and to the cathode of the tube through the .1-mfd ac by-pass capacitor marked 11 on the diagram, and through part of the oscillator coil.

The oscillator circuit is a conventional Hartley oscillator circuit. Remember that the small gimmick winding shown on the oscillator coil is actually used to provide capacity between the oscillator tank circuit and the oscillator grid of the 12BE6 tube. The oscillator signal developed on the No. 1 grid of the tube modulates the electron stream flowing from the cathode to the plate as does the input signal applied to the No. 3 grid of the tube, so that we have a mixing of the two signals in the tube.

Notice the 15-meg resistor marked 15 on the diagram. This resistor connects from the oscillator grid of the 12BE6 tube to the avc line. The avc line in turn connects, through the loop antenna, to the control grid of the 12BE6 tube, and to the grid of the 12BA6 tube. The purpose of this resistor is to provide a minimum bias on the 12BE6 and 12BA6 tubes. The grids of these tubes rely on the voltage on the avc line for most of their bias. When the set is first turned on or when there is no station tuned in, there will be no avc voltage, and hence no bias at all on the No. 3 grid of the 12BE6 tube, and very little bias on the control grid of the 12BA6 tube. Under these circumstances the tubes may draw excessive current, which would shorten their lives. The 15-meg resistor connected from the avc lines to the oscillator grid provides a certain minimum bias at all times from the oscillator section of the 12BE6 tube. You will remember that when an oscillator is working, the signal drives the grid so hard that it goes positive once during each cycle. When the grid is driven positive, electrons will be attracted to it. These electrons will charge the grid capacitor and at the same time flow through the grid resistor back to the cathode of the tube. When the grid is not drawing current, the grid capacitor will discharge through the grid resistor. The grid capacitor in this circuit is, as we mentioned, the capacity between the gimmick and the tank circuit of the oscillator coil. The grid resistor is the 22K resistor 16. The oscillator operation will set up a dc voltage across this resistor. Electrons flowing from the oscillator grid back to the cathode will develop a voltage across the resistor, making the grid end negative. This negative voltage is divided by the 15-meg resistor and the combination of the 3.3-meg resistor 18 and the 500K volume control, 14. The portion of this voltage across the 3.3-meg resistor and the volume control is used as the minimum bias for the 12BE6 and 12BA6 tubes.

I-F Amplifier. The i-f amplifier is similar to the i-f amplifiers you have already studied. The primary winding of the input i-f transformer forms a parallel resonant circuit with the capacitor connected across it. The current flowing through the primary winding will induce voltage in the secondary winding; this voltage is applied to the grid of the 12BA6 tube and to the cathode through the .1-mfd capacitor 11 and the 120-ohm cathode resistor 17.

The signal applied between the grid and cathode of this tube will cause the plate current to vary, and the varying plate current flowing through the parallel resonant circuit in the plate circuit of the 12BA6 tube will induce a voltage in the secondary of the output i-f transformer.

Second-Detector—First Audio. The second detector and first audio stage uses a type 12AT6 tube. This is similar to the second-detector-first-audio stage you have studied already. Notice that the diode plate connected to the No. 5 pin of the 12AT6 tube is used as the second detector. The diode plate that connects to the No. 6 pin is connected directly to B− and is not used in this receiver at all. The diode load resistor is the 500K volume control, and the diode filter capacitor is the 220-mmf capacitor 13. You will remember that when the diode plate is driven positive, electrons flow from the cathode to the diode plate and through the secondary winding of the i-f transformer, charging the 220-mmf capacitor. At the same time, electrons will flow through the 500K volume control back to the cathode. When the diode is not conducting, the 220-mmf capacitor will start to discharge through the 500K volume control. The voltage across the capacitor and resistor will depend on the strength of the signal, and this will vary with the modulation. The 3.3-meg resistor 18 and .1-mfd capacitor 11 form the avc filter network.

The signal developed across the volume control is taken from the center terminal through the .002-mfd capacitor marked 10, and fed to the grid of the triode section of the 12AT6 tube. This tube is biased by convection bias; in other words, the electrons accidentally striking the grid of the tube and flowing through the 15-meg grid resistor 19 back to B− develop sufficient voltage to bias the tube.

The triode section of the 12AT6 tube is what is known as a high-mu triode. You will remember that the mu of the tube is the amplification factor; in other words, the triode section has a high amplification factor.

Electrons flowing from the cathode of this tube to the plate and through the 470K resistor in the plate circuit to B+ will vary as grid voltage varies. This will result in an amplified voltage appearing across the 470K plate load resistor. The 220-mmf capacitor marked 12 and connected from the plate of the tube to B− is an rf by-pass. If any rf signal gets through to the plate of the 12AT6 tube, this capacitor provides a low impedance path back to B− to keep it out of the output circuit.

Output Stage. The signal developed across the 470K plate load resistor is fed through the .005-mfd coupling capacitor marked 9 to the grid of the 50B5 tube. The 470K resistor 21 is the grid resistor, which is in the circuit to provide a path back to B− for any electrons accidentally striking the grid of this tube. Incidentally, it would be well to know that the size of this resistor should not be increased beyond the value shown. Output tubes are quite susceptible to gas, and if too large a grid resistor is used, the gas molecules may develop a positive voltage on the grid of the tube. If this happens, the current flow through the tube will increase, and this usually results in still more trouble by ionizing the remaining gas molecules in the tube and by overheating the tube, releasing still more gas.

Notice the .02-mfd capacitor connected from the plate of the 50B5 to B−. This capacitor by-passes many of the high-frequency parts of the audio signal. It reduces the strength of the higher frequency audio signals, and in so doing makes the receiver sound like it has good bass response. The .02-mfd capacitor serves another purpose —it eliminates any tendency of the 50B5 output stage to go into oscillation.

SUMMARY

This receiver is typical of the 5-tube ac-dc receivers that you are likely to get for servicing. It does not contain any particularly unusual circuits. In your career as a technician you will probably be called on to repair many receivers having circuits almost identical to the circuit used in this receiver. Don't be at all surprised if you receive many sets for servicing that have a tube lineup that is identical to the tube lineup used in this receiver, and circuits practically identical to those used in it.

A Pre-War AC-DC Receiver

Five-tube ac-dc receivers are not new. Manufacturers have been making sets like this for many years. A schematic diagram of a pre-World War II receiver is shown in Fig. 2, which is on the diagram sheet you removed from the center of the book. There were many of these sets manufactured and they did not differ too much from the ac-dc receiver shown in Fig. 1. However, there are some circuit variations so we will analyze the circuit of one of these older receivers. There are millions of them still in use —you can be sure you'll get them for servicing as well as newer sets.

THE HEATER CIRCUIT

First let us look at the heater circuit used in this receiver. Again, a quick glance at Fig. 2 tells us that the heaters of the various tubes are connected in series. However, there are a few minor variations between this heater circuit and the heater circuit shown in Fig. 1.

Notice the on-off switch shown on the diagram near the power plug. This switch is a double-pole switch. This simply means that the switch opens the circuit on both sides of the power line. Therefore, when the receiver is turned off, the power is completely removed from the receiver circuits by the switch. In the set shown in Fig. 1 only one side of the power line is opened, and therefore it would be possible to be shocked if you touched one of the circuits in the receiver with the power cord plugged into the wall outlet, even though the receiver was turned off. In this receiver, with the double-pole switch you could still be shocked by touching the terminals on the switch, but the other circuits in the receiver are completely disconnected from the power line so that there is no danger of being shocked from them. Of course, the way to avoid being shocked when replacing parts in either receiver type is to pull the plug out of the power outlet—this is a safety precaution that all smart technicians take.

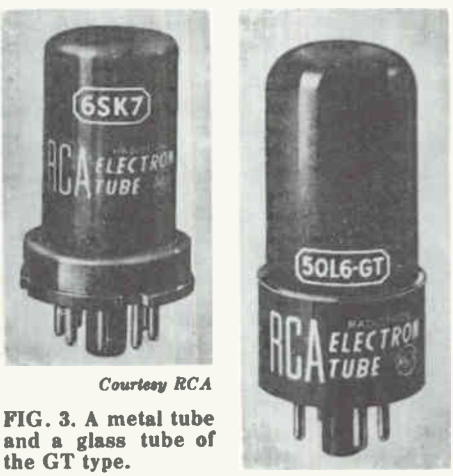
In tracing the heater circuit of this receiver, we see that the side of the power line shown on the bottom in the diagram connects to B+. Connected to this side of the power line is the heater of the 12SQ7, which is a dual diode-triode tube. This is the second detector-first audio stage, and as we mentioned previously, this is the tube whose heater is usually connected to the side of the power line that is next to B−. Remember this is done to keep the heater-to-B− potential as low as possible in order to prevent hum pickup by the first audio stage.

The next tube in the heater string is the 12SK7, which is the pentode i-f amplifier tube. Next to it is the 12SA7, which is a pentagrid converter type tube. As in the case of the receivers studied previously, the tubes whose designations start with the numbers 12 are 12-volt tubes; to be exact, they require a heater voltage of 12.6 volts.

The next tube in the heater circuit is the 35L6 beam power tube. This is a tube with a 35-volt heater. The letters GT following the designation 35L6 indicate that the tube has a glass envelope. These are called GT-type tubes. Tubes of this type are about the same size as metal tubes, whereas the older glass tubes used in the earlier days of radio were substantially larger than the metal tubes.

Between the heater of the 35L6 and the heater of the 35Z5 we have an 86-ohm resistor marked R11 on the diagram. This resistor is needed in the circuit to use up, or waste, some of the power-line voltage so that the tubes in the set will have the correct heater voltage applied to them. We'll go back to it in a minute. The last tube in the heater string is the 35Z5 rectifier tube. Notice that this tube has a tapped heater, and a dial lamp or pilot light is connected in parallel with part of it. Finally, the other side of the 35Z5 heater connects to the power line.

All of the tubes used in this receiver have what is known as an octal base. An octal base tube is a tube with 8 pins. The pins are spaced evenly around the tube. In the center of the tube base there is a stem that fits inside a hole in the tube socket. There is a key on the base stem of the tube and a keyway in the tube socket so



Courtesy RCA

FIG. 3. A metal tube and a glass tube of the GT type.

that the tube can be put into the socket in only one way. The 35L6 and the 35Z5 tubes are glass tubes, the other tubes are metal tubes. In Fig. 3 we have shown a GT-type tube similar in appearance to the 35L6 and 35Z5 tubes, and a metal tube similar to the three metal tubes in the receiver, to give you an idea of what these tubes look like.

Now let's go back to the 86-ohm resistor used in the heater circuit between the 35Z5 and 35L6 tubes. Let's see why this resistor is necessary. To do this, let's determine what the total heater voltage required by the tubes connected in series is. The 35Z5 and 35L6 tubes require a heater voltage of 35 volts each. Thus the two tubes in series need a voltage of 70 volts. The remaining three tubes require a heater voltage of 12.6 volts each, so connected in series they need a total of 37.8 volts. Therefore, the total voltage required by these 5 tubes will be 70 volts plus 37.8 volts, which is 107.8 volts. Most power lines have a higher voltage than 107.8 volts, and if these tubes were simply connected in series and placed across the line, the voltage applied to them would be somewhat higher than normal. We can eliminate this difficulty by adding resistance in the heater circuit.

If we want to design this receiver to operate from a 120-volt power line without operating the tube heaters at too high a voltage, we must get rid of 12.2 volts. 12.2 volts is the difference between the 107.8 volts required by the tubes and the voltage of a 120-volt power line. Ohm's Law tells us that the resistance needed to get rid of this 12.2 volts will be equal to the voltage divided by the current. The heaters of the tubes in this receiver require a current of .15 amps (which you could find in a tube manual), so the resistance will be 12.2 divided by .15. 12.2 divided by .15 is about 82. Thus, if we put 82 ohms in the circuit, the heater voltage required by the combination of the tubes and the resistors would be 120 volts. Apparently the manufacturer decided to use a slightly larger resistor than 82 ohms. This would mean that on a 120-volt power line, or a power line with a voltage lower than 120 volts, the tube heaters would be operated at a voltage slightly below normal. This will not impair their efficiency, but operating the tubes with excessive heater voltage would shorten their useful life.

THE DC CIRCUITS

In many respects the dc circuits in this receiver are the same as those in the receiver shown in Fig. 1. However, don't skip over these circuits. There are some differences, and also by tracing out these circuits you will get additional practice, which will be helpful to you when you start doing service work and have to trace out circuits like these on your own.

Cathode Circuits. Again, as in the case of the preceding receiver, we will trace the circuit from B— to the cathodes of the various amplifier tubes, and then trace from the plates and screens of the tubes back to B+, rather than taking each tube separately.

The cathode of the 12SA7 tube is the number 6 pin. You identify this pin by first locating the key shown on the tube base. This is shown on the diagram as a little black rectangle on the edge of the tube envelope. Then you count in a clock-wise direction. You will find the No. 6 pin identified with the letter K to indicate it is connected to the cathode. In the tube symbols used here, the cathode is shown at the top, and the plate at the bottom. The cathode of this tube connects to B— through part of the oscillator coil. Incidentally, notice that in the small box on the right of the diagram the manufacturer has indicated two ground symbols. The upper symbol indicates a chassis ground and the lower symbol indicates a connection to B—, which is insulated from the chassis and called a floating ground.

The cathode of the 12SK7 tube, which is the No. 5 pin, connects to B— through the 330-ohm resistor R-3. The cathode of the 12SQ7 tube, which is the No. 3 pin, connects directly to B—. The cathode of the 35L6 tube, the No. 8 pin, connects to B— through the 150-ohm resistor R-10.

Plate and Screen Circuits. Now let's trace the plate and screen circuits of the tubes back to B+. Starting with the 12SA7 tube we find that the plate, the No. 3 pin, connects to the primary winding of the first i-f transformer. Notice that the screen grid, which is the No. 4 pin, is shown on the diagram connected to the other side of this transformer primary winding, and this lead is connected back to C-23, which is the output filter capacitor. Let's leave this circuit here and trace out the circuits in the other stages, we'll trace out the power supply circuit last.

The plate of the 12SK7 tube, which is the No. 8 pin, connects to the primary of the second i-f transformer, and the screen, which is the No. 6 pin, connects to the other side of the primary winding. The primary of the second i-f transformer connects back to meet the lead to the output filter capacitor.

The triode plate, the No. 6 pin, of the 12SQ7 tube, connects to B+ through the 220,000-ohm resistor R-8. The screen of the 35L6 tube, the No. 4 pin, connects directly to the positive side of the output filter capacitor, and the plate of this tube connects back to the same point through the primary winding of the output transformer, which is marked T1 on the diagram.

In order to study the power supply circuit for this receiver more closely we have shown it in Fig. 4. First notice that there are two values indicated for both C-22, the input filter capacitor, and C-23, the output filter capacitor. This receiver was manufactured in two slightly different models, one for use on a 60-cycle power line and the other for use on a 25-cycle power line. The 60-cycle power supply has a 20-mfd input filter capacitor and a 12-mfd output filter capacitor. However, if the receiver is to be used on a 25-cycle power line, then the value of the input filter capacitor C-22 is 40-mfd and the value of the output filter capacitor is also 40-mfd. Remember, as we mentioned previously, when we studied rectifiers, the greater the number of pulses we receive from the rectifier, the easier it is to filter the pulsating dc at the output to pure dc. On a 25-cycle power line there will be 25 current pulses per second obtained from the rectifier. On a 60-cycle power line there will be 60 current pulses per second. It is easier to filter the output from the rectifier operating on the 60-cycle power line than it is if it is operating from a 25-cycle power line. If the receiver built for 60-cycle operation is operated on a 25-cycle power line, there will be an objectionable hum in the output. On the other hand, the receiver built for 25-cycle operation could be operated from a 60-cycle power line quite satisfactorily. In the 60-cycle model the manufacturer used smaller capacitors because they were entirely satisfactory, and they are more economical than the higher-capacity filter capacitors.

Notice that this power supply uses a filter choke between the input and the output filter capacitors. This choke is actually the speaker field coil. The speaker used in this receiver is an electrodynamic speaker. This means that an electromagnet rather than a permanent magnet is used in the speaker. The magnet is energized by the B− supply current from the receiver flowing through it. At the same time the speaker field, because it does have inductance, serves as a choke in the power supply to help filter the pulsating dc, so that we will have pure dc at the power-supply output.

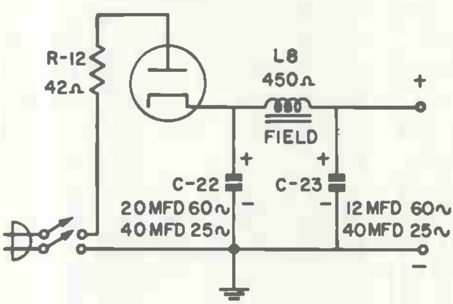


FIG. 4. The power supply circuit of the receiver shown in Fig. 2.

Notice that immediately above the symbol for the choke coil we see 450 ohms on the diagram. This indicates that the dc resistance of the field is 450 ohms. If you had to replace the speaker in this receiver, you could use another electrodynamic speaker with a speaker field resistance of 450 ohms. You could also use a permanent magnet dynamic speaker and substitute a choke coil in the receiver in place of the speaker field. If the choke coil resistance is slightly less than 450 ohms, which it is for most small choke coils, then the operating voltages throughout the receiver will be slightly higher than normal. In this receiver it probably would not cause any difficulty, but in some receivers the operating voltages are critical, and increasing them might cause the set to go into oscillation; if it does, the resistance between the filter capacitors can be increased by connecting a resistance in series with the choke so that the total resistance of the choke coil plus the resistor is equal to the resistance of the original speaker field.

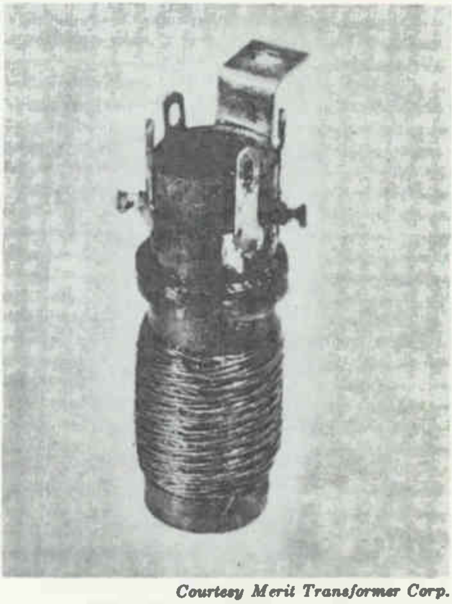
So much for the dc circuits in this receiver; now let's take a quick look at the signal circuits.

THE SIGNAL CIRCUITS

RF Stage. In the input of this receiver an antenna coil is used instead of a loop antenna. A picture of an antenna coil is shown in Fig. 5. Although we call it a "coil" it is actually a transformer with a primary winding and a secondary winding. The antenna coil itself does not have a great deal of signal pickup, so the receiver must be used with some type of external antenna. In most cases a piece of wire 10 or 15 feet long, strung around the room in which the receiver is operated, will give satisfactory results. Many people connect this antenna to a water pipe or radiator for better signal pickup. Since the primary winding of the antenna coil is isolated from the secondary winding and from B−, this will not cause any difficulty as long as a short does not develop in the antenna coil. However, if a short did develop, and the set happened to be plugged in so that the ungrounded side of the power line was connected to B−, the primary winding of the antenna coil could, in effect, be connected directly across the power line, if it were not for capacitor C-1, which is in series with the antenna. With C-1 in the circuit, if either the coil or the capacitor should break down, there is no likelihood of any trouble. However, if both should break down, the primary winding of the antenna coil could be connected directly across the power line if the antenna is grounded. If this happens, the antenna coil will be burned up almost instantly. The chances are that in your servicing career you will encounter a receiver in which the antenna coil is burned and charred almost beyond recognition. When you get a receiver in this condition for servicing, the primary winding of the antenna coil has probably been accidentally connected across the power line.

The secondary winding of the antenna coil is inductively coupled to the primary, and hence a signal voltage will be induced in it. This voltage is applied to the grid of the 12SA7 tube, which is the No. 8 pin, and to the cathode, which is the No. 6 pin, through the .1-mfd avc filter capacitor C-15, and part of the oscillator coil. (Both C-15 and the oscillator coil are connected to B−, so they are in effect connected to each other.)

The oscillator used in this receiver



Courtesy Merit Transformer Corp.

FIG. 5. An antenna coil.

is a conventional Hartley oscillator. Notice that in this receiver the oscillator coil does not have a gimmick winding as the oscillator coil did in the circuit shown in Fig. 1. There is a 60-mmf capacitor connected from the oscillator grid of the tube, pin 5, to the oscillator coil.

I-F and First Audio. The i-f stage is practically identical to the i-f stage discussed in Fig. 1. The only difference is in the type of tube used. The second detector also is quite similar. However, both diode plates are used, connected in parallel. The only other differences are that a 47,000-ohm resistor R-5 is used in series with the volume control, and that there is a 250-mmf capacitor C-16 connected from the center terminal of the volume control to B−. This is to eliminate any rf that may get through to the volume control and keep it out of the grid circuit of the 12SQ7 tube. You will remember that in the receiver described in Fig. 1 there was a plate by-pass capacitor in the first audio stage for the same purpose. In this receiver the by-pass is placed in the grid circuit instead of the plate circuit.

Notice that in the grid circuit of the triode section of the 12SQ7 there is a Victrola jack. This is usually labeled phono jack on later model receivers. Two capacitors are used in conjunction with this jack to feed the signal from a phono pickup to the input circuit of the tube. The .005-mfd capacitor C-18 is used to couple the phono output to the grid of the tube, pin 2. The .01-mfd capacitor C-19 is used to connect the grounded side of the phono output to B− in the receiver. A capacitor is used rather than a direct ground connection to isolate the phono pickup from B− in this receiver. This is done because if the power cord is plugged in with the *hot* or ungrounded side of the power line connected to B−, if this capacitor is not in the circuit, the phono pickup will be connected directly to the hot side of the power line. If you touch the pickup and ground at the same time, you will get a rather serious shock. This could be dangerous in a basement or near any grounded object, such as a water pipe. However, with the capacitor in the circuit, even though you may get a slight shock through the capacitor, it will not be as serious a shock as it would be without the capacitor in the circuit.

The plate circuit of the 12SQ7 tube is coupled to the grid circuit of the 35L6 through the .01-mfd coupling capacitor, C-20. The 150-ohm cathode resistor in the output stage is left without a by-pass capacitor in order to introduce degeneration to reduce distortion and improve the tone quality of the receiver.

Output Stage. The plate circuit of the output stage in this receiver is somewhat different from the plate circuit of the preceding receiver. The plate of the tube is by-passed to B− by a .01-mfd capacitor. Again, this capacitor will have a greater effect on the high-frequency audio signals, and have the apparent effect of increasing the bass response of the receiver. It will also reduce any tendency of the 35L6 output tube to go into oscillation.

Notice that the plate return to B+ is to the output filter capacitor in this receiver. Because the speaker field is used as a filter choke, the plate of the tube can be brought back to the output filter capacitor and the better-filtered dc used for the plate circuit. As you will remember, in the receiver in Fig. 1, the plate of the output tube was brought back to the input filter capacitor so that the high current in the plate circuit of the output tube would not flow through the filter resistor, causing such a high voltage drop across it that the voltage for the plates and screens of the other tubes would be too low. In this receiver the speaker field used as a filter choke has a lower resistance than the filter resistor used in the receiver shown in Fig. 1. The resistance of the filter resistor was 1000 ohms, whereas the resistance of the speaker field is only 450 ohms. The chances are that the voltage drop across the speaker field will be no greater even with this increased current flowing through it than the voltage drop across the 1000-ohm resistor in a receiver like the one shown in Fig. 1.

In the secondary circuit of the output transformer we see two coils, one is the speaker voice coil and the other is called a *hum-neutralizing coil*, or sometimes a *hum-bucking* coil. The speaker voice coil is operated by the varying current that is induced in the secondary winding of the output transformer. This current causes the coil to move in and out and actuate the speaker.

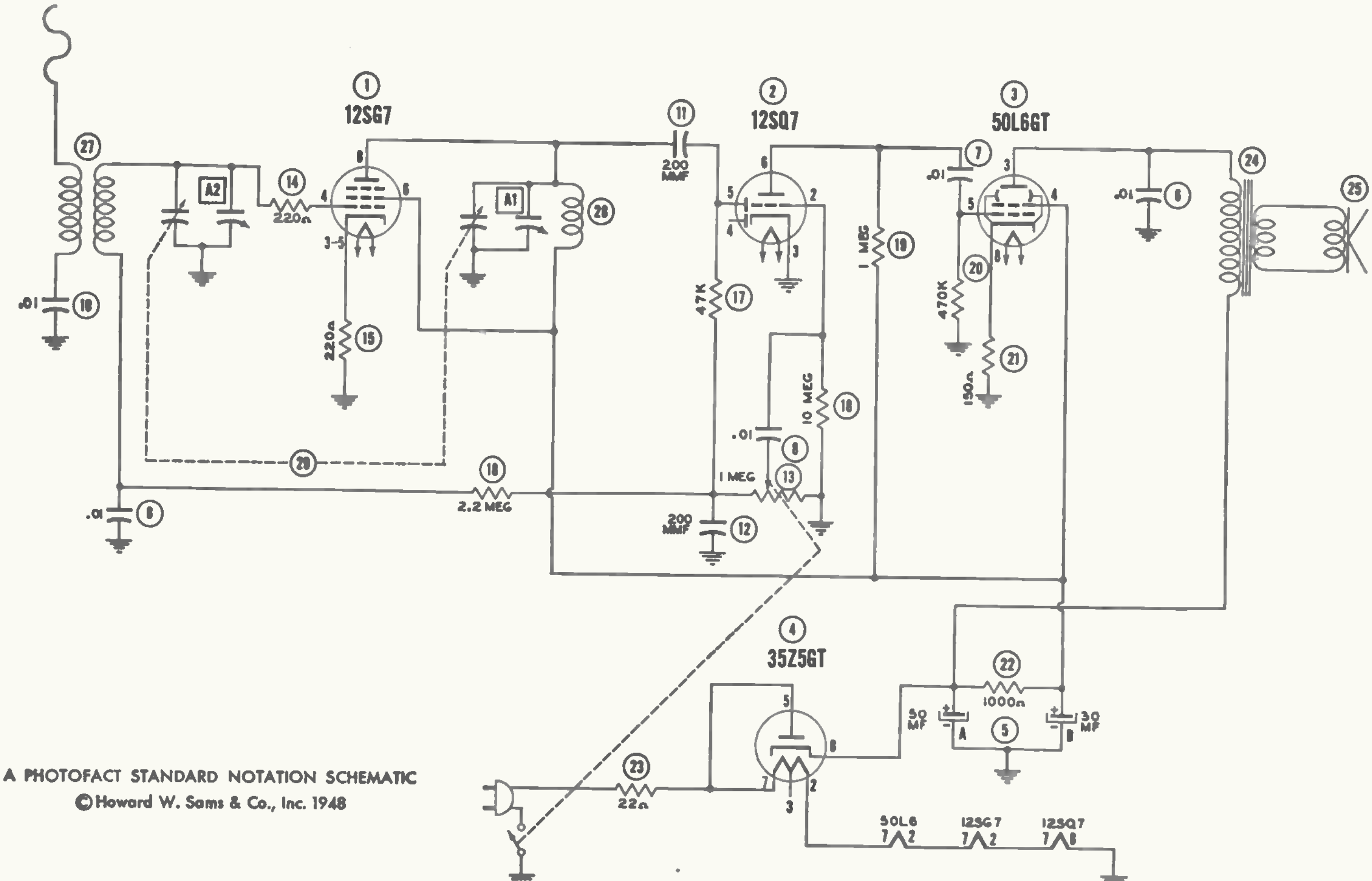
Now let's see what the hum-neutralizing coil is for. As we have said, the speaker field is used as a filter choke. This means that the pulsating dc at the output of the rectifier flows through it. The ac component of the pulsating dc will produce a varying magnetic field around the field coil. This varying magnetic field will cut the turns of the voice coil, which is wound around the field coil, and induce a hum voltage in the voice coil. This hum voltage would cause a hum current to flow which would cause the speaker cone to vibrate, and produce hum if the hum-neutralizing coil were not in the circuit.

The hum-neutralizing coil is wound right on the speaker voice coil frame so it, too, will be cut by the varying magnetic field produced by the speaker field and a voltage will be induced in it. However, the coil is wound in the opposite direction to the speaker voice coil. The voltage induced in it by the ac in the field coil will be equal to the voltage induced in the speaker voice coil, but will be of the opposite polarity so the two voltages will cancel. Since the voltages cancel, there will be no hum current flow in the circuit and hence no hum output in the speaker from this source.

Not all electrodynamic speakers have hum-neutralizing coils. However, these coils are quite effective, and if you were to replace a speaker that had a hum-neutralizing coil with one that did not have a hum-neutralizing coil, you might encounter excessive hum output in the receiver. Sometimes this can be overcome by increasing the size of the filter capacitors in the set.

SUMMARY

At first glance the circuit shown in Fig. 2 looks almost identical to the circuit shown in Fig. 1, except that different tubes are used. As you saw, the two circuits are very similar. However, as we studied these receivers in detail, we found many places in which the circuits differed. To the beginner these variations may seem confusing, and it may look as if receiver manufacturers use widely varying circuitry. However, to the experienced technician the circuits look very similar, because he realizes the circuit variations are minor. Each stage in one receiver is performing exactly the same function as the corresponding stage in the other receiver. For example, in both receivers, the first stage is a combination mixer-oscillator; the next stage is the i-f stage; the third stage is a combination second-detector-first-audio stage, and the fourth stage is the power-output stage. Although there are minor variations in these circuits, the general circuitry is the same. By learning to read schematic diagrams and quickly



A PHOTOFACT STANDARD NOTATION SCHEMATIC

FIG. 8. A four-tube trf receiver, the Meck Model 4C7, reproduced from Photofact Set No. 35, Folder No. 14, with permission of Howard W. Sams & Co., Inc., Indianapolis, Indiana.

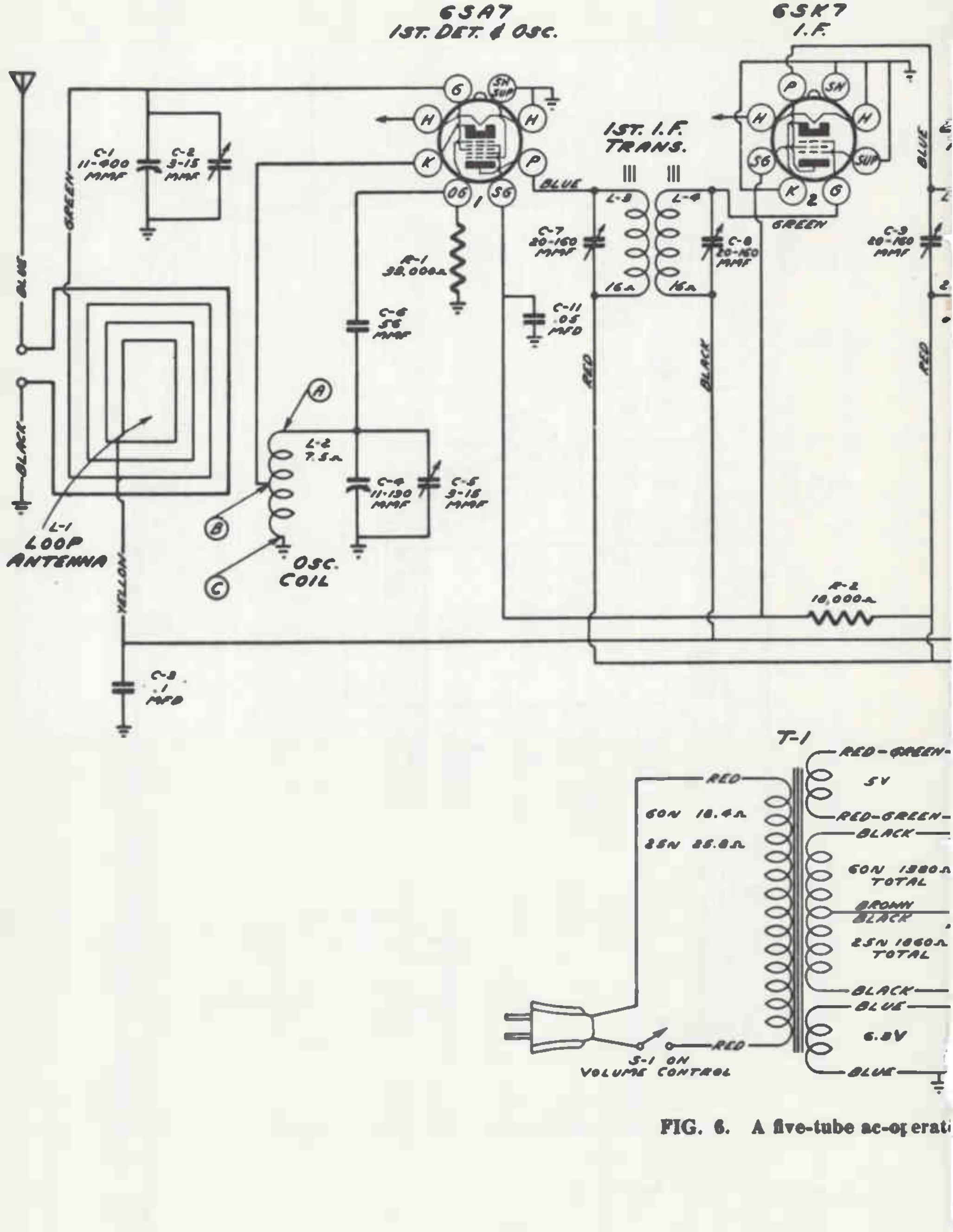
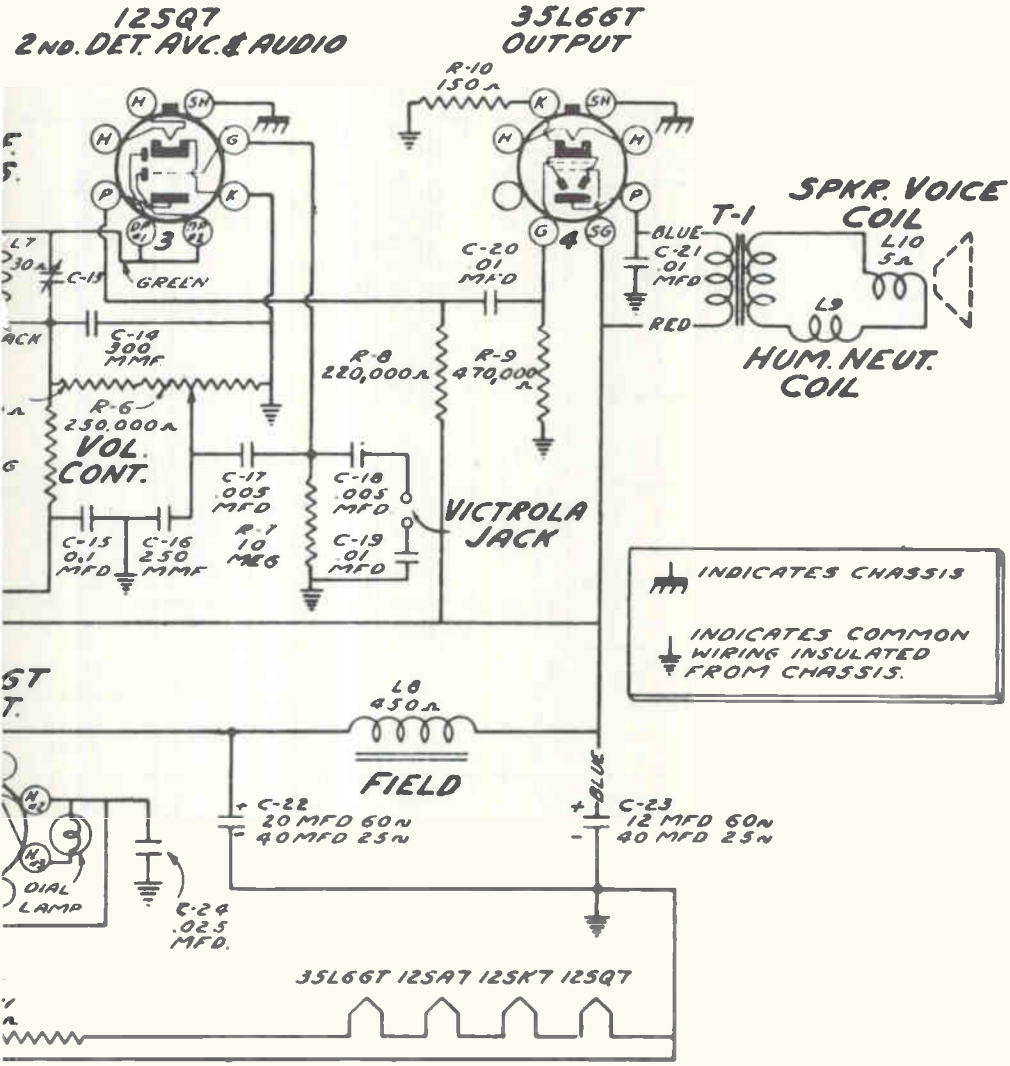
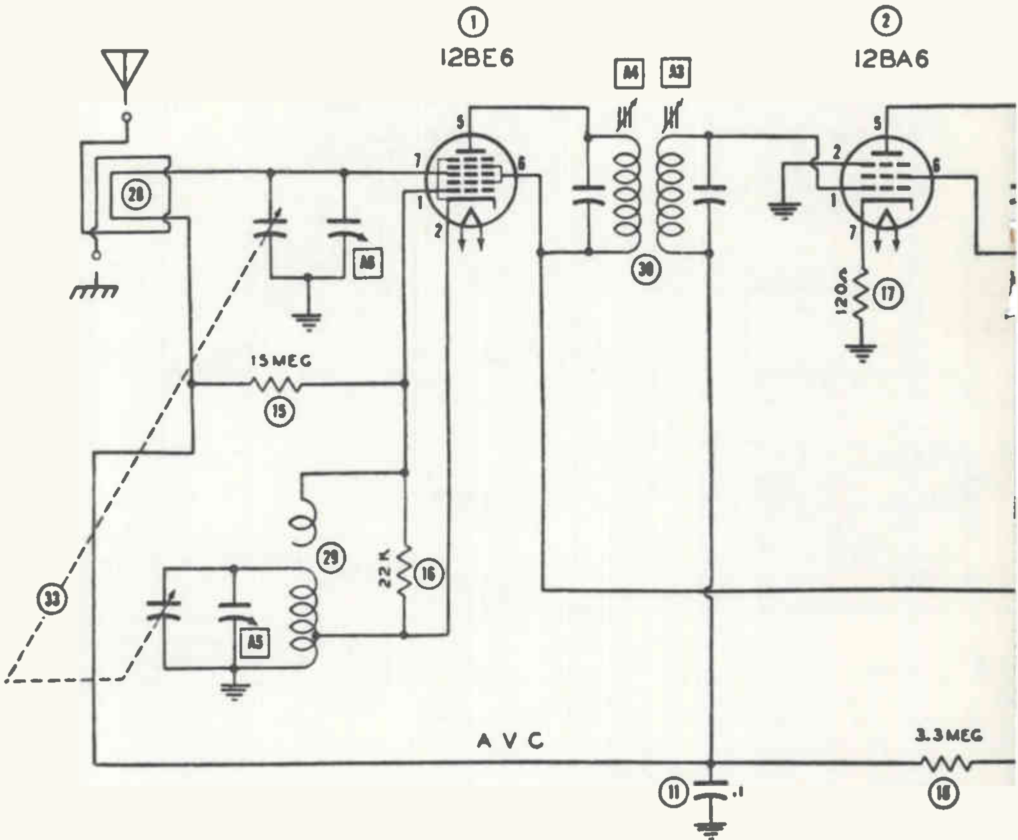


FIG. 6. A five-tube ac-operat



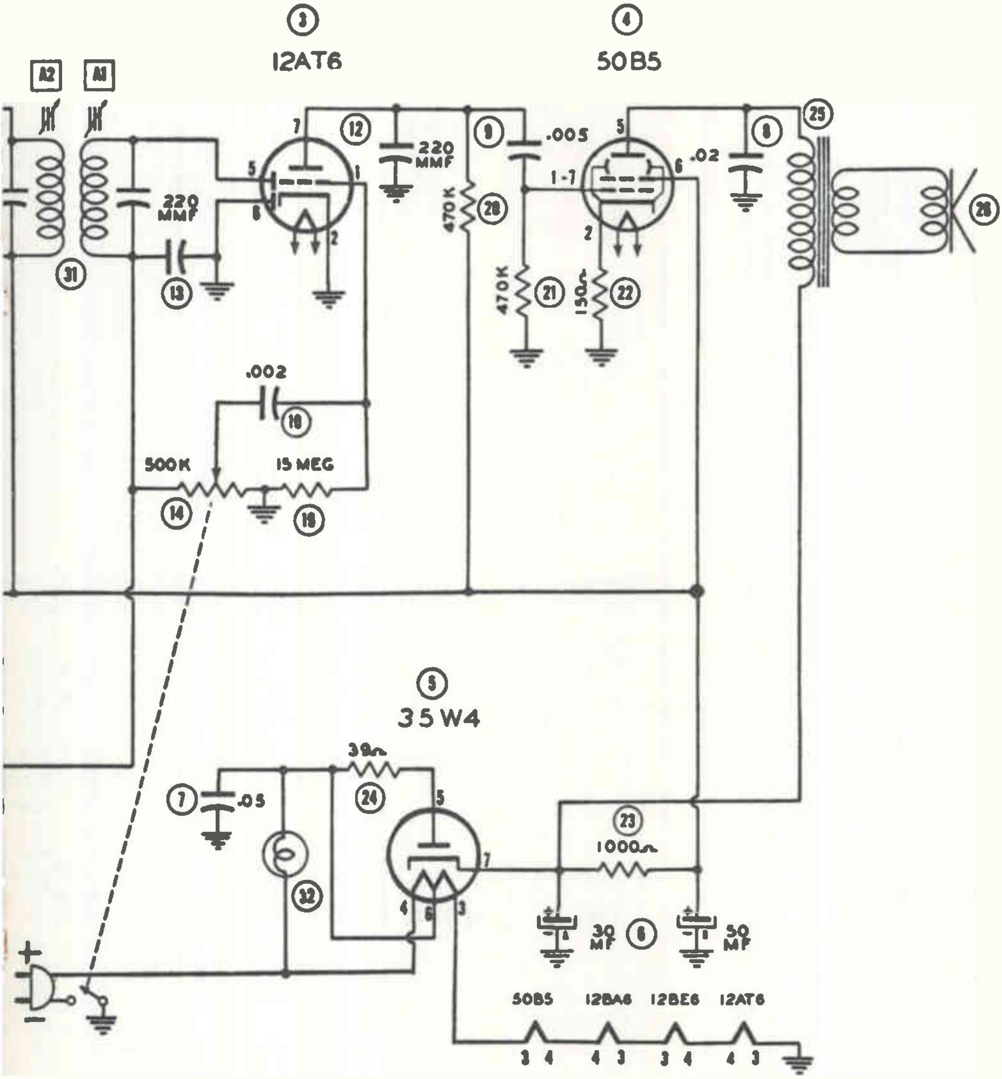
Courtesy RCA

ic receiver, the RCA Little Nipper.



I F = 455 KC

FIG. 1. A modern five-tube ac-dc ra



...io receiver, the Emerson Model 547A.

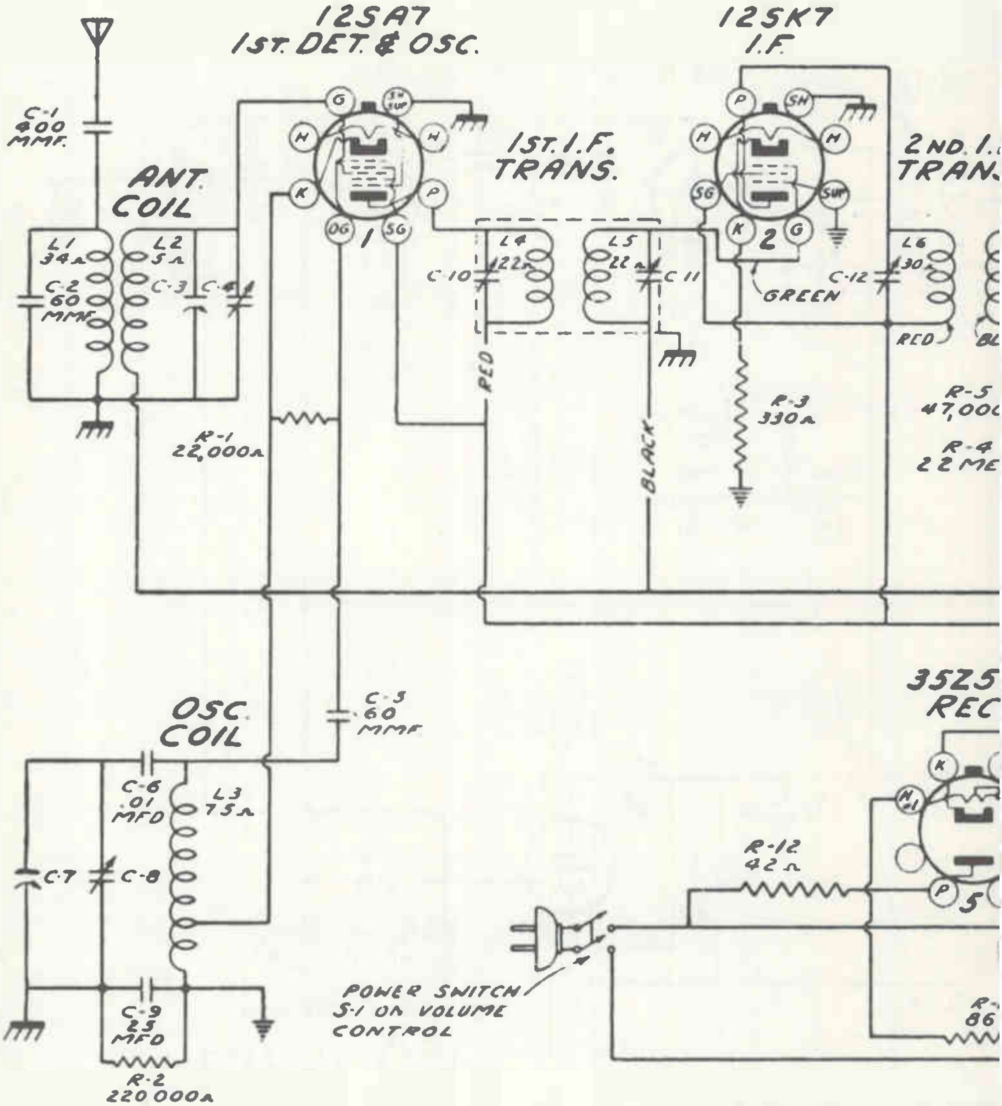
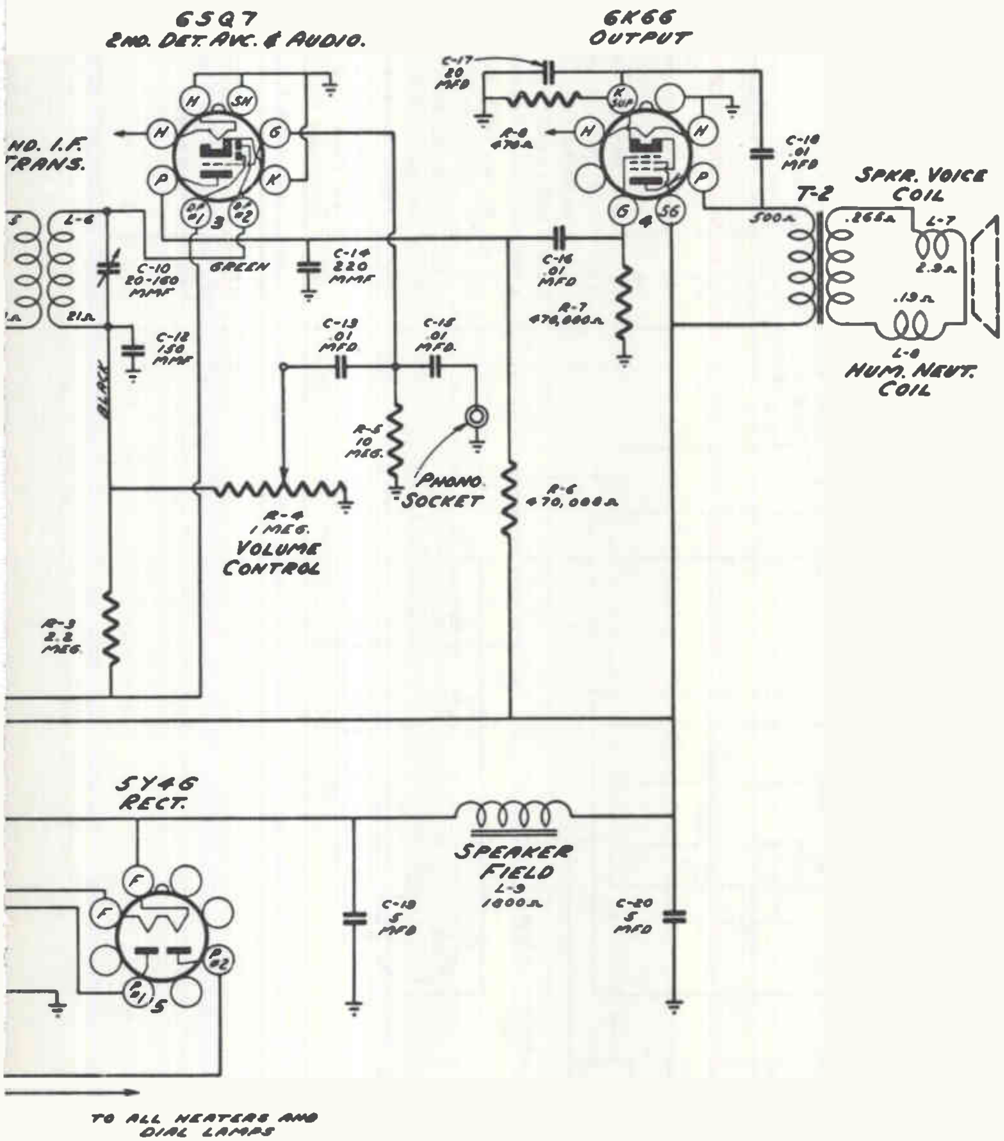
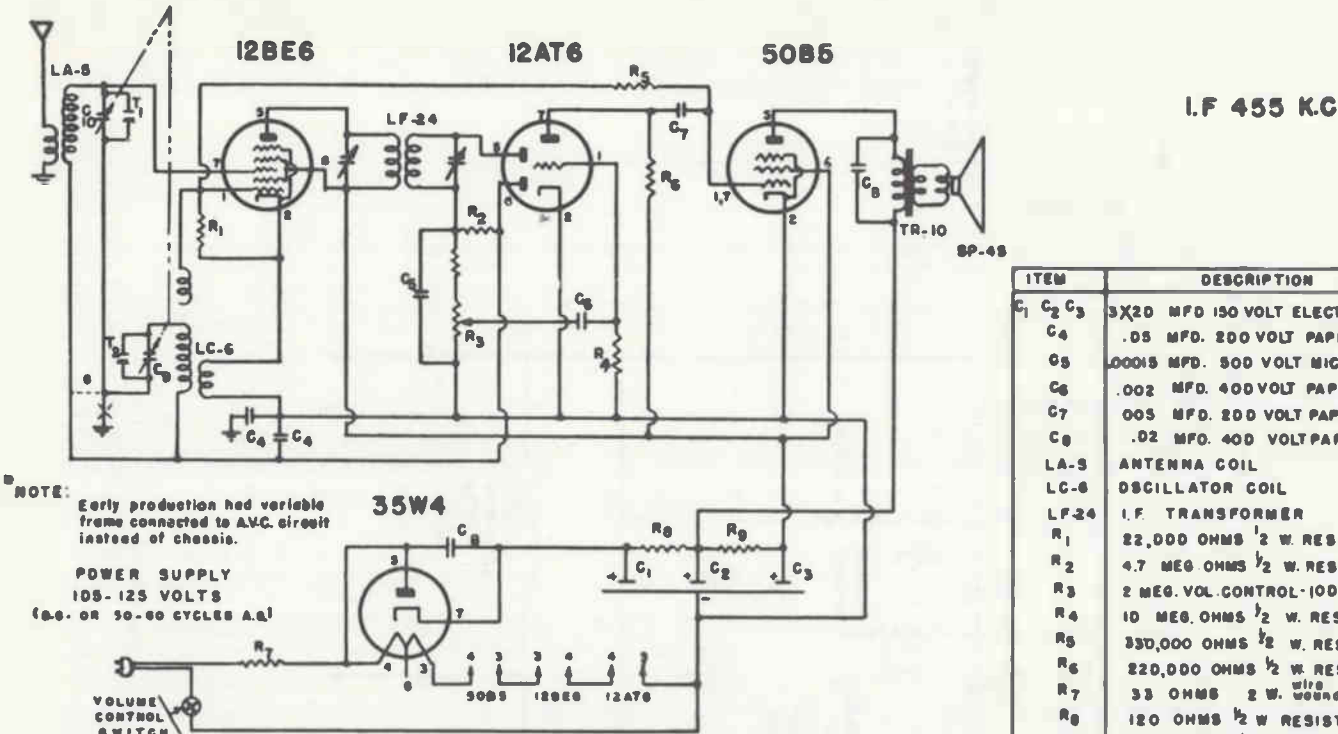


FIG. 2. A pre-war five-tube ac-



Courtesy RCA

ed receiver, the RCA Mascot.



ITEM	DESCRIPTION
C_1 C_2 C_3	3X20 MFD 150 VOLT ELECTROLYTIC
C_4	.05 MFD. 200 VOLT PAPER COND.
C_5	.00015 MFD. 500 VOLT MICA COND.
C_6	.002 MFD. 400 VOLT PAPER COND.
C_7	005 MFD. 200 VOLT PAPER COND.
C_8	.02 MFD. 400 VOLT PAPER COND.
LA-5	ANTENNA COIL
LC-6	OSCILLATOR COIL
LF-24	I.F. TRANSFORMER
R_1	22,000 OHMS 1/2 W. RESISTOR
R_2	4.7 MEG. OHMS 1/2 W. RESISTOR
R_3	2 MEG. VOL. CONTROL-100K STOP
R_4	10 MEG. OHMS 1/2 W. RESISTOR
R_5	330,000 OHMS 1/2 W. RESISTOR
R_6	220,000 OHMS 1/2 W. RESISTOR
R_7	33 OHMS 2 W. wire wound RES.
R_8	120 OHMS 1/2 W RESISTOR
R_9	1500 OHMS 1/2 W. RESISTOR
SP-45	SPEAKER
TR-10	OUTPUT TRANSFORMER
C_9 C_{10}	VARIABLE CONDENSER
T_1 T_2	TRIMMERS

Courtesy John F. Rider

FIG. 7. A four-tube superheterodyne receiver, the Tele-Tone Model 165.

analyze the receiver circuits, you will be able to spot similarities and dissimilarities quickly. You will eventually get a mental picture of a five-tube ac-dc receiver, and you will reach a point where you will glance at the diagram of a receiver of this type that you are about to service, you will quickly see that it is a standard circuit like most other sets of this type, with perhaps one or two minor variations, and then be able to wade into the servicing of this receiver with little or no difficulty.

Five-Tube AC-Operated Receiver

The receivers that we have shown in Figs. 1 and 2 have been 5-tube ac-dc receivers. These receivers are called ac-dc receivers because, as we mentioned previously, they can be operated from either an ac or a dc power line. When these sets are operated from an ac power line, the operating voltages are sometimes a little higher than they are if they are operated from a dc power line of the same input voltage. This is because the filter capacitors are charged by the peak ac line voltage, which, as you will remember, is 1.4 times the effective ac voltage.

In Fig. 6 on the second diagram sheet, we have shown a schematic diagram of a 5-tube ac receiver. This receiver can be operated from an ac power line only, because the power supply of the receiver contains a power transformer. You will remember that a power transformer can be operated only on ac.

Let's start our study of this receiver with the power supply; then we'll trace out the dc supply circuits in the amplifier stages, and finally the signal circuits.

THE POWER SUPPLY

The first thing to notice in the power supply in this receiver is that it uses a power transformer. Notice that the power transformer has a primary winding and three secondary windings. The primary winding of the power transformer connects to the power line through an on-off switch. When the switch is open, current cannot flow through the primary winding, and there will be no voltage induced in any of the secondary windings.

Let's consider the effect of having a power transformer in this receiver. First, notice that the only connection to the power line is to the primary winding. Thus the transformer not only provides operating voltages other than the voltage available from the power line, but also it isolates all of the receiver circuits from the power line. Since the B — supply circuits as well as the heater circuits will all be isolated from the power line, the metal chassis of the receiver can be used as the B — connection without any shock hazard. In fact, we can even ground the metal chassis without worrying about a short circuit, because regardless of which way the power plug is put into the power outlet, there is no way that the hot side of the power line can be accidentally shorted to ground.

Heater Circuit. Looking at the three secondary windings on the transformer, we see that the connections to the lower winding are not shown. We simply have two arrows at the ends of the leads and the notation that these leads connect "to all heaters and dial lamps." All of the tubes and dial lamps used in this receiver except the 5Y4 are 6-volt types. These tubes and the dial lamps require a heater voltage of 6.3 volts to be exact. This voltage is provided by this winding which is called a *filament winding*. It got this name, rather than heater winding, because the early tubes first heated from a power transformer had filaments rather than heater-type cathodes. Since the heaters of the tubes and the dial lamps all require the same operating voltage, they are operated in parallel instead of in series as in the ac-dc receivers.

Notice that one side of this winding on the power transformer is grounded. This is done so that it is not necessary to run two heater leads in the receiver. One side of the winding is connected directly to the chassis; one of the heater connections in each tube and one connection on each pilot light is also connected to the chassis. You will notice that one heater connection, the No. 2 pin, on the 6SA7, 6SK7, and 6K6G tubes, and the No. 8 pin on the 6SQ7, connects directly to ground. In a receiver with this type of arrangement, the other lead coming from the filament winding on the power transformer will connect first to the ungrounded pin on one tube heater and then to another, and so on to all the tubes. For example, this lead will be brought to the No. 7 pin of any one of the tubes. There will be a lead going from the No. 7 pin of this tube to the No. 7 pin of another tube and so on to the remaining tubes. This puts all the tube heaters in parallel.

It might be well to mention one other effect of this type of heater arrangement. In an ac-dc receiver with the tube heaters connected in series, if the heater of any one of the tubes burns out, the series circuit will be open and none of the tubes will light. However, with the tubes connected in parallel, if the heater of one of the tubes burns out, this does not interrupt the current path through the other tube heaters, so they will continue to light. Therefore, if in a receiver of this type you spot a tube with the heater not lighting, the chances are that the heater is burned out, and replacing the tube will restore the receiver to normal operating condition.

Rectifier Filament Winding. The secondary winding of the power transformer shown nearest the top is a 5-volt filament winding used to operate the filament of the rectifier tube. The rectifier is a type 5Y4G full-wave rectifier tube, and it requires a filament voltage of 5 volts. No other tubes are connected to this winding on the transformer, because the filament of the tube is the B+ point in the receiver. In this filament-type tube, the filament is the cathode, or source of electrons. If the other tubes were operated from this winding, all of the heaters would be connected directly to B+, and this would result in excessive voltage between the tube heaters and cathodes. This would cause cathode-to-heater shorts to develop in the tubes.

High-Voltage Winding. The secondary winding shown between the two filament windings is the high-voltage winding. Notice that it is center-tapped and that each of the outside connections connects to one plate of the rectifier tube. You will recognize this as a full-wave rectifier circuit. If this receiver is operated from a 60-cycle power line, there will be two current pulses through the rectifier tube during each cycle, one pulse to one plate of the rectifier during one half-cycle, and one pulse to the other plate during the next half-cycle. If the set is operated from a 25-cycle power line, we will get 50 pulses per second, one pulse during each half-cycle.

Before leaving the power transformer, notice that resistance readings are listed for the primary and high-voltage secondary windings. Two values are given for each winding, one for a 25-cycle transformer and the other for a 60-cycle transformer. The 25-cycle transformer has a higher resistance because it is larger and has more turns on each winding.

The resistance on the two filament windings is not given. This is because the dc resistance of both of these windings is very low and difficult to measure. These windings are wound with rather large size wire, and, since the voltage needed from these windings is comparatively low, there are only a few turns in each winding. The resistance is so low, that even if a short developed that cut the resistance of one of these windings in half, it would be very difficult to detect the difference by taking resistance measurements with the type of test equipment generally available to the serviceman.

The total resistance shown for the secondary winding is 1380 ohms for the transformer designed for 60-cycle operation. If you measured a resistance anywhere between 1300 and 1400 ohms, you would have good cause for thinking this was normal.

Since the tap on the secondary winding is the center tap and is placed in the electrical center of this winding (so there are an equal number of turns on each side) you might at first expect that each half of the winding would have half the total resistance. However this is not necessarily true, because of the fact that the transformer is wound in layers. Each layer is wrapped with a special insulating paper. The next layer will, of course, have a slightly larger diameter than the preceding layer. Thus, on the first layer the amount of wire in a single turn will be shorter than the amount of wire in a single turn on an outside layer. Since the resistance of the wire depends on its length, the longer turn will have a higher resistance. In a high-voltage secondary winding made up of many turns this can cause quite a noticeable difference in resistance between the two halves of the secondary winding.

Notice that the filter capacitors used in the power supply are 5-mfd capacitors. The input filter capacitor is marked C-19, the output filter capacitor C-20. These capacitors have a much lower capacity than the capacitors found in ac-dc receivers, because with a full-wave rectifier such as we have here, the filter network will receive 120 pulses per second instead of 60 as with a half-wave rectifier, and this pulsating dc will be much more easily filtered.

Although the capacity of the filter capacitors is lower, their voltage ratings will be higher. In an ac-dc receiver the B− supply voltages seldom are much above 120 volts, and filter capacitors rated at 150 volts are usually used. In an ac-operated receiver using a power transformer of this type, the filter capacitors are usually rated at 450 volts because the operating voltages often exceed 300 volts.

Notice that the speaker field is again used in the power supply as a filter choke. The speaker field in this receiver has a dc resistance of 1800 ohms. A higher resistance filter can be used in an ac-operated receiver because higher operating voltages are available at the rectifier output.

Now that we have looked at the power supply, let's trace the dc circuits out and see how electrons get from B− to B+ through the various amplifier tubes in the receiver.

THE DC CIRCUITS

You will remember that in a full-wave power supply, electrons flow from the center tap on the high-voltage winding of the power transformer to B−. They then flow through the load, consisting of the four amplifier tubes, back to the cathode or filament of the rectifier tube. The electrons charge the input and output filter capacitors so that the grounded side is negative and the other side is positive. Electrons reaching the filament of the rectifier tube will flow to one of the plates of the rectifier tube. During one half-cycle one plate will be positive, and they will flow to it, and during the next half-cycle, the other plate will be positive, and they will flow to it. Now let's see how electrons get through the load, which consists of the four amplifier tubes.

Starting with the 6SA7 tube, which is called the first detector and oscillator in this receiver, electrons flow from B− through part of the oscillator coil to the cathode, which is the No. 6 pin of the 6SA7 tube. From the cathode, the electrons are emitted and flow to the No. 2 grid of the tube, which is the oscillator plate, and the No. 4 grid, which is the screen, and to the plate of the tube. Electrons striking the plate of the tube flow through the primary winding of the first i-f transformer back to the output filter capacitor, through the speaker field, and to the rectifier tube. Electrons reaching the oscillator plate and the screen grid, which are connected together inside the tube, will flow through the 18,000-ohm resistor R-2, and then back through the filter network to the rectifier tube. This resistance is needed in the screen circuit of the 6SA7 because the output voltage from the power supply is much higher than in an ac-dc receiver. The voltage is too high for the screen of this tube, and if it were applied directly to the screen, it would result in excessive screen current, which would overheat the tube and soon destroy it. The 18,000-ohm resistor R-2 is called a screen-dropping resistor. The current flowing through it produces a voltage drop across it, and the actual voltage applied to the screen of the tube will be equal to the B supply voltage minus the voltage drop across the resistor. This reduces the screen voltage to a safe value.

In the 6SK7 tube, electrons flow from B− directly to the cathode of the tube. They are emitted from the cathode and flow to the plate of the tube, through the primary winding of the second i-f transformer, back to the output filter capacitor and to the filament of the rectifier tube. Electrons reaching the screen of the tube must also flow through the 18,000-ohm resistor R-2 and back to the filament of the rectifier tube. Resistor R-2 is used as a common voltage-dropping resistor for both the 6SA7 and 6SK7 tubes. In some receivers, a separate resistor is found in the screen circuit of each stage.

In the 6SQ7 audio stage, electrons will flow from B− to the cathode, which is the No. 3 pin. The heated cathode emits electrons, which flow to the triode plate, which is the No. 6 pin, and from there they flow through the 470,000-ohm resistor R-6 to the output filter capacitor C-20, through the speaker field, and back to the filament of the rectifier tube.

In the output tube, electrons flow from B− through the 470-ohm cathode resistor R-8 to the No. 8 pin of the 6K6G output tube, which is the cathode. The heated cathode emits electrons, which will flow to the plate and screen of the tube. The electrons reach ing the plate flow through the primary winding of the output transformer, and the speaker field back to B+. Electrons reaching the screen of the tube will flow directly to B+ through the speaker field.

We might point out that the screen grid of the 6K6G output tube is made to operate on a much higher voltage than the screen grids of the 6SA7 and 6SK7 tubes. Therefore, this screen can be connected directly to B+. In fact, since the plate current must flow through the primary winding of the output transformer, causing a voltage drop across the primary, whereas the screen circuit connects directly back to the output filter capacitor, the voltage on the screen will be slightly higher than the voltage on the plate. The plate voltage will be equal to the voltage across the output filter capacitor minus the voltage drop across the transformer. The screen voltage, on the other hand, will be equal to the voltage across the output filter capacitor. Having the screen operating at a slightly higher voltage than the plate does not normally cause any difficulty. The tube is designed for operation in this manner.

THE SIGNAL CIRCUITS

Antenna. This receiver has a loop antenna, which will usually provide sufficient signal pickup to give satisfactory operation. However, there is also a separate winding inductively coupled to the loop that can be used in conjunction with an outside antenna. In areas where the signals are weak, an outside antenna may be necessary. However, connecting an outside antenna to a receiver of this type can cause interference. It is quite possible that under some circumstances signals may be picked up from stations operating so close together that this receiver, even though it is a superheterodyne, will be unable to separate the stations. Interference of this type is often encountered in the evening during the winter months when reception from distant stations is at its best. A signal from a distant station operating on the same, or nearly the same, frequency as a local station may be picked up almost as strongly as the signal from a local station.

The loop antenna is connected to the No. 3 grid of the 6SA7 tube, which is the No. 8 pin, and is connected to B− through the .1-mfd capacitor C-3. The cathode of the tube connects to B− through the oscillator coil, and therefore the signal is applied between the cathode of the 6SA7 tube and the No. 3 grid.

Oscillator. The oscillator circuit used in this stage is a Hartley oscillator. The cathode connects to a tap on the coil, which provides the necessary feedback to the tank circuit. Notice that the terminals on the oscillator coil are identified by letters, and beneath the schematic disgram the manufacturer has shown a sketch of the oscillator coil identifying these terminals.

There are two variable capacitors connected across the oscillator coil and also two connected across the loop.

The capacitor C-2 across the loop is a trimmer capacitor. You'll notice that the manufacturer gives the capacity of this capacitor as 3-15 mmf. This means that the range through which the capacitor can be adjusted is from 3 mmf to 15 mmf. C-1 is the capacitor that tunes the loop circuit to resonance. In the oscillator circuit C-5 is the oscillator trimmer and C-4 is the oscillator tuning capacitor. Notice that the oscillator tuning capacitor has a much lower maximum capacity than the loop tuning capacitor. C-4 is labeled 11-190 mmf. This means that the minimum capacity is 11 mmf, and the maximum is 190 mmf. On the other hand, C-1, which tunes the loop, has a range from 11 to 400 mmf.

You might wonder why the capacity of these capacitors does not drop to zero when they are tuned to the minimum capacity position. The reason for this is that even though the rotor of the variable capacitor is rotated so that the plates are not meshed with the stator plates at all, there will still be a certain capacity between the ends of the rotor plates and the ends of the stator plates. In the case of C-1 and C-4 this capacity is 11 mmf.

In the screen circuit of the 6SA7 tube you'll notice a .05-mfd capacitor marked C-11. This capacitor is a screen by-pass capacitor for both the 6SA7 and 6SK7 tubes. You'll notice that the screen grid of the 6SA7 is connected directly to the screen grid of the 6SK7. You will remember from your earlier studies of multi-element tubes using a screen grid that a screen grid is operated at rf ground potential. Capacitor C-11 has a low reactance at the frequencies encountered in both of these stages and therefore as far as the signal frequencies are concerned, the screen is operated at ground potential. In the ac-dc receivers we studied earlier in this lesson, a separate screen by-pass capacitor was not used because the screen was connected directly to the output filter capacitor. The output filter capacitor acted as the screen by-pass capacitor and kept the screen at signal ground potential.

The input i-f transformer used in this receiver has an iron core. The iron core used in an i-f transformer is usually made of powdered iron. The two resonant circuits are tuned by means of trimmer capacitors connected in parallel with the two windings.

The second i-f, or output i-f, transformer is an air-core transformer. This means that there is no core, other than air, in the windings.

Mixer and I-F. The mixer and i-f stages in this receiver are similar to those you studied previously. The signal picked up by the loop antenna is fed to the No. 3 grid of the 6SA7 tube. The oscillator signal is developed in the 6SA7 tube, with the No. 1 grid acting as the oscillator grid, and the No. 2 grid as the oscillator anode. In the 6SA7 tube, the two signals are mixed, producing two new signal frequencies, one equal to the sum of the two frequencies and the other equal to the difference between them. The i-f transformer is tuned to the difference frequency, which is 455 kc. The 455-kc signal voltage will be developed across the primary winding of the i-f transformer. Current flowing through the primary will induce a voltage in the secondary, and this voltage will be applied between the grid and cathode of the i-f tube. The i-f stage will amplify the signal, causing a signal current to flow in the plate circuit of the i-f amplifier. The signal current will flow through the primary winding of the second i-f transformer and induce a voltage in the secondary.

Second Detector and Audio Stage. The signal voltage developed across the secondary of the second i-f transformer is applied to the diode plate of the 6SQ7 that is connected to the No. 4 pin of the tube. This diode plate and the cathode form a diode tube. When the plate is driven positive, current will flow from B− to the cathode of the 6SQ7, through the tube to the diode plate connected to the No. 4 pin, through the secondary of the i-f transformer, and through the 1-megohm volume control to B−. At the same time, current flowing in this circuit will charge the 150-mmf capacitor C-12. The charge across C-12 and the voltage across the volume control will depend upon the amplitude of the rf signal. As the strength of the signal varies with the modulation, the voltage across the volume control will vary.

The volume control selects the desired amount of audio signal, feeds it through the .01-mfd coupling capacitor C-13 to the grid of the triode section of the 6SQ7 tube, which is the No. 2 pin. The 10-megohm resistor R-5 is used to develop convection bias for the triode section.

The audio signal applied between the grid and cathode of the 6SQ7 triode section will cause the current flowing from the cathode to the triode plate, which is the No. 6 pin of the tube, to vary. This current flowing through the 470,000-ohm triode plate-load resistor R-6 will develop an amplified audio voltage across this resistor. This audio voltage is coupled to the grid of the 6K6G audio tube through the .01-mfd coupling capacitor C-16. The 470,000-ohm grid resistor R-7 again is the grid leak for the output tube. It provides a path back to B− for any electrons accidentally striking the grid of the tube. You'll notice that the plate of the 6SQ7 tube is by-passed to ground by the 220-mmf by-pass capacitor C-14. Again this is an rf by-pass to provide a low-impedance path to ground for any rf signal that reaches the plate of the triode section of the tube.

Output Stage. In the 6K6G tube the current flowing from the cathode to the plate of the tube varies as the grid voltage on the tube is varied by the audio signal. This causes the plate current flowing through the primary of the output transformer to vary, and the varying current flowing through the primary winding sets up a varying magnetic field, which induces a voltage in the secondary of the output transformer T-2. This voltage causes a current to flow through the secondary of the output transformer, the speaker voice coil, and the hum-neutralizing coil. The varying current flowing through the speaker voice coil causes the speaker cone to vibrate in and out.

AVC Circuit. The avc filter consists of a 2.2-megohm resistor R-3 and the .1-mfd capacitor C-3. You'll remember that the purpose of this filter network is to act as a voltage divider to separate the audio from the dc component at the diode detector output. Remember that the .1-mfd capacitor will have a low reactance to audio signal frequencies. Since the reactance of this capacitor is low, most of the audio voltage will be dropped across the large 2.2-megohm resistor. The net result will be that there will be no audio voltage appearing across the capacitor. At the same time, the capacitor has a very high resistance to dc. In fact, as we have mentioned previously, if it were a perfect capacitor, it would not pass dc at all. However, since there is no such thing as a perfect capacitor, there will be some dc leakage through it. However, the resistance of the capacitor will be many times the resistance of the 2.2-megohm resistor, so practically all of the dc voltage will appear across the capacitor. This dc voltage will be negative with respect to ground or B−, and its strength will depend upon the strength of the incoming signal. A strong signal will produce a high avc voltage, and a weak signal a low avc voltage. This negative voltage fed back to the grid of the 6SA7 tube and the grid of the 6SK7 tube will automatically control the gain of these stages. It will reduce the gain when the signal is strong, but let the stages operate at maximum gain when the signal is weak.

Notice that the diode plate of the 6SQ7 connected to pin No. 5 is connected to the avc line. This acts to protect the tubes in case a positive voltage should develop on the avc line. If any defect develops in the receiver, either in the 6SA7 or 6SK7

stages, that results in a positive voltage appearing on the avc line, the diode plate will be driven positive, and the diode will begin to conduct. Since the diode will act like a very low resistance once it starts conducting, this will practically ground the avc line and keep the positive voltage across it to a minimum.

Now you might wonder how we can get a positive voltage on this line. One way that this could happen would be for either the 6SA7 or the 6SK7 tube to develop excessive gas. The electrons flowing through the tube would strike the gas molecules, knocking other electrons off the molecules. This leaves the molecule with a shortage of electrons or a positive charge. Now the molecule with its positive charge will be attracted by the negative voltage on the grid, and hence will drift over to the grid. When a molecule reaches the grid, it will attract electrons from the grid. These electrons would have to flow from B− through the volume control and through the 2.2-meg resistor R-3. In doing so they would develop a voltage that would make the avc line and the diode plate positive with respect to B−. This will cause the diode to conduct, as we already mentioned. Because this circuit eliminates this undesirable effect caused by gas, it is called a *gas gate*. Another defect that could put a positive voltage on the avc line is a short between the control grid and the screen grid in the 6SK7 tube. The screen grid is operated at a positive potential of about 100 volts. If the screen shorted to the control grid of the tube, we would have a positive voltage of about 100 volts applied to the control grid. This voltage would be fed back through the secondary winding of the first i-f transformer to the avc line. At the same time it would be fed through the loop antenna to the No. 3 grid of the 6SA7 tube and would soon ruin it. However, once the positive voltage appears on the avc line, the diode section of the 6SQ7 begins to conduct and effectively grounds the avc line, keeping the positive voltage on it at a minimum. The current flowing in the screen-grid circuit of the 6SK7 would increase somewhat, which would result in a greater voltage drop appearing across R-2. The screen voltage on the 6SK7 tube will drop, and this will keep the voltage on the avc line at a low value, so that the 6SA7 and the 6SQ7 will not be ruined. The 6SK7 with the short between the control grid and the screen grid will, of course, no longer be usable.

Phono Socket. You'll notice also that there is a phono socket on this receiver. The phono socket connects to the grid of the 6SQ7 through a .01-mfd capacitor marked C-15. With the phono socket in use, a phono pickup can be used to play records through the audio system of the receiver. Since the phono socket connects directly to the grid of the tube, the volume control in the receiver will not be effective in controlling the volume of the phono pickup. It might have some slight effect because the center terminal is connected to the grid through a .01-mfd capacitor, and turning the control to a minimum volume position places a fairly low reactance circuit from the grid of the 6SQ7 to ground, but this would not be enough to control the volume from the record player. The player would need a built-in volume control. When operating the receiver with a phono pickup, the set should be tuned to a spot on the dial where there is no local station, and the volume control on the radio adjusted to a low volume setting.

SUMMARY

This type of receiver, using a power transformer, offers several advantages over the ac-dc receiver. Perhaps the most important of these advantages is the isolation that the power transformer provides between the receiver circuits and the power line. There is little chance of being shocked by touching the chassis of this type of receiver while you happen to be touching a grounded object. You should never touch the chassis of an ac-dc receiver while it is operating if you are standing on a concrete floor or touching any grounded object.

The higher operating voltages in the receiver usually result in somewhat better sensitivity than in an ac-dc receiver. In addition, with the full-wave rectifier it is easier to filter the B supply and obtain pure dc. As a result, larger speakers that have a reasonably good low-frequency response are often used in this type of set. The speakers used in ac-dc receivers usually do not have a particularly good low-frequency response, because if the low-frequency response is good, the hum output is sometimes objectionably high.

You will not encounter as many new receivers of this type today because ac-dc receivers are cheaper to manufacture. However, there are millions of receivers of this type still in use and you can be sure that you will be called on to service them. It is likely that you will find that most receivers that use a power transformer also have an rf stage ahead of the converter. The rf stage provides amplification before the signal frequency is changed. This amplification is particularly helpful in the elimination of image interference. You will remember that an image is an interfering signal from a station operating at a frequency equal to twice the i-f frequency above the signal to which the receiver tunes. The extra gain and the additional circuit in the rf stage usually eliminate image interference. The rf stage also provides a better signal-to-noise ratio. The mixer stage in a receiver develops considerable noise. If a weak signal is amplified by an rf stage before it is fed to the mixer, there is a much better chance that it will be able to over-ride the mixer noise than if it is fed directly to the mixer.

A Four-Tube Superheterodyne

A number of the midget superheterodyne receivers use only four tubes instead of five tubes as in the receivers we have discussed previously. In most of these superheterodynes there is no i-f amplifier stage. You will remember that we defined a superheterodyne receiver as a receiver that converts the incoming signal to a lower frequency before it is detected. In most superheterodynes, after the frequency of the signal is changed, there is a stage in the receiver that amplifies this new signal frequency. However, in some small superheterodynes the frequency is changed, and the signal is fed directly to the detector. In other words, the i-f signal is not amplified. However, the fact that the signal frequency is changed before the signal is detected makes the receiver a superheterodyne.

In Fig. 7 on the diagram sheet, we have shown a 4-tube ac-dc superheterodyne. Notice that the values of the various parts used in this set are not marked on the diagram but instead are given in a table shown with the schematic. Manufacturers often do this to cut down on the amount of lettering on the diagram.

We are not going to go into much detail with circuits used in this receiver because you are already familiar with most of the circuits and because you are not likely to encounter very many of these receivers. However, we will study the circuit briefly and also point out a few unusual characteristics of the receiver

THE POWER-SUPPLY CIRCUITS

First, let us look at the heater circuit. You will see that the heaters of the tubes are connected in series as in other ac-dc receivers. In addition we have a resistor marked R-7 in series with the heater string. This resistor has both the heater current and the B-supply current flowing through it. The purpose of the resistor is to drop the line voltage so that the heater voltage applied to the various tubes will not be excessive.

Notice that the power supply circuit in the receiver contains two filter resistors, marked R-8 and R-9, plus a triple-section filter capacitor.

Section C-1 is the input filter capacitor. Section C-2 provides some filtering for the plate circuit of the 50B5 tube. Section C-3 in conjunction with resistor R-9 provides additional filtering for the dc voltage supply for the screen of the 50B5 and the plates and screens of the other tubes.

Capacitor C-8, connected between the plate and cathode of the 35W4 rectifier tube, keeps line noise out of the B supply and hence out of the receiver.

THE DC CIRCUITS

To trace out the dc circuits, let's first trace the cathodes of the three amplifier tubes to B−. You'll notice that the cathode of the 12BE6 tube connects back to B− through a winding on the oscillator coil. The cathodes of the 12AT6 and the 50B5 tubes connect directly to B−. Notice that there is no cathode resistor used in any of these stages.

The circuit from the plate and screen grid of the 12BE6 tube can be traced to the positive side of the output filter capacitor C-3. The plate circuit is through the primary winding of the i-f transformer, and the screen grid connects directly back to this capacitor.

The plate of the 12AT6 tube connects back to the output filter capacitor through the 220,000-ohm plate sistor R-6.

The screen of the 50B5 output tube is connected directly to the positive side of C-3, and the plate is connected to the positive side of C-2 through the primary winding of the output transformer.

While we are looking at the dc circuits let's look at the bias circuit of the 50B5 output tube. Notice that the cathode connects directly to B−, and therefore is operated at ground or B− potential. The grid, however, connects through the resistor R-5 back to the No. 1 grid of the 12BE6 tube, which is the oscillator grid. Now, you know that when the oscillator is operating, the oscillator grid is driven positive by the signal, and when this happens, electrons flow to the grid of the tube and then through the oscillator grid resistor R-1. The electrons also charge the oscillator grid capacitor, which in this circuit is a gimmick on the oscillator coil. When the grid is not attracting electrons, this capacitor discharges through R-1, maintaining the grid of the oscillator tube negative.

Since the grid of the 50B5 is connected back to the oscillator grid through R-5, there will be a negative potential applied to the grid of the 50B5 tube. There will be no voltage drop across R-5 because as long as the grid of the 50B5 is negative, there will be no current flow in the grid circuit. Thus the grid of the 50B5 is simply maintained at the same negative potential as the grid of the oscillator. This is sufficient to provide an operating bias for the 50B5 tube.

THE SIGNAL CIRCUITS

The signal circuits found in this receiver are similar to the signal circuits described in the receivers already discussed. However, we'll go through these circuits once again. Notice that an antenna coil is used on this receiver instead of a loop. The primary winding of the antenna coil is connected to an outside antenna. The signal picked up by the antenna flows through the primary winding, inducing a voltage in the secondary. The secondary circuit is tuned to resonance by the capacitor connected across it. This is one section of the tuning capacitor. The output from the secondary winding is connected to the No. 3 grid, which is connected to pin No. 7 of the 12BE6 tube, and to the cathode of the tube through the .05-mfd capacitor C-4 and the oscillator coil. You will notice two capacitors marked C-4 on the diagram; both are .05-mfd capacitors. Manufacturers sometimes give all the parts of the same value the same part number. The capacitor mentioned here is the one connected from B− to the antenna coil.

The oscillator circuit is a Hartley oscillator. The feedback from the cathode circuit to the oscillator tank circuit is inductive. Notice that the oscillator coil has a gimmick winding which forms the capacity from the No. 1 grid, which is the oscillator grid, to the oscillator tank circuit.

The incoming signal is mixed with the signal from the local oscillator in the 12BE6 tube, producing two new signal frequencies, one equal to the sum of the two signals and the other equal to the difference. The primary winding of the i-f transformer is tuned to this difference frequency, which is the i-f.

The signal current flowing through the primary winding of the i-f transformer induces a voltage in the secondary winding. Now this voltage, instead of being fed to an i-f tube for amplification, is fed to the detector for detection. The signal across the secondary winding is applied to the diode plate connected to the No. 5 pin. When the diode plate is driven positive, electrons flow from the cathode of the tube to this diode plate, through the secondary of the i-f transformer, and then through the volume control, which is R-3, back to B−. Capacitor C-5 is the diode load capacitor, which is charged by this current. R-2 and C-4 make up the avc filter network. The avc voltage is fed to the control grid of the 12BE6 tube through the secondary of the antenna coil. Notice that the avc line connects to the other diode plate, which is the No. 6 pin of the 12AT6 tube. This is a gas gate similar to the one used in the preceding set.

The signal from across the volume control is fed to the triode section of the 12AT6 tube through the .002-mfd capacitor C-6. Bias for the 12AT6 tube is developed across the 10-megohm grid resistor R-4 by convection.

The audio signal applied between the grid and the cathode of the 12AT6 tube will cause the plate current flowing from the cathode to the plate of the triode section to vary. This causes the current flowing through the 220,000-ohm plate load resistor R-6 to vary, developing a voltage across it. This voltage is fed to the grid of the 50B5 through the coupling capacitor C-7, and this audio signal fed to the input circuit of the 50B5 tube causes the plate current flowing in this tube to vary. The varying current flowing through the 50B5 tube goes through the primary of the output transformer, inducing a voltage in the secondary, which in turn causes current flow through the voice coil of the speaker, and operates the speaker.

Notice that the plate by-pass on the 50B5 output tube is connected directly across the primary winding of the output transformer. Insofar as the signal is concerned, the end of the primary winding of the output transformer winding of the output transformer that connects back to C-2 is at signal ground potential because the size of C-2 is so large that the capacitor has a low reactance at signal frequencies. Thus the by-pass capacitor is connected from the plate of the 50B5 to B− electrically.

SUMMARY

You are not likely to run into too many of these small superheterodyne receivers to service, but you will probably encounter some. The circuit is interesting because this is the first time you have seen a superheterodyne that does not have an i-f amplifier. As far as servicing this type of receiver is concerned, people who own these sets usually are not too willing to spend a great deal to have them repaired, because the sets were originally quite inexpensive. However, you may be called on to make simple repairs, such as replacing tubes or possibly a filter capacitor in one of these sets.

A Four-Tube TRF Receiver

Some of the small four-tube receivers that were manufactured not too long ago are trf receivers. The schematic diagram of a receiver of this type is shown in Fig. 8 on the diagram sheet. This receiver usually has rather poor selectivity and you may find that it simply is not capable of separating strong local broadcast stations.

We'll run through the circuits in this receiver briefly.

B-SUPPLY CIRCUITS

Notice that the heaters of the tubes used in this receiver are once again connected in series. The filter network used at the power supply output is similar to the filter networks you have seen previously. The plate of the 50L6 output tube is brought back directly to the input filter capacitor, whereas the screen of the 50L6 tube and the plates and screens of the other tubes are brought back to the 30-mfd output filter capacitor.

The cathode of the 12SG7 rf amplifier is connected to B− through the 220-ohm cathode resistor. The cathode of the 12SQ7 connects directly back to B−, and the cathode of the 50L6 tube connects to B− through the 150-ohm cathode bias resistor marked 21 on the diagram.

The screen of the 12SG7 tube connects directly back to the output filter capacitor; the plate of the 12SG7 tube connects to the output filter capacitor through the rf coil marked 28 on the diagram. The plate of the triode section of the 12SQ7 is connected directly back to the output filter capacitor through the 1-megohm plate load resistor marked 19. The screen of the 50L6 connects directly back to the output filter capacitor, and the plate of the 50L6 connects to the input filter capacitor through the primary of the output transformer.

THE SIGNAL CIRCUITS

This receiver is operated with a short external antenna. The signal picked up by the antenna is fed to the antenna coil and causes a current to flow through the primary winding. Notice that the primary winding of the antenna transformer connects to B− through a .01-mfd capacitor. This is to avoid a direct connection between the antenna and B− through the primary winding of the coil. This direct connection must be avoided to keep from shorting the primary winding of the coil if the antenna is grounded.

The signal current flowing through the primary winding of the antenna coil induces a voltage in the circuit. The secondary is tuned to resonance by the variable capacitor connected across it. The lower end of the secondary winding connects to ground through the .01-mfd capacitor marked 9 on the diagram, so that the tuning capacitor is, in effect, in parallel with the secondary of the antenna coil.

The signal from the antenna coil is fed to the cathode of the 12SG7 through the 220-ohm resistor 15, and the .01-mfd capacitor, and to the grid through the 220-ohm resistor marked 14. The 220-ohm resistor is used in the grid circuit to prevent oscillation, which would probably otherwise occur, because both the plate circuit and the grid circuit are tuned.

The signal is amplified by the 12SG7 rf amplifier. In the plate circuit of this tube we have a parallel resonant circuit consisting of a coil marked 28, and the second section of the tuning capacitor with the trimmer connected across it. The second tuned circuit is used to get additional selectivity.

The amplified rf signal is fed to the diode plate connected to the No. 5 pin of the 12SQ7 tube through the 220-mmf capacitor 11. The diode detector works like the diodes we have discussed previously. When the plate is driven positive, electrons will be attracted from the cathode. The electrons reaching the diode plate will flow through the 47K resistor 17 and through the 1-meg volume control, 13. The electrons will charge the 200-mmf capacitor 12; the charge across it and the voltage across the volume control will depend upon the strength of the signal fed to the diode detector. Thus, we'll have a dc voltage with an audio signal superimposed on it appearing across these components.

The dc component is separated from the ac component by the avc network made up of the 2.2-meg resistor, 16, and the .01-mfd capacitor, 9, and fed to the grid of the 12SG7. The audio signal is taken from the center terminal on the volume control and fed through the .01-mfd capacitor to the grid of the 12SQ7 triode section. The signal is amplified by this tube and the amplified plate current flowing through the 1-meg plate load resistor 19 will develop an amplified voltage across it. This voltage is coupled to the grid of the 50L6 tube through the .01-mfd capacitor, 7.

The audio signal applied to the grid of the 50L6 tube will cause the plate current flowing through this tube to vary at an audio rate. This current flowing through the primary winding of the output transformer 24 will induce a voltage in the secondary, which will cause current to flow in the secondary and the speaker voice coil.

SUMMARY

Notice the simplicity of this receiver. The signal is picked up, amplified, detected, and then the audio signal is amplified and fed to the speaker. Notice that the signal frequency is not changed as it is in a superheterodyne receiver. The signal is amplified at the rf frequency at which it is picked up instead of being changed to a lower intermediate frequency.

LOOKING AHEAD

The receivers we have discussed in this lesson are typical of some of the receivers you may service. If you are able to trace out the circuits in these sets, if you understand the various circuits, and if you will study them until you are reasonably familiar with the circuit arrangement, you should be well on the way towards understanding the circuits of any receiver in these categories that you're likely to encounter. Although there are other types of sets, understanding these basic circuits is actually a big step forward in understanding some of the other types that we have not discussed yet.

Many modern receivers manufactured today use transistors. We did not cover transistor radios in this lesson because most transistor radios are portables. We'll study portable receivers in detail in later lessons.

Two other important receiver types that you'll encounter are the all-wave broadcast receiver and the FM receiver. Both of these types will be studied in detail in later lessons.

Incidentally, circuits fround in the radio receivers you studied here, and those you will study in the next few lessons are very similar to circuits found in TV receivers. Learning these receivers is a big step toward learning TV receiver circuits and how to service them. As a matter of fact, even if you're interested in doing only television service work and do not plan to do any radio service work at all, it's a good idea to become familiar with these sets and also to do some radio service work simply to get practice in servicing electronic equipment. It is far easier to work on a 5-tube radio receiver than it is on a 20-tube television set. Don't be afraid to start small and work up to bigger sets. There are very few top-notch TV technicians today who did not get their start servicing radios. Furthermore, there are many more radio sets in use than there are television sets. Even if you eventually expect to concentrate on TV service work, there is no reason why you should pass up the opportunity of picking up some extra money repairing radios.

Lesson Questions

Be sure to number your Answer Sheet 22B.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. In the circuit shown in Fig. 1, why is the B+ lead from the output transformer brought back directly to the cathode of the rectifier tube rather than to the output filter capacitor?
2. In Fig. 1, what is the purpose of the 15-megohm resistor marked 15, connected between the oscillator grid of the 12BE6 tube and the avc line?
3. In the circuit shown in Fig. 1, through what part is the signal fed from the plate circuit of the 12AT6 tube to the grid of the 50B5?
4. In the circuit shown in Fig. 2, what is the purpose of the 86-ohm resistor R-11?
5. What is the dc resistance of the field coil of the speaker in Fig. 2?
6. If the heater of the 6SK7 tube burns out in the circuit shown in Fig. 6, will the heaters of the other tubes still light? Why?
7. In the circuit shown in Fig. 6, through what parts do electrons flow in going from the oscillator anode of the 6SA7 tube to the filament of the rectifier tube?
8. What is the name given to the circuit in which a diode plate, such as pin 5 of the 6SQ7 tube in Fig. 6, is connected to the avc line?
9. Where does the 50B5 output tube get its bias in the circuit shown in Fig. 7?
10. What type of receiver is the four-tube receiver shown in Fig. 8?

THE VALUE OF REVIEW

Man has acquired so much new knowledge in recent years that it has become impossible for one person to know everything available about even a limited subject. Educational authorities realize this fact, and the colleges of today consider a man well-educated if he knows the elementary ideas *and knows where to find other information when he wants it.*

The field of radio and television has outgrown the memorizing ability of the human mind. Also, it is such a comprehensive field that occasionally you cannot recall important facts previously studied. Review is obviously needed.

Time spent in review several weeks or months after a book is studied will be far more profitable than an equivalent amount of extra time spent on the book initially, for your mind has then had a chance to file and store away the information secured from the first study. Each review results in more information being transferred from the textbook to your mind, and soon, with no conscious attempt to memorize, you will find yourself able to recall an amazing number of valuable facts.

J. E. Smith

HOW TRANSISTORS WORK

24B
(Same as 24 FR-2)

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE No. 24

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ 1. Introduction .... Pages 1-3

☐ 2. Semiconductor Fundamentals .... Pages 3-13

Here you learn about semiconductor materials, their atomic structure, and why they work as semiconductors.

☐ 3. Semiconductor Diodes and Transistors .... Pages 14-30

You learn about junctions between two types of semiconductors and what takes place there.

☐ 4. Basic Transistor Circuits .... Pages 31-36

How transistors are used.

☐ 5. Answer the Lesson Questions.

☐ 6. Start Studying the Next Lesson.

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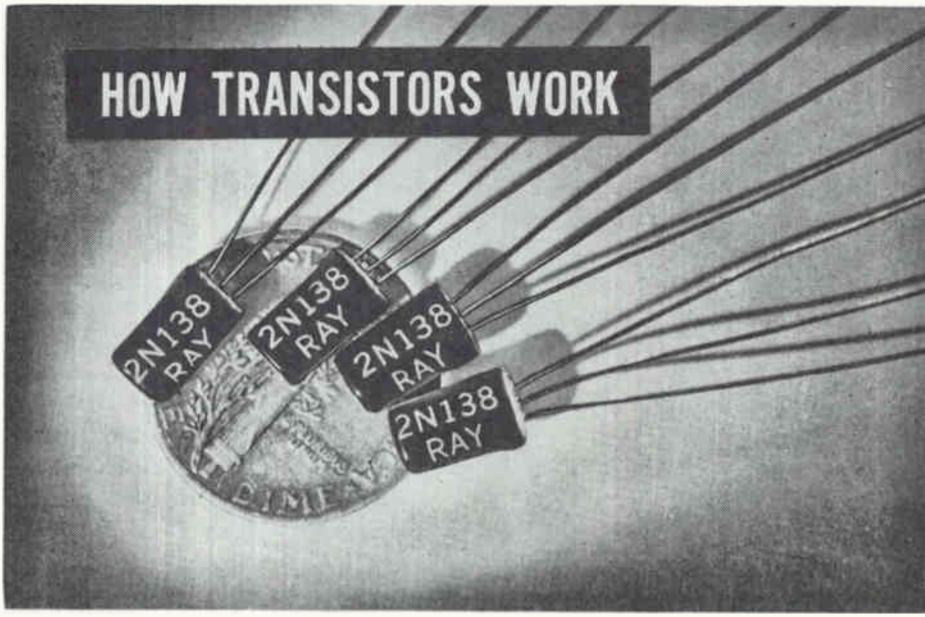


IN THIS lesson and in the following one, we will discuss a relatively new field of electronics — one that promises many advances in circuit types and applications. Since the transistor was first developed, it has been improved to the point where it can perform many of the jobs originally done by vacuum tubes. The transistor is a very small light-weight device; and because of its small size, it is ideal for such compact-unit designs as personal radios, hearing aids, and other portable electronic equipment.

The development of the transistor is a result of many years of research into the electrical characteristics of various solid materials such as germanium and silicon. These elements belong to a group called semiconductors. The members of this group have electrical characteristics that differ greatly from those of metals.

A very early application of some of these materials was in the crystal detectors used in the first radio receivers. The crystal was mounted so that one side was in contact with a metal plate or cup. A very fine wire, called a cat whisker, was used to locate a current-sensitive spot on the surface of the material. The crystal acted as a detector because it allowed current to flow more easily in one direction than in the other. This device, however, did not amplify the applied signal.

With the development of the vacuum tube, research on crystals for use in electronic circuits practically ceased. During World War II, germanium and silicon diodes were developed for radar use. The work was carried on in various laboratories, and finally led to the development of the transistor. These units may never entirely replace vacuum tubes in all applications, but they can replace tubes in many low-power amplifier, oscillator, computer, and switching circuits. They are better

Photo Courtesy Raytheon Mfg. Co.

than tubes in many circuits, and can do work in other circuits that vacuum tubes cannot duplicate.

The transistor has many advantages over the vacuum tube. The size is extremely small; the entire transistor, including the protective shield, may be as small as one-eighth of an inch in diameter by one-quarter of an inch high. Because the material used is solid, the transistor is very rugged. It can withstand severe mechanical shock without physical damage or change in electrical characteristics.

Another advantage is that the transistor requires no filament voltage. In addition, the supply voltage is usually only a few volts at very low current. Thus, the transistor can be operated from a small lightweight battery, which makes it ideal for use in small, compact equipment.

For the same amount of power consumed, it is possible to obtain higher output voltage and power gains with a transistor than with a vacuum tube. At present, however, there are few high power-output transistors available. Most of them are low power units. After more improvements are made, transistors will probably be more efficient than vacuum tubes operating at similar power outputs. Transistor life extends to 100,000 hours, as compared to approximately 5000 hours for the vacuum tube. As you can see, a transistor, when operated within the manufacturer's recommended voltage and power levels, doesn't need replacement very often.

A disadvantage of the transistor, at present, is that it has more noise output than a vacuum tube. This noise is particularly noticeable at low frequencies—especially in the audio range. However, at higher frequencies, the noise decreases; and at extremely high frequencies, the unit has approximately the same noise output as the vacuum tube.

Much of the electron theory we are familiar with from our study of vacuum tubes is inadequate to describe the operation of transistors. We learned that electrons from a heated cathode are made to flow through a vacuum when a positive potential is applied to the plate. This electron flow is controlled by an element called a grid, which is inserted between the cathode and the plate. The material of which the transistor is composed, however, is a *solid*. Instead of an electron movement between elements in a vacuum, as in the vacuum tube, the current in a transistor flows through a very small piece of solid material. Although the net result is the same (an amplified signal at the output), the operation of the transistor differs greatly from the vacuum tube operation.

The fundamental transistor theory that we will give in this lesson is accepted by *most* of the scientists who are concerned with transistor research. The transistor is a comparatively new development; some of the reasons why it is able to produce an amplified signal at its output are not fully understood at this time. Further research will, no doubt, modify some of the explanations now considered to be correct, and clear up some points on which scientists do not fully agree.

Most of the theory can be proved by highly involved mathematics, but some of it has been derived from the results obtained from transistor circuit action. We will not give you a highly technical or mathematical explanation in this lesson. Instead, we will include only enough information to give you a clear picture of how transistors work.

We will discuss the fundamental operation of the transistor, describe the various types that have been developed, and briefly discuss the basic transistor circuits.

Semiconductor Fundamentals

A word of caution right at the start—do not think of the transistor as a kind of vacuum tube or anything like it. Transistors can be used in some circuits which are electrically similar to those used with vacuum tubes. Most of the simple circuits published in popular radio and electronics magazines take advantage of this fact. Even some of the best engineering texts include chapters on "Duality"; that is, designing transistor circuits by comparing them with similar tube circuits.

Unfortunately this approach does not lead to an understanding of transistors. It does, however, lead some people to believe that transistors are somewhat like vacuum tubes—only without the vacuum. Many popular magazine articles have even tried to explain transistor operation in this way.

Transistors and vacuum tubes operate on entirely different principles. You cannot understand transistors by comparing them with vacuum tubes; there are no grounds for comparison. Many times new equipment and ideas can be explained by comparison with older, better understood things. For instance, the grid of a triode tube is frequently compared to a valve in a water pipe. This comparison is a good one since it explains the action of the grid without being misleading. No one ever tried to put a brass faucet in a tube envelope. When a grid does not cut off the current flow in a tube, you don't grind the seat and replace the washer. The two things are so different in appearance and actual use that no confusion results.

Because many of the circuits in which they are used are so much alike, it is easy to fall into the habit of thinking of transistors in terms of vacuum tubes. This comparison is harmful; the internal operation of a transistor is no more like that of a vacuum tube, than a solid material is like a vacuum.

The first thing we are going to do is to look inside an atom to find out why some materials are good conductors of electricity and others are insulators. Then we will show how semiconductors differ from both. When we do this we will find that current conduction in a semiconductor is not only by means of electrons but also by what are apparently positive charges. We will find also that there are three basic types of conduction in these new materials. The type of conduction will depend upon whether the current is carried by electrons, by the positive charges, or by both.

Transistors are only one type of semiconductor device used today in radio equipment. As we prepare the ground work for the study of transistors, we will also show how silicon and germanium diodes work. We will spend considerable time getting an understanding of the operation of transistors and semiconductor diodes. These devices are new; they are undergoing constant changes. Each day new circuits using these devices are being developed. Many of these circuits are totally unlike anything used with vacuum tubes. An example of one such new circuit is an oscillator using a diode instead of a triode. This type of operation is possible only with semiconductor materials. It is only by having a thorough understanding of the operation of these devices, that you will be able to keep up with the rapid advances and changes in their use. The great strides taken in the last few years in the development and uses of semiconductors have been only a start. From here on the development will move at a much more rapid pace.

SEMICONDUCTOR MATERIAL

The material used in transistors and crystal diodes has electrical characteristics midway between a conductor and an insulator. From your early studies, you know that a *conductor* presents a low resistance to current flow because its electrons are arranged so that they can easily be removed from their atoms. Examples of conductors are copper, aluminum, and silver.

An *insulator*, on the other hand, has a high resistance to current flow. The electrons in the atoms of an insulator, such as glass, paper, wood, and dry air, are arranged so that they cannot easily be removed from their atoms.

A material, called a *semiconductor*, having characteristics between these two extremes (conductors and insulators) is used in transistors and similar devices. The electrons in a semiconductor can be removed from their atoms if some type of external energy, such as voltage, heat, or light, is applied to the material. Then, it acts like a conductor.

Typical semiconductor materials are germanium, silicon, lead sulphate, and selenium. By far the most widely used semiconductor material for transistors is *germanium*—a hard metallic substance. Although germanium is an abundant element, it is not found in a pure state in nature. Most of the germanium used in forming transistors is obtained as a by-product of zinc mining and from the coal dust from chimneys.

Before germanium can be used in transistors, it must be refined and as many of the impurities as possible removed. The purifying process is rather complicated, and a detailed description is not necessary to the understanding of transistor action. It is interesting to note, however, that amounts of impurities so small that they could not affect the electrical characteristics of other substances will make germanium totally unsatisfactory for transistors. Germanium crystals used in the manufacture of transistors are among the purest substances made by man.

When germanium is in its purest form, it is practically an insulator. That is, it offers a very high resistance to current flow. To make it conductive enough to be used in transistors, small amounts of other elements must be added to the pure germanium. The quantity of the added materials, called impurities, must be closely controlled. If too many impurities are added, the germanium becomes too conductive and is again unsuitable for transistor purposes. The amount of impurity is about 1 atom of impurity for each 10,000,000 atoms of germanium.

As the impurity atoms are added, the germanium becomes more conductive, and the resistance to the flow of current decreases. Thus, the current flow in a piece of germanium can be controlled either by varying the amount of impurities in the substance or by applying an energy source to the semiconductor material. Both methods can vary the conductivity of the material and cause it to act as a variable resistance. Transistor action is possible only because of this variable resistance characteristic. In other words, the transistor operates by controlling the resistance of the semiconductor material. From this ability, the unit gets its name — TRANSfer resISTOR. It *transfers* variations in external potential into variations in *resistance* of the semiconductor.

The resistance of germanium also depends upon the temperature. In most metals, the resistance increases with increase in temperature. With germanium, however, the resistance *decreases* with increase in temperature. This is important in the design of circuits using transistors. Operation of the units will be affected if they are placed near vacuum tubes or other components that radiate a large amount of heat.

ATOMIC STRUCTURE OF SEMICONDUCTORS

The best way to understand the operation and characteristics of a transistor is to study the atomic structure of the semiconductor material. You have learned that a conductor is a material in which a great many electrons are free to move and break away from the atomic structure when a voltage is applied across the material. An insulator, on the other hand, has no free electrons. Whether a substance is a conductor or insulator, therefore, depends upon whether or not it has free electrons.

At this point we could simply say that a semiconductor has a few free electrons, less than a conductor but more than an insulator. If we said that we would be half right—part of the time. Furthermore this simple explanation does not explain several other characteristics of semiconductors in an electrical circuit. The semiconductor never has as many free electrons as a metal conductor. However, it is possible for a semiconductor to have no free electrons, and consequently act as an insulator.

There are two other characteristics of semiconductors which are quite important in their use in transistors. The first of these is the fact that semiconductor materials do not follow Ohm's Law. The resistance of a semiconductor material does change when the voltage changes; but the resistance is *reduced* as the voltage increases. A second characteristic which affects transistor operation very greatly is that as the temperature of a semiconductor rises, the resistance is reduced. This is exactly opposite to most conductors. Metallic conductors have higher resistances at higher temperatures. These characteristics are extremely important in transistor action and in order to understand them we will have to take a look into an atom.

An atom of any element consists of a central positively charged nucleus which is surrounded by a cloud of electrons. In a neutral or uncharged atom there are just the right number of electrons to neutralize the positive charge. The charge on the nucleus is different for different atoms. Hydrogen, the simplest atom, has a single positive charge on the nucleus while aluminum has 13, silicon 14, copper 29 and germanium 32. In the neutral or uncharged state, each of these atoms has enough electrons to exactly neutralize the charge of the nucleus. Thus the hydrogen atom has only one electron, while aluminum has 13, silicon 14, copper 29 and germanium 32. These electrons place themselves systematically in a series of "shells" around the nucleus.

Each of these shells can accommodate only a certain number of electrons. The first shell can hold no more than two electrons; the second shell, 8; the third shell, 18; and the fourth shell 32. While there is a maximum number of electrons that may be found in any shell, there is no minimum. There can be any number of electrons in a shell, from zero to the maximum number allowed in that shell.

An atom from which one of the outer shell electrons has been removed is said to be charged or *ionized*. The restraining force that tends to prevent such removal is the electrostatic attraction between the electron about to leave, and the remainder of the atom. Such attraction exists because, as an electron starts away, its departure leaves the atom positively charged. The negative electron trying to leave the atom is pulled back to the positively charged atom. Before the electron can leave the atom, the attractive force between the electron and the nucleus must be overcome. Some form of outside energy must be supplied to this electron in order for it to leave. The amount of energy required is different for each different type of material.

Under the circumstances which we will consider, the only electrons which can be removed from an atom are those in the outermost shell. These outer electrons are the ones which determine most of the electrical and chemical characteristics of each type of atom. They are known as *valence electrons*.

For a given electron arrangement, the valence electrons which are located in the shells closest to the nucleus require the greatest amounts of energy before they can be ionized. The farther away the valence shell is from the nucleus, the less energy is required to remove its electrons.

The number of electrons in the valence shell also determines the energy necessary to remove one of them. Any electron that has the entire outer shell to itself, is in general, much less strongly attached to its atom than one which has many companions in its own shell. Good electrical conductors are made from the elements in which the farthest out shell that is occupied, contains only one, two, or at the most three electrons.

In solids, billions of atoms are bound together to form crystals. Within each crystal the atoms are held in a regular pattern which is called a space lattice. The number and arrangement of electrons within each atom determines the shape of the crystal and of the space lattice which makes up the crystal. The type of crystal structure in turn determines many of the physical properties of the material.

Within these crystals, the atoms are located so close together that the outer shell electrons are really no more closely associated with one atom than with another. When there are only one or two valence electrons, the attachment of these electrons to the individual atoms is weak to begin with. It vanishes completely in this very closely spaced arrangement of atoms. At least one, sometimes two, and in a few cases three, electrons per atom are not bound at all to any one atom, but are free to move throughout the interior of the metal. They can therefore move very easily in response to electric fields. For this reason these materials make good conductors of electricity.

On the other hand, in the case of insulators, the valence shell of the atom is full or nearly full of electrons. In this case a great amount of energy is required to separate an electron from its atom. Even in the closely packed atom arrangement of a crystal, the valence electrons are not free to move about. Since there are no available free electrons, this material is an insulator.

In the case of the semiconductor, the valence ring is not full, but in forming the crystal lattice the outer electrons arrange themselves about the atoms in such a manner that each valence shell appears full. We will show how this is possible using germanium as an example.

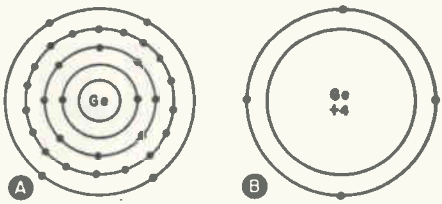


FIG. 1. A, arrangement of electrons about germanium nucleus. B, simplified symbol for germanium.

Fig. 1 shows the arrangement of the electrons about the nucleus of a germanium atom. In this picture, the shells around the nucleus are shown as rings, and the dots on each ring show the number of electrons in each shell. This is the common method of showing an atom. You can see from this that the electrons are arranged in four shells which contain respectively 2, 8, 18, and 4 electrons. Of the 32 electrons surrounding the nucleus, only the four outer ones concern us. The 28 electrons in the three inner shells are bound so closely to the nucleus that it is very difficult to remove them. For this reason it is customary to indicate the germanium atom in an abbreviated form as shown in Fig. 1B. In this abbreviated form, the nucleus and inner shells are represented by the inner circle and only the valence electrons are shown. The number in the center is the net positive charge of the combined nucleus and inner shells.

The arrangement of atoms in a crystal of germanium is shown in Fig. 2. In this figure the balls represent the centers containing the nucleus and the 28 electrons which are closely bonded to it. The rods represent the forces holding these atoms together within the lattice. You will notice that there are four of these links for each atom. That is, there is one link for each electron in the valence shell. Since the three dimensional structure is more difficult to follow, we will flatten this lattice out and use the picture of Fig. 3 to show a simpler arrangement. Each germanium atom shares each of its four valence electrons with one other atom and in return shares a valence electron which is received from the second atom. This arrangement is shown in Fig. 3.

Each pair of shared electrons, one from each of two atoms, is called a

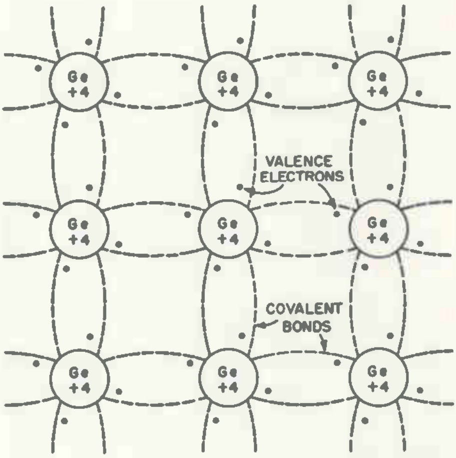


FIG. 3. Plan diagram of arrangement of atoms in germanium nucleus.

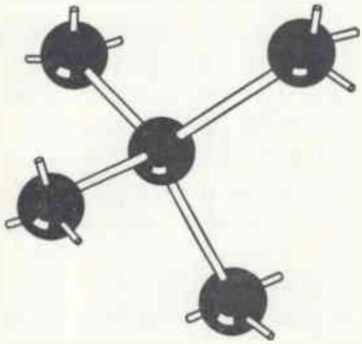


FIG. 2. Lattice structure of germanium.

COVALENT BOND. You may have noticed that throughout the book we have referred to "valence shells" not "valence rings." This is because the electron is not restricted to a flat circular orbit but may move anywhere on the surface of a sphere which has the nucleus at its center. Furthermore, the electron is continuously spinning on its axis. The movement of the two electrons of a covalent bond with respect to each other, provides the force that holds the atoms of the crystal together. Before an electron can leave its covalent bond, it must receive enough energy to overcome the force of attraction between the two atoms.

In a perfect crystal containing only pure germanium, and receiving no energy of any kind from outside the crystal, germanium would be a perfect insulator. In order for the germanium to be sufficiently conductive for use in transistors, some source of outside energy must be applied, or impurities must be added to the crystal.

The heat energy received by the crystal even at room temperatures is sufficient to cause a few of the electrons to move out of their proper place in the lattice structure. Because of this heat energy there are always a few free electrons available for conduction of electric current. As the temperature increases, more and more electrons are freed from the valence bonds, and the speed of the electrons becomes greater. As more electrons are freed and the speed of the electrons is increased, the resistance of the material is reduced. This is the reason why semiconductors have a resistance which decreases with rising temperature.

Heat is not the only form of energy which can reduce the resistance of semiconductor materials. You learned in an earlier lesson on electron tubes, that electrons can be emitted from a metal by applying heat, light, by bombarding the metal with other electrons, or by subjecting the metal to a high voltage field. These electrons were originally a part of the crystal structure. Therefore, they must be removed from their atoms and made free electrons before they can be emitted. In semiconductor devices, we need only free electrons from the valence shells of atoms. It is not necessary to cause them to be emitted from the material. Electrons may be freed from their valence bonds by any of the forms of energy which cause emission. However, in any material, the energy required to free electrons from their valence bonds is not as great as the energy required for emission from the metal. The number of free electrons will, of course, depend upon the amount of energy used.

As the amount of energy is increased, not only is the number of free electrons increased, but the free electrons travel faster.

When the heat energy drives an electron from the valence bond it leaves an empty space in the crystal lattice. This empty space is called a "hole." An electron from a neighboring atom can move into this hole, thus creating a new hole at the place it left. This movement of electrons to fill holes makes it appear that the holes themselves move.

The filling of holes by valence electrons from another atom is possible since the electrons are in constant motion about their atoms. If in its movement an electron comes closer to a hole than to its own atomic nucleus, it will be more strongly attracted to the hole and will leave its atom. When there is no voltage applied across the crystal, the movement of a hole is at random. It can and does move in any direction.

When a voltage is applied across the crystal, the free electrons are attracted toward the positive pole of the voltage source and the holes move toward the negative pole. In other words the hole moves in exactly the same way that a positively charged particle within the crystal lattice would move.

It is easy to see why the hole would move in this direction, when you remember that electrons moving from an atom to fill a hole will move most easily towards the positive pole. When an electron leaves an atom to fill a hole, it leaves a hole in the atom from which it moved. Thus the hole moves in the opposite direction to the electron. In transistors you can think of these holes as excess positive charges. It is important to note at this point that the movement of holes is only about half as fast as the movement of electrons.

Electrons and holes are referred to as carriers, and are responsible for the conduction of electricity in a crystal. The electrons are negative carriers just as in metals, but the holes are positive carriers. There is no equivalent to current conduction by means of holes in a metal. In a pure crystal, holes and free electrons are formed in pairs. The removal of one electron from an atom always leaves one hole in that atom. Thus there are an equal number of holes and electrons.

The removal of an electron from an atom leaves a positive ion. At each hole, therefore, there is a localized region of positive charge. These positively charged ions attract free electrons which pass near them. These electrons fill the holes and return the atoms to their normal electrically neutral condition. At room temperatures about one ten thousandth of a second passes between the time an electron leaves the valence ring to become free, and the time a free electron fills the hole in that valence ring.

The formation of hole-electron pairs and their recombination is a continuous process. Both formation and recombination take place all the time in any crystal. The conductivity of the material depends on the average length of time an electron is free and on the number of free electrons, and this conductivity rises rapidly above room temperatures.

Conduction of this type in pure germanium, caused by the formation of hole-electron pairs, is called INTRINSIC CONDUCTION. In transistors and semiconductor diodes this intrinsic conduction is undesirable. It is kept as low as possible by shielding the unit from light and holding the operating temperature as low as possible. The way in which intrinsic conduction affects transistor operation will be covered later in this book. At this time it is necessary only to state that the operation of the transistor can be greatly limited, or the transistor completely destroyed if this intrinsic conduction becomes too great.

Intrinsic conduction is used in some types of light-sensitive cells. The older selenium photocells and the new germanium photo-resistors use the increase in hole-electron pairs, resulting from light energy, to control the conductivity of a simple series circuit. These circuits will be taken up in a later book. The conductivity of germanium can be increased in a manner that will allow transistor action by "doping" or adding impurities.

The impurities used in germanium and silicon transistors are materials which contain either one more, or one less electron in the valence shell than germanium itself. Each impurity atom displaces one germanium atom in the crystal structure. However, neither type of impurity has the proper num-

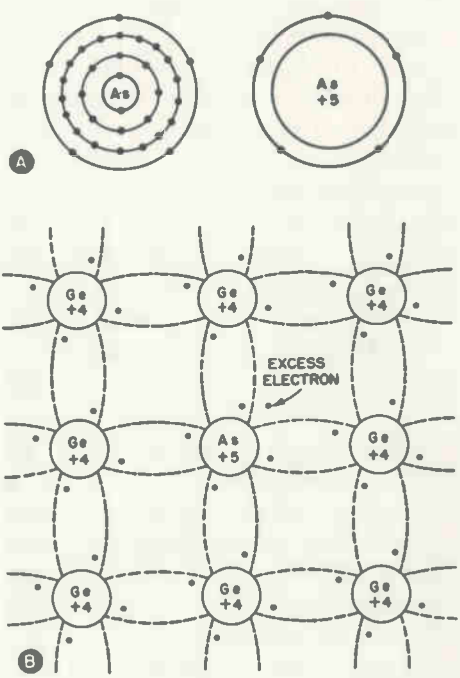


FIG. 4. A, arsenic atom showing arrangement of electrons and simplified drawing of nucleus and valence shell. B, excess electron produced by arsenic atom in germanium crystal lattice.

ber of valence electrons to link with germanium atoms in exactly the same manner that a germanium atom can. The effect upon conductivity depends upon whether there are more or less electrons in the outer shell of the impurity, than there are in a germanium atom.

We will take up first the type of impurity which contains five electrons in the outer ring. Fig. 4 shows the effect on the crystal structure of adding small amounts of arsenic. As you can see, four of the five electrons in the outer ring form mutual bonds with each of four different germanium atoms. This sharing of electrons completes the covalent bonds of the germanium atoms, and adds four electrons to the valence shell of the arsenic. The extra electron which is not part of a covalent bond would be the ninth electron in this shell.

Now, we have already said that the fourth shell can have as many as 32 electrons. However, it may hold 32 electrons only under certain conditions. There can be nine electrons in the fourth shell only if the fifth shell has two. So, with eight electrons bound in the fourth shell, the ninth acts as if it were the first electron in the fifth shell. As such it is free to move about readily within the crystal in exactly the same manner as the single valence electron of a good metal conductor. The addition of these free electrons greatly reduces the resistivity of the material. When a semiconductor has been doped in this fashion it is called N-type. The "N" refers to *negative* carriers. The impurity atom is called a *donor,* since it donates an easily freed electron. In the example, arsenic was used as the impurity; however, both phosphorus with a total of 15 electrons, and antimony with 51 electrons have been used as donors.

If the impurity which is added to the germanium is one that has only three electrons in its outer ring, such as the element indium, it does not provide sufficient electrons to fill the outer shells of each of the four germanium atoms lying closest to it. For each atom of indium added there is one electron missing from some covalent bond in the lattice structure. The effect on the lattice structure of replacing a germanium atom with an atom of indium is shown in Fig. 5B. Fig. 5A shows the arrangement of the

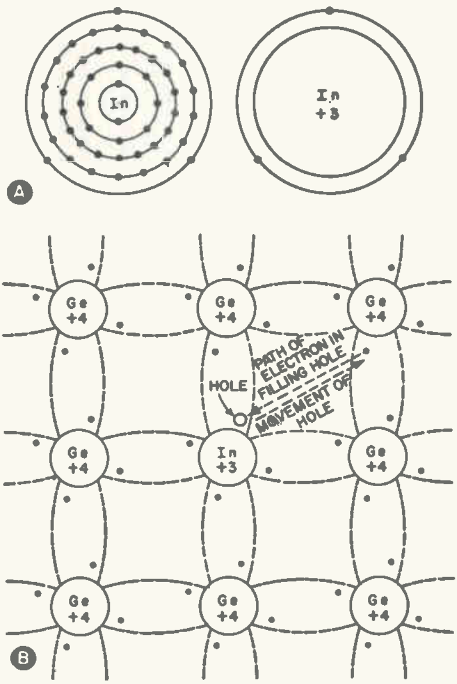


FIG. 5. A, arrangement of electrons around indium nucleus and simplified form showing valence electrons only. B, hole produced by indium atom in germanium crystal lattice.

electrons in their shells around the indium nucleus.

Since there is always some heat energy within the crystal there are always a few electrons moving about within it. These free electrons are strongly attracted to the vacancy in the covalent bond left when the indium atom replaced the germanium atom leaving an incomplete covalent bond at that point in the lattice structure.

Adding a three valence-electron material produces P-type semiconductor. "P" for positive, since holes act as positive carriers. This type of impurity is called an acceptor because its atoms leave holes in the crystal lattice that accept free electrons. Boron, aluminum and gallium each with three electrons in the outer ring are also used as acceptor impurities.

The hole in the covalent bond of the indium atom need not be filled by a free electron. This hole may capture an electron from one of the covalent bonds of a nearby germanium atom. When this happens, the hole appears to have moved to the germanium atom. An example of this type of hole movement is shown by the arrows in Fig. 5B. The original indium atom was electrically neutral; that is, there were just enough electrons in its outer shells to balance the positive nucleus charge. When the hole at the indium atom catches an electron, there is one more electron around the atom than there are positive charges in the nucleus. This gives rise to a small region within the crystal which has a negative charge of —1. At the same time, the germanium atom which gave up the electron has a positive charge of +1. The original germanium atom was also electrically neutral and after losing an electron has one unit of positive charge in the nucleus that is not balanced by the negative charges of the electrons surrounding the nucleus.

Even though the giving up of an electron by a donor atom or the acceptance of a free electron by an acceptor atom ionizes the atom involved, the net charge on the crystal is still zero. The crystal itself does not take on any charge. Each atom in a crystal lattice was originally neutral. It has just enough electrons surrounding the nucleus to neutralize the positive charge on the nucleus. Even though individual atoms may give up or take on electrons, the total number of positive and negative charges within the crystal remains the same. Furthermore, the ionized atoms will be scattered uniformly throughout the crystal. If any region within the crystal were to have a very large number of positively ionized atoms, these charged atoms would attract free electrons which would fill the holes and neutralize all or part of the ions. In the same way if a large number of atoms within a small region of the crystal were to have excess electrons, these electrons would repel each other and leave the region, thus neutralizing the charge.

Nothing we have said about holes and electrons in semiconductors limits electrical conduction to only one type of carrier. In fact, we have definitely stated that "N-type" means more electrons than holes, and "P-type" means more holes than electrons. It is then apparent that both positive and negative carriers are involved in conduction at all times. The carrier which is present in greatest quantity is called the majority carrier; the other is called the minority carrier. Keep this fact in mind—both types of carriers are present in all semiconductor materials. A material is N-type, P-type or intrinsic according to which type of carrier is found in the greatest number.

This is a good place to sum up our knowledge of semiconductor materials. First; we know that a pure semiconductor crystal protected from outside energy is an insulator. Second; a semiconductor at room temperature conducts by means of hole-electron pairs. There are both positive and negative carriers of electricity in semiconductor material. Third; it is possible to increase the number of carriers in the crystal by doping it with very small amounts of either three valence electron materials called acceptors, or five valence electron materials called donors. Fourth; A semiconductor is termed P-type when there is an excess of holes; N-type semiconductor results from an excess of electrons. When there are the same number of holes as there are electrons, the material is called intrinsic. Fifth; When an electron is freed, or a hole captures an electron, the atoms involved become ionized. Sixth; A semiconductor crystal has no net charge and all charges within it are evenly distributed.

Before you go any further in this book, take time out for a self-examination. That last paragraph contains the knowledge of semiconductors you should have at this point. Go back over that paragraph point by point. As you take up each point, explain or account for it in your own words. If you cannot explain to yourself why each of these points is true, reread the text. Make sure that you understand. From here on, everything in this text will be based on those six statements.

Semiconductor Diodes and Transistors

Transistor action does not take place within the body of the semiconductor material, but at a point of contact between two different types of material. Most transistors in use today are made up of three sections in sandwich form. The two outer sections have the same type of majority carrier. That is, they are both either P-type or N-type. The center section is also doped, but has the opposite polarity carrier. The action which gives rectification, amplification, or switching, takes place at the junction between these sections.

The first diode and the first transistors used just a single piece of semiconductor, usually N-type. In the diode, a single cat whisker contact was used as the second electrode. When a voltage was applied across the crystal, a small P-type region was formed at the contact wire.

The first transistors also used wire electrodes. In this case, two contact points were used and a small region of P-type crystal was formed at each contact. This type of transistor is called a point-contact type.

The next step in transistor development was to dope adjoining sections of crystals with opposite type impurities. In this way, a small N-type section of a crystal could be sandwiched between two P-type sections. Rectifier action takes place where the two types of material come in contact. This type of transistor is called a junction transistor. The region of contact is called the junction.

The action of the carriers at a junction is the same whether or not there is another junction nearby. In other words, the current flow through a junction and the voltage across a junction is the same whether the junction is in a diode rectifier or a triode transistor.

The second stage in understanding transistor operation is to learn what happens to the carriers at a junction. To show this action, we will first study the carrier movement in a plain bar of doped semiconductor. This plain bar will have only one type of impurity atom. Next we will see what happens when two unlike types of semiconductor are brought together to form a junction. This is the diode rectifier. Then finally, we will see how current flow through one junction of a triode transistor can control the current flow through the other junction. This is the transistor action in which we are interested.

Diode rectifiers and transistors of the junction type will be described first. While junction transistors were developed after point-contact transistors, the operation of junction units is more basic and more easily understood. The manner in which point-contact transistor action is obtained is not yet fully understood, but all present theories are based on the formation of junctions near the contacts when a current flows between the contact and the crystal.

CURRENT FLOW IN SEMICONDUCTORS

When no voltage is applied across a crystal, the motion of the holes and electrons is completely at random in the sense that there is no net movement in any one direction. Their movement may be in any direction but never in long straight lines. Holes move one atom at a time, and any hole may move from its starting location to any of the surrounding atoms. A free electron in motion is forced to change direction by collisions with an atomic nucleus. When a large number of electrons or holes are in motion, different carriers are moving in different directions. The effective current flow of any one carrier is cancelled by the movement of another carrier, and the resultant current flow in any direction is zero. This random motion of carriers is called diffusion.

When a voltage is applied across a crystal, an electron can still be made to change direction by collision with a nucleus, and holes still move atom by atom. The voltage difference provides a steady force which makes movement in one direction easier than in any other direction. Therefore, more electrons are moving toward the positive pole than in any other direction, and the holes move most easily in the opposite direction. The result of this type of movement is a net current flow through the material. Movement of carriers in response to a voltage difference is called drift. When a voltage is applied across the crystal, drift and diffusion occur together. This is important; even with voltage applied there is still diffusion.

In N-type semiconductors, the electrons greatly outnumber the holes and will carry nearly all of the current. An external voltage attracts them to the positive terminal, leaving behind immovable positive ions. When electrons concentrate at one end of the crystal, that region has a local negative charge. This local negative charge sets up a potential difference between that portion of the crystal and the positive terminal. Electrons are drawn from the crystal into the wire by this potential difference. At the same time, there are more positive ions around the negative terminal than there are electrons. This sets up a potential difference which causes electrons to flow from the terminal into the crystal. These electrons replace the free electrons which left through the positive terminal. The number of electrons that leaves the crystal equals the number of electrons arriving. Since the crystal was electrically neutral, and the number of electrons in it remains constant, the crystal remains electrically neutral.

In P-type semiconductors, nearly all of the current is carried by holes. The external voltage causes a drift of holes toward the negative terminal. Holes reaching this terminal attract free electrons from the external circuit. As these holes are filled with electrons, they disappear. An acceptor atom which has its hole filled is a negative ion.

At the positive terminal electrons are drawn from the ionized acceptor atoms. This results in the formation of new holes at this terminal. Remember these ionizing electrons are only loosely bound to the atomic nucleus. As these electrons are drawn off, new holes appear. These holes drift toward the negative terminal where they are recombined with electrons from the external circuit. The number of holes formed at the positive terminal is always just equal to the number of holes filled at the negative terminal, and the crystal remains electrically neutral.

It is important to notice that even though conduction in P-type semiconductor materials is by means of holes, current flow in the external circuit is, as always in metals, by means of electrons.

It might appear that there was no real difference in conduction between P-type and N-type semiconductors. Electrons flow from the external circuit into the crystal and then out of the crystal into the external circuit in both cases. There are however, two differences between these two cases. It is these differences that necessitate the idea of a hole as a carrier.

The first and most basic difference is that in N-type crystals, the free electrons are really free. They can move to any point in the crystal. In the P-type, electrons are not free to move to any point in the crystal. They can move only to holes. Since a hole can capture an electron from any of its surrounding atoms, it is the hole that is free to move in any direction.

The second difference is the speed of movement. A free electron moves approximately twice as fast as a hole.

The difference in speed of electrons and holes, affects the conductivity of the two types of semiconductor material. Thus, when the number of impurity atoms is the same, the P-type crystal will have the larger resistance. The current through the N-type will be greater than that through the P-type.

Later on we will find that the speed of travel, or drift time, of carriers has a definite effect on the operation of transistors at high frequencies. In this sense it can be compared with transit-time of electrons in a vacuum tube.

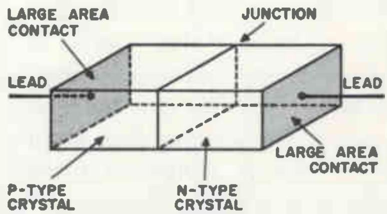


FIG. 6. Simple P-N junction.

JUNCTION DIODE

The physical arrangement of a simple P-N junction is shown in Fig. 6. In the construction of this junction, two important points must be kept in mind. First, the end contacts must not have rectifying properties. They must pass current equally well in both directions. Second, the crystal lattice must be continuous through the junction. The junction cannot be made by clamping a piece of P-type material to a piece of N-type. The junction is the boundary between two regions of the same crystal; one region containing donor and the other acceptor impurities.

When a junction is formed, free electrons in the N-type material diffuse across the junction into the P-type region. Holes diffuse across the junction in the opposite direction, from P-type to N-type.

When an electron leaves a donor atom, the atom becomes ionized; it has an excess positive charge equal to the negative charge of the electron which is lost. In the same way, when a hole "leaves" an acceptor atom (i.e. is filled by an electron), that atom takes on the negative charge of the electron and thus becomes a negative ion. These ions, being atoms, are fixed in place in the lattice structure and cannot move, so they make up a layer of fixed charges on either side of the junction. Since no potential difference exists across the junction, there will be no further diffusion and the layers remain in this position—a negative layer on the P side, and a positive layer on the N side. The ionization of these atoms results in a shortage or "depletion" of negative carriers on the N side, and of positive carriers on the P side. This is shown in Fig. 7A.

These layers form a barrier to any further drift or flow, which is known as the "depletion layer," "barrier layer" or "potential barrier." Remember all three terms, although "depletion layer" is preferred because it more aptly describes the actual conditions.

Figures 7B and 7C show the amount and polarity of charge on each side of the junction due to fixed ions and mobile carriers respectively. Fig. 7D shows the net charge, due to all charged particles, on both sides of the barrier. These unneutralized charges cause a voltage difference to exist across the junction.

Current Flow Through Unbiased Junction. Up to this point we have not considered what happens to the intrinsic hole-electron pairs that form within the depletion layer. Outside of the depletion layer, the intrinsic carrier pairs will recombine without materially affecting the carrier concentration in the crystal. Holes produced in the N region very near the junction will be attracted by the negative ions on the P side of the barrier and pass through the junction. These holes tend to neutralize the negative ions on the P-side. Similarly free electrons produced on the P-side pass through the junction and neutralize positive ions on the N-side. Note that holes on the N-side and electrons on the P-side are minority carriers. No external connection with the crystal is necessary for this movement of minority carriers.

This flow of intrinsic minority carriers weakens the charges in a

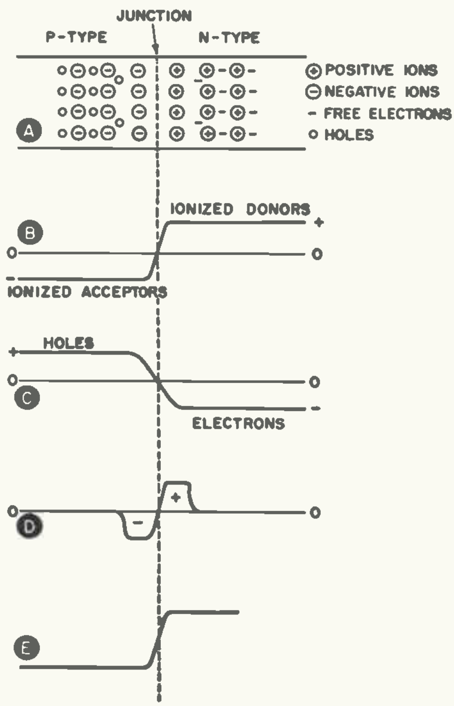


FIG. 7. A, locations of ions and carriers at a P-N junction. B, charges at junction due to ionized impurity atoms. C, carrier charges available to neutralize ions. D, resultant charges on opposite sides of junction. E, potential across junction.

small region around the neutralized ions. Majority carriers, that is holes from the P-side and electrons from the N-side, are able to cross the junction at the locations of these neutral atoms. The passage of these majority carriers offsets the reduction in charge density caused by the minority carriers. Thus we have holes passing through the junction in both directions, and electrons moving in both directions. These movements cancel and the charge densities remain constant. Equal current flow in both directions is the same as no current flow at all.

Current Flow Through Forward Biased Junction. If a battery is connected to the ends of a P-N junction with the positive terminal connected to the P-end and the negative terminal connected to the N-end, the distribution of charges at the depletion layer will be changed. The positive charge polarity at the P-end will drive holes away from it. This causes the holes to move toward the junction, neutralizing some of the charged ions. At the same time the electrons which give the ionic charge to the acceptor atoms are attracted toward the positive terminal. This reduces the negative charge on

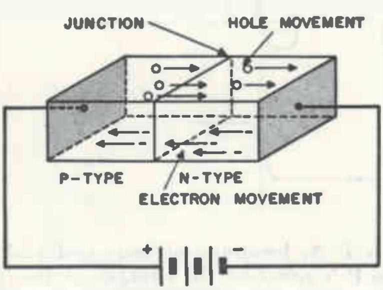


FIG. 8. Forward biased junction showing holes and electron movement on both sides of junction.

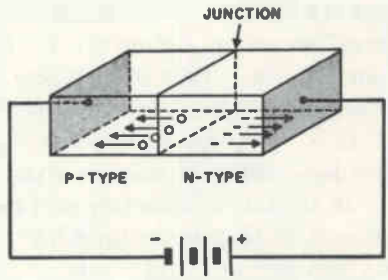


FIG. 9. Reverse biased junction showing how holes and electrons are drawn away from junction.

the P side of the junction. At the other end of the crystal, holes are drawn toward the negative terminal and electrons are forced toward the junction. Both of these carrier movements neutralize the charges on the N-side of the junction. This is shown in Fig. 8.

The effect of the battery then is to reduce the voltage difference across the junction. This allows more majority carriers, electrons from the N-side and holes from the P-side, to cross over. All the intrinsic minority carriers were already crossing over. Now the majority carriers outnumber them and a steady current flow from the negative terminal of the battery through the junction to the positive terminal exists. Biasing the junction in this direction drives majority carriers into the depletion layer and allows conduction through the junction. As the bias is raised more carriers arrive at the junction and the current flow is greater. If the bias is raised still more a point will be reached at which all charges at the junction are neutralized and current flow through the barrier is limited only by the resistivity of the material on both sides of it.

Current Flow Through a Reverse Bias Junction. Suppose we reverse the polarity of the battery, as shown in Fig. 9, so that the P-end of the crystal is negative and the N-end is positive. When this connection is used, holes are attracted away from the junction toward the negative terminal, and electrons are attracted toward the positive terminal. This movement of carriers adds to the potential difference across the junction and therefore helps in preventing current flow. The current through the barrier however is not zero as it is in the unbiased case. Minority carriers which are formed within the barrier layer still cross over the junction. Holes from the N-side will cross the junction but now they are attracted toward the negative terminal of the battery away from the junction. Electrons from the P-side are attracted to the positive terminal after passing through the junction. Since these minority carriers do not all remain near the junction to neutralize charged atoms, they no longer allow passage of majority carriers in the opposite direction. Therefore the flow of minority carriers is not fully offset by the flow of majority carriers and a small current flows in the direction indicated by the battery polarity. This current is very small and nearly constant at all normal operating voltages.

If the value of reversed bias is raised very high, the potential difference disrupts covalent bonds at the junction providing many more intrinsic carriers. When this happens the current rises very rapidly. The voltage at this point is called the breakdown voltage. After the breakdown point has been reached and the current rises, the voltage across the crystal begins to drop as the current goes up. This is exactly the opposite of what happens in a resistor. The condition of decreasing voltage drop with increasing current is called "negative resistance." This characteristic is made use of in some applications. Some diodes do not exhibit this characteristic but overheat and destroy themselves first. In any case, the negative

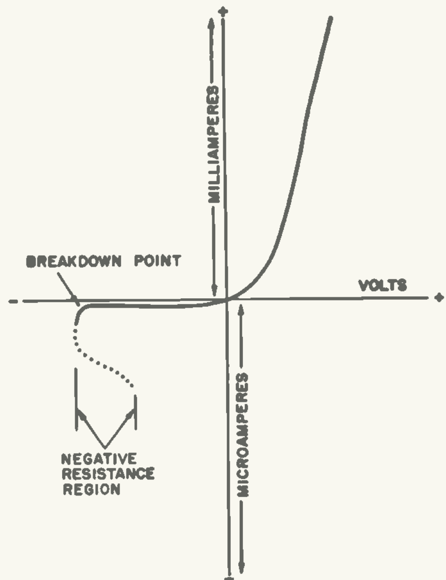
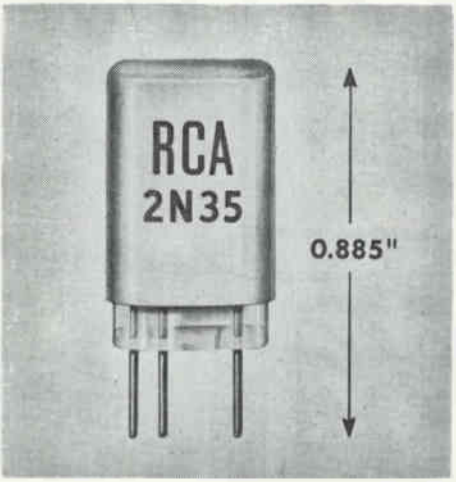


FIG. 10. Voltage-current characteristic of a junction diode.

resistance curve is found near the burn-out point of the crystal.

The change in current with changes in voltage are in a graphical form in Fig. 10. In using this graph, note the change in the scale on the current axis at the zero point. Positive currents are shown in milliamperes, and negative currents in microamperes.

If you compare this graph of Fig. 10 with the similar graph for a vacuum tube diode, you will find two important differences. First, the current is zero when the voltage is zero. There is no contact potential. Second, there is always a small reverse current flowing. Both of these facts have very definite effects in the circuits in which diodes are used. Both of these facts must be taken into consideration when deciding whether to use a semiconductor diode or a vacuum tube diode in a rectifier circuit.



Courtesy RCA

A junction transistor.

JUNCTION TRANSISTORS

A triode junction transistor is composed of a single semiconductor crystal. This crystal is divided into three regions by changes in type of impurity atom added to the three sections. The two end sections always have the same type of impurity and are separated by a very narrow band of the opposite type. The center section is called the base, and the end sections are the emitter and the collector.

A P-N junction is formed where the emitter and base regions meet, and another junction is formed between the collector and base. These junctions are called the emitter junction and the collector junction. The base region must be very thin to obtain proper operation of the transistor.

Triode transistors may be of two types: P-N-P or N-P-N. These letter groups indicate the type of impurity atom and majority carrier in each of the three regions. A different schematic symbol is used for each type. Fig. 11 shows the physical arrangement of the three regions in each of the two types. The schematic symbol for each type is also shown. You can see on the schematics that the difference between the symbols for the two

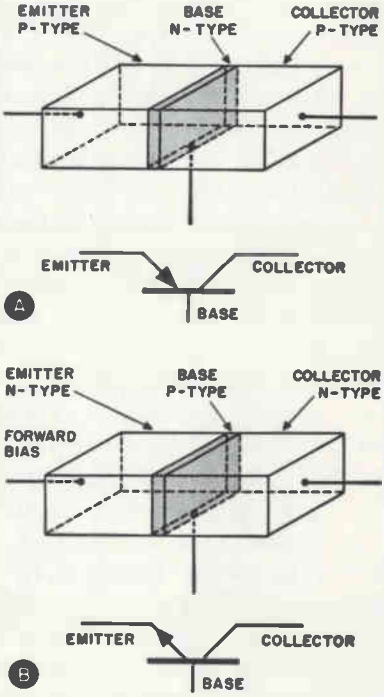


FIG. 11. A, junction P-N-P transistor and schematic symbol. B, junction N-P-N with schematic symbol.

types lies in the direction of the arrow on the emitter lead.

In addition to describing a junction transistor by the type of semiconductor used in each section, transistors are also described by the method of manufacture: grown junction, fused junction, rate-grown junction, alloy junction and the diffused junction. All these junctions operate on the same basic principles.

The names given these transistors in most cases show the methods which different companies developed to manufacture transistors in large quantities under careful control. In general, one type of manufacture cannot be said to result in a better transistor than any other, unless the methods used result in better control of the manufacturing process. However, at present, transistors made by one process are not always directly interchangeable with those made in a different way. There are differences in frequency limits, efficiency and power handling ability. As the different forming processes are perfected, it is to be expected that junction transistors made for the same use will be interchangeable, regardless of the manner in which they were made.

Regardless of the method used to form them, all junction transistors operate on the same principles. The depletion layers of junction transistors are formed in exactly the same way as the depletion layers of junction diodes. The understanding of junction transistors is based on an understanding of current flow through a junction diode. The only additional fact that we need, is to note the effect of two junctions close together in the same crystal. When one of these junctions is biased in the forward direction and the other in the reverse direction, the presence of one junction can affect the operation of the other.

Current Flow in N-P-N Transistors. In transistor operation the emitter-base junction is always biased in the forward direction and the collector-base junction is biased in the reverse direction. Each of the two junctions by itself, behaves just like the P-N junction that was described in the last section.

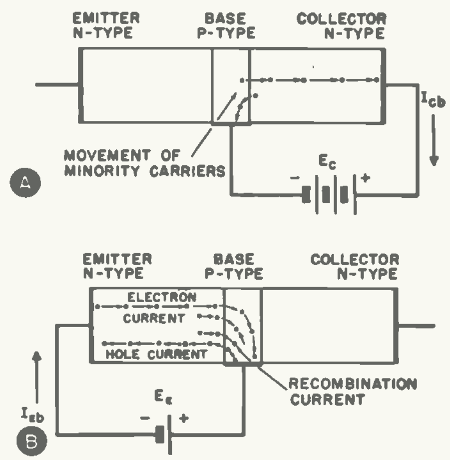


FIG. 12. A, carrier movement at reverse biased collector junction. B, carrier movement in forward biased emitter junction.

The movement of carriers in the collector-base circuit when the emitter circuit is open is shown in the diagram in Fig. 12A. The only current is the small reverse current due to minority carriers. The battery Ec sets the bias level high enough so that the reverse current is saturated, that is, it falls on the straight line portion in the lower left section of the curve in Fig. 10. We will call the current which flows as the result of this carrier movement Icb.

Fig. 12B shows the carrier movement through the emitter junction with the collector open circuited. We will call this current Ieb. The diagram shows that the current across the junction is in two parts, current flow through the complete circuit and recombination current flow. When electrons cross the junction from the N-side to the P-side they are in a region with many holes, therefore, some of the electrons will be captured by acceptor atoms. Fig. 12B does not show any minority carrier reverse current. This is because this current is so very

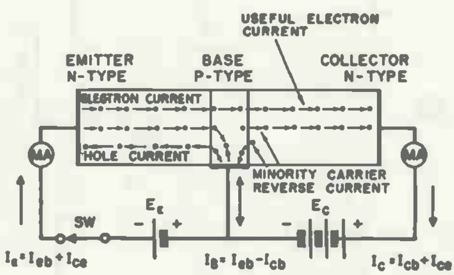


FIG. 13. Current flow and carrier movement through N-P-N junction transistor.

small compared with the forward majority carrier current.

If we put a meter in the collector circuit of a transistor and then connect the emitter bias battery, we find that the collector current becomes much greater than before the emitter was connected. It is apparent that passing a current through the emitter junction has affected the current flow in the collector circuit. What has happened is shown in Fig. 13. Part of the emitter current now flows through the base into the collector instead of back through the base connection to the battery. This current adds to the reverse current to make up the total current in the collector circuit. The flow of electrons from the emitter to the collector can be explained in the following manner.

Carrier movement is always in two parts, drift and diffusion. Electrons moving under the influence of an electric field tend to travel in straight lines unless they are deflected by an atomic nucleus. The base layer is very thin. Most electrons from the emitter region are moving fast enough when they enter the base to come within the range of the electric field at the collector junction. This field is of two parts, one part is positively charged atoms and the other part is due to the battery potential. Current flow through the collector due to the reverse bias is so small that most of the battery voltage appears across this junction. The electric field at the collector junction, therefore, is of the right polarity to attract electrons from the base. It might appear at first, though, that most of the electrons would be attracted by the positive battery terminal at the base. A very few are, but the width of the base between the two junctions is so much less than the distance from most of the emitter junction to the base terminal, that the electrons are more strongly attracted by the positive field at the collector side of the junction.

However not all of the electrons get across the base. Some recombine with holes in the P-type base. Part of the current in the emitter circuit is due to holes crossing the junction from the P-type base to the emitter. These holes and the recombination current, flow through the external base-emitter circuit.

The current that we are interested

in is the current in the collector circuit. The current in the base-emitter circuit is all loss. This current is kept as low as possible by making the junction unsymmetrical. By this we mean that the number of donor atoms on the emitter side of the junction is made several hundred times as great as the number of acceptor atoms on the base side. By doing this the number of holes crossing the junction is made much smaller than the number of electrons, and at the same time there are fewer acceptor atoms to capture electrons which cross over from the emitter side. In a good transistor 95% to 98% of the electrons which cross the emitter junction flow to the collector.

The current flow in the base, emitter, and collector circuits is shown by the arrows on the diagrams. The emitter current is made up of useful current from the emitter circuit to the collector, and hole flow from the base to the emitter plus the recombination current. The collector current is made up of the very small, and nearly constant, saturated reverse current, plus the emitter-collector current. Direction of current flow in these two circuits is always in the direction indicated by the arrows. Current flow in the base circuit may have either polarity. This current flow is also composed of two parts, the emitter-base current and the collector-base current. As you can see from the carrier movement at the base electrode on the diagram, these two currents flow in opposite directions. With low values of collector bias, the emitter-base current is the larger and the net current flow is from the base to the external circuit. This is the condition you will find in broadcast receiver circuits and all amplifiers.

When the collector bias is made very high, the collector-base current becomes the larger of the two. The higher voltage at the collector junction, causes more of the electrons from the emitter to flow into the collector and the recombination current is reduced. At these high values of collector bias, the current flow is from the external circuit to the base. When

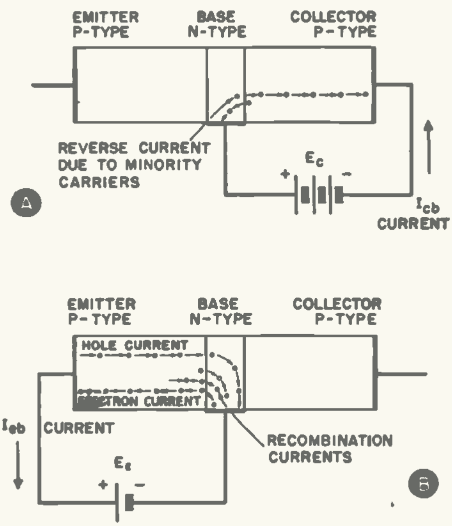


FIG. 14. Current through transistor junctions. A, reverse biased collector junction. B, forward bias emitter junction.

operated under these conditions, the transistor cannot be used as an amplifier, but makes a fine multivibrator oscillator, clipper, or switch such as might be used in the video section of a TV receiver.

Current Flow Through P-N-P Transistors. The movement of carriers through a P-N-P transistor is very similar to the current flow through an N-P-N transistor. Fig. 14 shows the carrier movement and current flow through each of the junctions, when the other is open circuited. If you compare these diagrams with those of Fig. 12, you will note three differences. First, the battery polarities have been reversed; second, the current arrows are in opposite directions; and third, the type of carriers moving into and out of the base region are changed. All three of these differences are to be expected from what you know of carrier movement through a P-N junction.

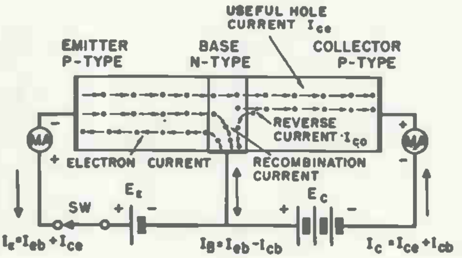


FIG. 15. Current flow and carrier movement in P-N-P junction transistor.

In Fig. 15 the current flow and carrier movement through a P-N-P junction transistor are shown. Again we have the same three reversals, battery polarity, current flow, and carrier type. The explanation of the operation of an N-P-N transistor applies equally well to the P-N-P type when the three reversals are kept in mind.

TRANSISTOR ACTION

We have shown that passing current through the emitter junction of a transistor increases the current in the collector circuit. The emitter current controls the collector current. From our knowledge of carrier movement through the transistor, we can make a good guess that a change in the value of the current in the emitter circuit will cause a change in the collector current in the same direction.

The next thing we need to know in order to use transistors in circuits, is how much the collector current changes for a known change in the emitter current. We will also need to know what effect changing the emitter-base voltage has on the collector current, and the effect on both the emitter and collector currents of changing the collector-base voltage. When we have determined these things we will be ready to use transistors in circuits.

We can best see what happens in a transistor circuit by means of a simple experiment. Fig. 16 shows the test setup we will use. A P-N-P transistor, a voltmeter, two milliammeters, two small batteries and the variable resistance are all we need. We will make a few preliminary measurements first, and then we will make the necessary measurements to construct a set of characteristic curves.

For the first test we adjust the resistor so that there is no voltage between the emitter and the base. With no voltage on the collector, we find no

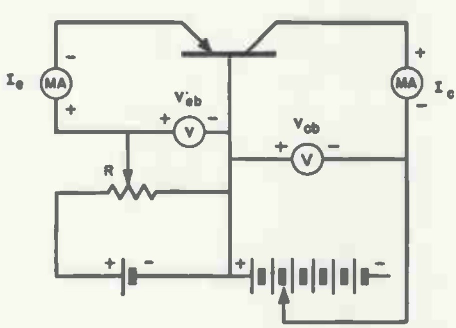


FIG. 16. Circuit for obtaining collector voltage-collector current curves for P-N-P junction transistor.

current indicated by either meter. There is nothing unusual in that, so let's see what happens if we increase the collector voltage. As soon as we put voltage on the collector, the meter in the collector lead indicates a very slight current. Next we will increase this voltage step by step and write down the voltage and current at each step. As we do this we note that the current increases very slowly. Finally at about —24 volts on the collector, the current has risen to around 15 microamperes, but the meter in the emitter circuit still reads zero.

Next we will drop the collector voltage down to —6 volts, and adjust the resistance for one milliampere through the emitter. When we do this we find that the collector current is just about 1 milliampere also. We mark down the readings of all four meters; we will need this data later. As we vary the collector voltage both above and below —6 volts, we find that the collector current increases about 20 microamperes at —24 volts on the collector and drops 20 microamperes at zero volts. During these readings we made any necessary readjustments of the resistor to keep the emitter current constant.

These two tests have demonstrated a very important point about transistor action. The collector-base voltage has very little effect on the collector current.

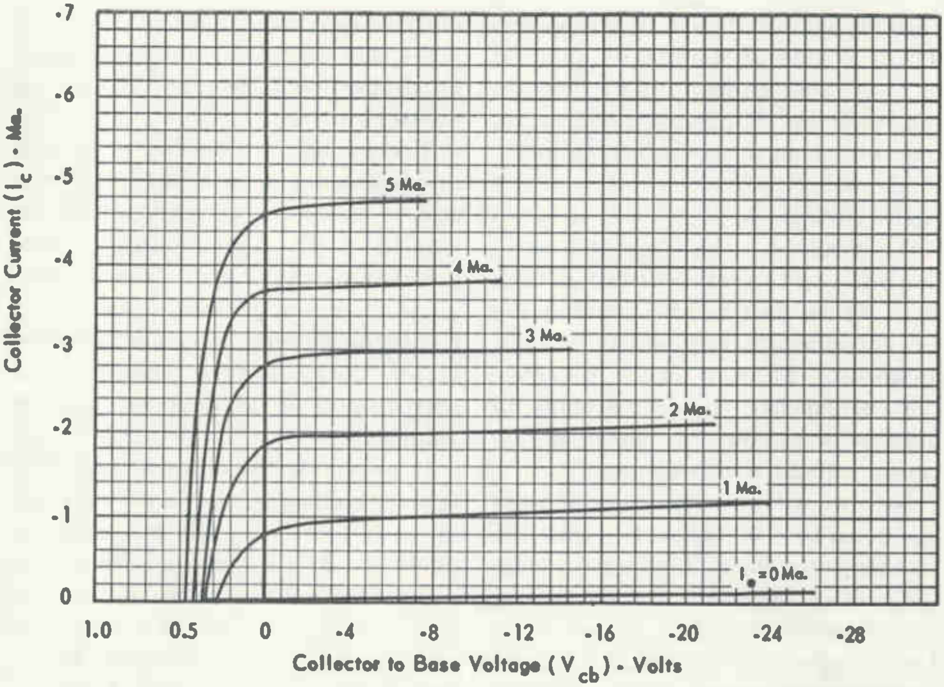
Now set the collector voltage back to —6 volts and increase the current through the emitter in 1 milliampere steps up to 5 milliamperes. Record the readings of all four meters for each step. These meter readings will show us that each time we raise the emitter current one milliampere, the collector current increases about .95 milliamperes. The change in collector current is proportional to the change in emitter current.

The change in the collector current divided by the change in emitter current is called the current-gain of the transistor. The manufacturers characteristics sheets show the current gain. It serves the same purpose in transistor circuits that amplification factor does in tube circuits. The current-gain is abbreviated a or α (alpha).

If we divide the different values of emitter voltage by the emitter current in each case, we will get different quotients. If the emitter circuit followed Ohm's Law, we would get the same answer each time. From this we can see that the emitter-base resistance changes with the applied voltage. The resistance is reduced as the voltage is increased. This effect is most noticeable at low voltage levels.

By combining these last two facts about transistor information, we come up with a guide in the use of transistors. The collector current is proportional to the emitter current; the emitter current is not proportional to the emitter voltage. Therefore, the collector current cannot be proportional to the emitter voltage. This is very important, since it tells us that the collector current reproduces the emitter current, and we must apply a signal current, not a signal voltage, for amplification.

For the last test we will start with the collector voltage at zero, and an emitter current of about 1 milliampere. Then without readjusting the resistance, increase the collector voltage in steps and note the change in



Courtesy Raytheon Mfg. Co.

FIG. 17. Grounded base typical collector characteristics.

emitter current. We find that the emitter current increases slightly as the collector to base voltage is increased. The change in emitter current is very small for small changes in collector voltage; however, the fact that it changes at all is extremely important.

This change in emitter current points up one of the big differences between tube and transistor operation. In a tube, changing the plate voltage does not affect the input signal or input impedance of the tube. Not so in transistors. Changing the collector voltage changes the emitter current, so there must be coupling between the input and output of the transistor.

With this experimental circuit, we will now obtain a set of characteristic curves. First we adjust the resistor for no emitter current and take readings of the collector current for different values of collector to base voltage. We vary this voltage from slightly positive to about —26 volts negative. Then the resistor is adjusted for 1 milliampere of emitter current and the collector voltage is again changed in steps but this time only to —24 volts. Additional sets of readings are taken at emitter currents of 2 milliamperes, 3 milliamperes, 4 milliamperes and 5 milliamperes. The maximum voltages used on the collector for these steps are respectively —20 volts, —14 volts, —10 volts, and —7 volts. The collector voltage range over which readings are taken is reduced as the current goes up, so that the collector dissipation rating will not be exceeded. Readjustment of the emitter circuit resistance should be made, when necessary, so that the emitter current is constant for each set of readings.

Plotting these readings on graph paper will give curves like those in Fig. 17. These curves are called "collector characteristics in grounded base connection," and are for a type CK722 transistor.

Resistive Coupling Through a Transistor. Two more simple tests will point out a great difference between transistors and tubes; differences which have a great effect on the operation of transistors in circuits. The circuit of Fig. 18, measures the voltage across an open collector-base circuit. With this circuit we find that changes in the current through the emitter cause changes in the voltage across the collector circuit. The presence of the voltage across the collector and base shows that there is a resistive connection between the emitter and collector. If the emitter is used as the input and the collector as output, this means that part of the input signal will feed through from input to output. In most cases, this feed-through signal is so small compared to the amplified signal that it can be ignored.

The second test circuit, Fig. 19, shows that current through the collector circuit causes a voltage to appear

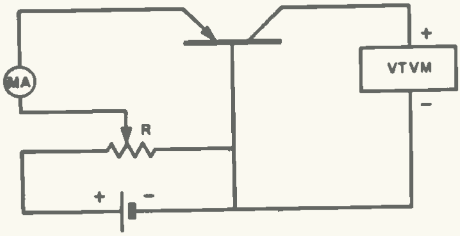


FIG. 18. Circuit to show feed-through takes place in a junction transistor.

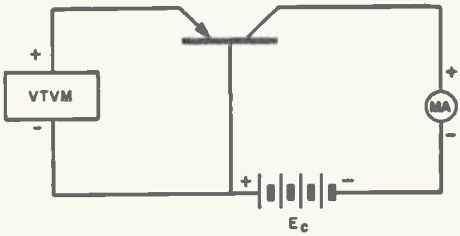


FIG. 19. Circuit to show that resistive feedback from output to input takes place in a junction transistor.

between the emitter and base. This voltage shows that there is a resistive feedback connection from the output to the input within the transistor. This feedback signal must be considered in most cases when designing circuits. Because of this resistive connection, the input is not isolated from the output and a signal can flow both ways through a transistor.

There is nothing really amazing about the presence of either the feed-through or feedback resistances. After all, the transistor is composed of one solid piece of resistive material. You must, however, whenever you work with transistors, keep in mind the fact that these resistances exist. Most of your work will be with vacuum tubes in which there is no direct connection between input and output. A vacuum tube is a unilateral device, that is, signals can only pass through it in one direction (and then only when all voltages are applied). The transistor is bilateral (signals can pass through it in both directions) even with no voltage on the output circuit.

Summary of Transistor Action. This is a good place to list the things which we have learned about the operation of junction diodes and junction transistors. This list will bring together the points which we must keep in mind when using these semiconductor devices. Go over this list just as you did the summary on semiconductor materials. Use the list to check yourself.

The points to keep in mind concerning diodes are: (1) Rectification takes place only at junctions. (2) When a battery is connected across a P-N junction with the positive terminal connected to the P-side, current flows easily through the junction. This is forward bias. (3) When a battery is connected across the junction with the positive terminal connected to the N-side, the diode is reverse biased. (4) A small current always flows through a reverse bias junction. (5) No current flows through an unbiased junction.

There are six points to keep in mind when working with transistor circuits. These are as follows: (1) The emitter of a transistor is always forward biased, and the collector is reverse biased. (2) The collector voltage has very little effect on the collector current. (3) The emitter resistance changes as the voltage changes. (4) The collector current reproduces changes in the emitter current, but not changes in the emitter voltage. (5) There is a resistive connection between the emitter and the collector. (6) Signals can pass through a transistor in both directions.

POINT-CONTACT DIODES AND TRANSISTORS

Most of the diodes which you will encounter in your service work will be of the point-contact type. The transistors on the other hand will nearly all be of the junction type.

Even though point-contact transistors and diodes were made and used before the junction types, their operation is not as well understood. Scientists agreed only on the fact that P-N junctions are formed in the base material near the cat whisker contacts. The explanations which will be given in this lesson are those which account for most of the experimental evidence.

Point-Contact Diodes. The point-contact diode, or crystal rectifier, is made up of a small semiconductor block and a pointed wire contact. The semiconductor crystal may be either P-type or N-type, but the N-type is the more common. This construction

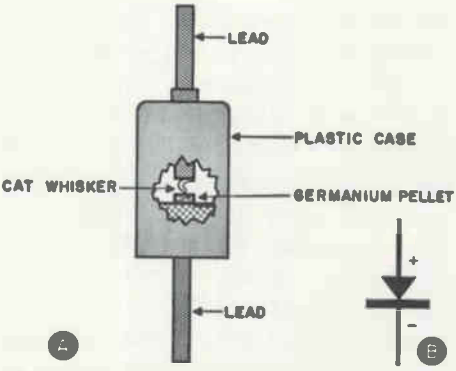


FIG. 20. A, cut-away view of crystal rectifier. B, schematic symbol for crystal diode.

is shown in Fig. 20 along with the schematic symbol for a diode made with N-type germanium.

After the diode is assembled a pulse of current is passed through it. This is called "forming" and without that forming, the diode is not as good a rectifier. It is believed that this current pulse causes a small P-type region to be formed at the point where the cat whisker touches the base. This small P region, and the P-N junction around it are shown in the diagram of Fig. 21.

The conduction curve of a point-contact diode is shown in Fig. 22. This curve differs from that of the junction diode in both forward and reversed bias regions. The more gradual slope of the curve in the forward bias region shows that the resistance is greater in this direction than for a junction diode. In the reverse bias region, the current increases more rapidly than for a junction diode, which indicates that the current is not independent of the voltage. The point contact diode does, however, have a lower capacity between the P and N regions, and for this reason it is more efficient when used at the higher frequencies.

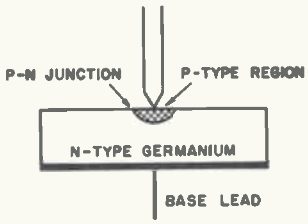


FIG. 21. Formation of a P-N junction in a point-contact diode.

Point-Contact Transistors. Point-contact transistors are made by using two cat whiskers spaced about two-thousandths of an inch apart on the surface of a small germanium slab. The construction of a typical transistor of this type is shown in Fig. 23. Like the point-contact rectifier, the transistor must be formed by passing a current through the electrodes. The point-contact transistor acts as if a small P-region were formed directly under each cat whisker point. Therefore, a point-contact transistor may be thought of as a special type of P-N-P transistor.

As in junction transistors, point-contact units are forward biased at the emitter and reverse biased, on the collector. The characteristics of the emitter and collector P-N junctions will be similar to the forward and reverse biased portions of the point-contact diode curve shown in Fig. 22.

The emitter-base resistance of a point-contact is six to ten times greater than in a typical junction transistor. The collector-base resistance is many times less than in the junction unit. The internal resistance of the base is only about one-quarter as large as the base resistance of a junction transistor.

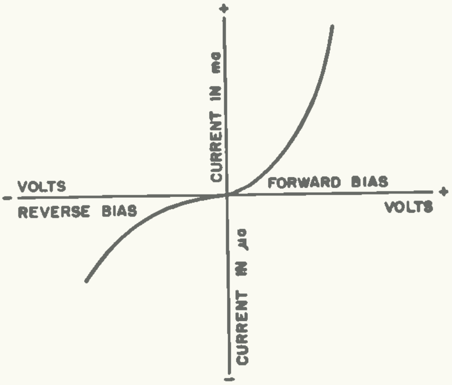


FIG. 22. Conduction curve of a typical point-contact rectifier.

There is one great difference between point-contact and junction transistors that limits the usefulness of the point-contact as an amplifier but at the same time greatly increases its value as an oscillator. To demonstrate this difference, we will hook up our point-contact transistor according to the diagram in Fig. 24. This is the same test circuit that was used for junction transistors in Fig. 16. With zero emitter current, we read the collector current. Then we increase the emitter current in steps and record the meter readings at each step. When we compare the readings, we find that the increase in collector current between steps was greater than the increase in the emitter current, and that the collector current at each step is greater than the emitter current.

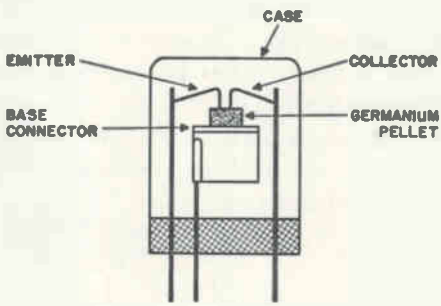


FIG. 23. Construction of a point-contact transistor.

The current-gain of a point-contact transistor is greater than one. At first this may seem to be an advantage, but actually it limits the use of this type of transistor. You recall that one of the tests we described on the junction transistor was to measure the voltage appearing across an open emitter circuit when a current passed through the collector junction. This test showed that feedback exists from the collector to the emitter. The phase of this feedback is such that it adds to the emitter bias, making the transistor regenerative. This regeneration is controlled by keeping the internal resistance of the base low, and holding the impedance from base to battery or ground as low as possible.

The positive feedback through a point-contact transistor makes some amplifier circuits unstable. Even when the amplifier is stable for low-level signals or sine waves, there is a danger that a large pulse from either noise or some switching operation will cause the amplifier to go into regeneration. Unless the circuit is properly designed, this regeneration continues to build up and both the emitter and collector current increase until the transistor destroys itself. A later lesson will show how this feedback can be used to make very simple oscillator circuits.

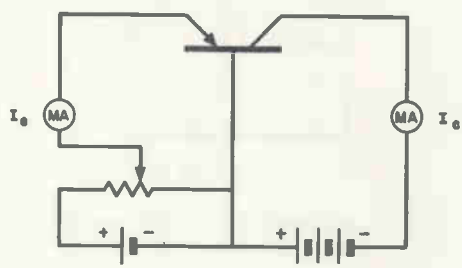


FIG. 24. Test circuit for point-contact transistor.

Since point-contact transistors are seldom used in present day receivers, we will not go into a detailed discussion of them. For the remainder of this lesson we will describe junction transistor circuits and make only occasional reference to point-contact transistors in similar circuits.

Basic Transistor Circuits

So far, we have demonstrated transistor action by varying the bias voltages and noting the effects. We have shown that changes in the emitter current are reproduced in the collector circuit. We have not added ac signals to the bias voltages nor attempted to use transistors in circuits.

In this section, we will study the use of transistors as signal amplifiers. We will learn the basic circuits that are used. Some of these circuits will give us voltage gain, some power gain, and some current gain. Some circuits have high input impedances and some low. Some circuits will result in high output impedances but one has a very low output impedance.

We will take the basic circuits one at a time. Then at the end of the section, we will summarize our results, so that the different circuits can be more easily compared.

GROUNDED-BASE CIRCUITS

In the preceding section of this lesson we obtained the static characteristics of a transistor. Now we will use this same transistor in the circuit of Fig. 25 in order to show how voltage and power gain can be obtained in a transistor amplifier. In this circuit, the generator is a low level audio generator, resistor Rg is the internal resistance of this generator, RL is the load resistor for the transistor. The bias battery E_E sets the forward bias on the emitter circuit to the straight line portion of the forward bias conductance curve. The current arrows for i_e and i_c follow the accepted practice of showing the current flow as always from emitter or collector into the base. This will be considered positive current flow.

On the positive half-cycle of the audio signal, the signal voltage will add to the bias and the emitter current will increase. In our earlier tests, we found that collector current increase is about 95% of the emitter current increase.

The input vacuum tube voltmeter reads the signal voltage from the emitter to the base. This voltage is

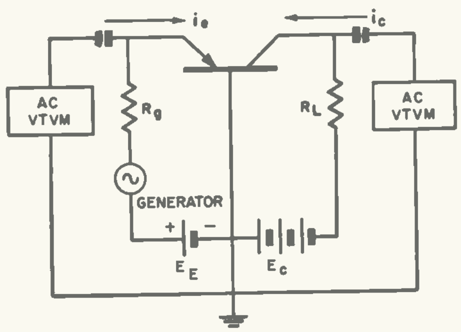


FIG. 25. Test circuit to show voltage and power gain through transistor in grounded-base connection.

equal to i_e x Rg. The output vacuum tube voltmeter reads signal voltage from collector to base. This voltage is equal to i_c x RL. However, i_c is equal to $.95i_e$, so that output voltage will be equal to $.95i_e$ x RL. Notice that as the input signal current and voltage are increased, the collector signal current and voltage also increase. In other words, the output signal is in phase with the input signal.

We showed by our earlier tests, that the emitter-base resistance or input impedance in this case is low, and the collector-base resistance, or output impedance, is high. In order to match the input and output impedances of the transistor, Rg should be low and RL very large. The values which we obtain for the input and output voltages in the last paragraph show us that if Rg is equal to RL, the output voltage will be 95% of the input voltage. Since RL must be much greater than Rg, the output voltage will be much greater than the input voltage. In fact, it will be equal to alpha times RL divided by Rg.

Since current flows in the input circuit, power will be consumed. The power consumed in the input is equal to the input signal current times the signal voltage. The output power is equal to the signal current through RL times the output voltage. We know that the input and output currents are nearly equal and the output voltage is much greater than the input voltage. It is, therefore, apparent that the output power is greater than the input power.

This test has shown us that while the current gain is less than 1 in this circuit, the voltage and power gains are both much greater than 1. This circuit arrangement, in which the input is connected between the emitter and base, and the output is taken across the collector and base, is called a common-base or grounded-base circuit. This circuit is only one of three arrangements that can be used in a transistor amplifier.

Before we take up the other two circuits, it might be well to mention the use of point-contact transistors in this circuit. With point-contact transistors, the current gain, voltage gain and power gain in this circuit are all greater than 1. This is the circuit arrangement most used for point-contact amplifiers. It provides the greatest gain and is the most stable.

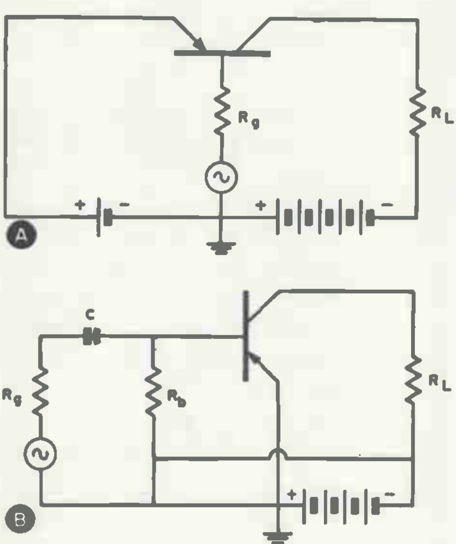
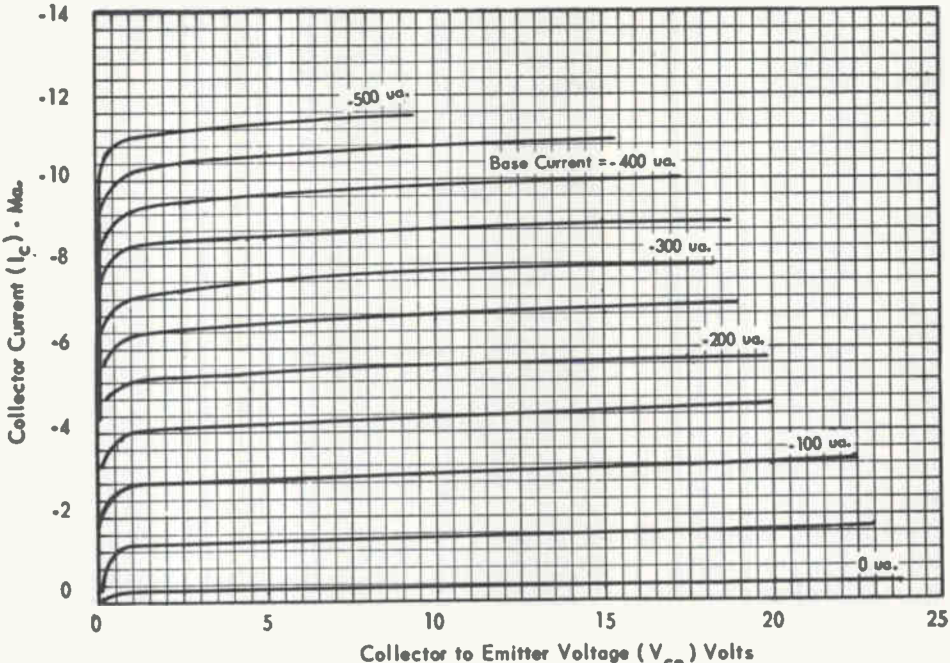


FIG. 26. A, basic common-emitter circuit. B, common-emitter circuit rearranged for one-battery operation.

GROUNDED-EMITTER CIRCUITS

In the common-emitter circuit, the input signal is applied to the base-emitter circuit and the output is taken off across the collector-emitter circuit. This circuit is shown in Fig. 26A. The circuit can be rearranged as shown in Fig. 26B so that only one battery need be used to provide both the forward and reverse bias. This is the way you will usually see the circuit diagram drawn.

In Fig. 26B, Rb is much larger than the input resistance of the transistor. Therefore, it does not shunt the signal. The capacitor prevents the generator from shunting the base bias to ground. The collector current is much smaller



Courtesy Raytheon Mfg. Co.

FIG. 27. Grounded emitter typical collector characteristics.

than the base current, so the voltage drops across Rb and RL are different. The large drop across Rb makes the base only slightly negative with respect to the emitter. The small drop across RL makes the collector much more negative than the base.

When the circuit of Fig. 26B is used, the characteristic curves which we obtained for the grounded-base circuit (Fig. 17) are not of much value. A different set of curves obtained by varying the collector-emitter voltage and the base current are used. The curves of Fig. 27 show the results. These curves are also for CK722, P-N-P junction transistors.

These curves show us that very small increases in base current result in much larger increases in collector current. Note for instance, that with 10 volts between emitter and collector, increasing the base current from 150 to 200 microamperes increases the collector current from 4.4 to 5.6 milliamperes. This is an increase of 50 microamperes in input current and results in an increase of 1200 microamperes in the output current. This is a current gain of 24. The base-collector current gain in a grounded-emitter circuit is called β (beta).

Note that the distance between constant base-current lines is greater at larger values of voltage. Also this distance is smaller for higher values of base current. This tells us that the current gain is not constant, but changes as the operating conditions change. It also tells us that when the input signal causes very large changes in base current, the output signal will be considerably distorted.

Now consider what happens when a signal voltage from the generator is applied across the base-emitter circuit.

On positive half-cycles, the signal voltage opposes the bias voltage making the base less negative with respect to the emitter. This reduces the current through the emitter junction, which in turn reduces the collector current. Reducing the collector current reduces the voltage drop across R_L, which is our output voltage. On negative half-cycles the input signal voltage adds to the emitter junction bias and the current through both the emitter and collector junctions increases. The increased current through R_L gives an increase voltage drop. The input and output signal voltages in an amplifier using a transistor in a grounded-emitter connection are out of phase. However, the input and output currents are in phase.

R_L is again much larger than Rg, so we have voltage and power gain as in the grounded-base circuit. However, since we also have current gain, the voltage and power gains are even greater than for the grounded-base circuit.

Because this circuit has higher gains as well as permitting the use of a single battery, it is the preferred circuit for junction transistor amplifiers. The point-contact transistor does not perform satisfactorily in this circuit. Its output resistance is negative and the circuit is very unstable.

Most manufacturers' data sheets on transistors do not give values for both alpha and beta. This is really unnecessary since it is possible to obtain one from the other. The formulas for calculating alpha when beta is known and vice versa are shown below:

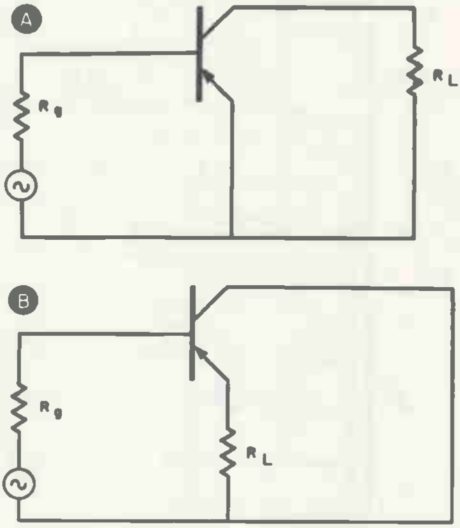


FIG. 28. A, simplified common-emitter circuit. B, simplified common-collector circuit.

$$\beta = \frac{\alpha}{1-\alpha}$$

$$\alpha = \frac{\beta}{1+\beta}$$

GROUNDED-COLLECTOR CIRCUITS

The third basic circuit is rarely encountered in receivers. The characteristics of this amplifier can best be understood by comparison with a grounded-emitter amplifier.

Fig. 28A shows a basic common-emitter circuit without bias sources. In Fig. 28B the basic common-collector circuit is shown. You can see from these two circuits that the grounded-collector amplifier may be thought of as a common-emitter amplifier with the output load in the emitter circuit. This results in a common-emitter amplifier with 100% voltage feedback. Fig. 29 shows the common-collector circuit as it will appear in most schematic diagrams.

This circuit has a high input impedance and a low output impedance. However, because of the resistance connection between input and output circuits, the input and output impedances depend on the load and source resistances respectively. The input resistance may be large when RL is large, and the output resistance may be small when Rg is small.

The input and output voltage of the grounded-collector amplifier are in phase. The input and output currents are out of phase. The current gain is nearly the same as in a common-emitter circuit, but the voltage gain is always less than 1. The power gain, because of the low value of RL usually used, is much smaller than with either of the other circuits.

This circuit is used principally to couple a high impedance source to a low impedance load. Because of negative feedback this amplifier has little distortion. This circuit can be used only with junction transistors, since point-contact transistors are unstable in this circuit arrangement.

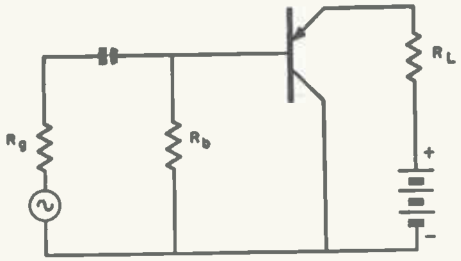


FIG. 29. Common-collector circuit as usually drawn in schematic diagrams.

SUMMARY OF BASIC TRANSISTOR AMPLIFIERS

1. Grounded-emitter circuit. Input and output voltages are out of phase; input and output currents are in phase. High output resistance; low input resistance. Current gain greater than 1; highest voltage and power gains. Single battery supply.

2. Grounded-base circuit. No phase reversal of either voltage or current. Low input, high output impedance. Current gain less than 1, but voltage and power gain greater than 1. Needs two battery supplies. Only circuit in which point-contact transistor can be used as an amplifier.

3. Grounded-collector circuit. No voltage phase reversal. Input and output currents out of phase. High input, low output impedances. High current gain, slight power gain, voltage gain less than 1. Single battery supply.

HIGH FREQUENCY EFFECTS

Transistor amplifiers are all characterized by a loss in current gain as the frequency increases. The operating conditions given in the discussions above hold good only for audio and the lower rf frequencies. At these frequencies the input and output impedances are almost pure resistance. As the frequency increases, the junction shows reactive effects and phase shift becomes important.

A second factor that reduces transistor gain at higher frequencies is the time it takes carriers to travel through the transistor. The effect of changing the voltage across the junction is instantaneous, but the movement of carriers in response to the voltage change takes time. If the voltage changes are rapid, as with high frequency signals, all of the carriers which enter the base from the emitter will not have reached the collector junction before the voltage changes polarity. These carriers become trapped in the base and many of them are lost due to recombination. The loss of carriers reduces the current gain of the transistor. The frequency at which the current gain is reduced to 70.7% of the value for dc, is termed the "alpha cut-off frequency." At this frequency, the output signal current will lag the input signal voltage, for a grounded base transistor, by about 58 degrees.

The alpha cut-off frequency can be increased during manufacture by making the base width smaller. The alpha cut-off frequency is a characteristic of the transistor and cannot be changed by changing the operating biases. This reduction in gain with increasing frequency is similar in result to transit time effects in a vacuum tube amplifier at ultra high frequencies.

LOOKING AHEAD

In this lesson we have covered the fundamentals of current flow in semiconductors, diode and transistor operation and the basic transistor circuits. Throughout the book, differences from vacuum tubes rather than similarities have been stressed. The emphasis has been on understanding transistors as semiconductor devices and not as substitutes for vacuum tubes. The understanding of transistors which you will have gained in this way, will make it much easier for you to understand transistor circuits in which tubes could never be used.

A following lesson will take up the use of transistors as amplifiers and oscillators. Typical circuit diagrams will be given and commercial receivers using transistors will be discussed. Later books will discuss the use of semiconductors as light sensitive devices, and give examples of the use of transistors in control circuits.

Lesson Questions

Be sure to number your Answer Sheet 24B.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. Why is pure germanium unsatisfactory for use in transistors?

2. Is intrinsic conduction a help in transistor operation?

3. When a symmetrical P-N junction is biased in the forward direction is conduction through the junction by means of (a) holes (b) electrons, or (c) both holes and electrons?

4. If the current gain of a transistor in grounded-base connections is .98, what is the current gain in a grounded emitter circuit?

5. What are the two biggest differences between the operation of a semi-conductor diode and a vacuum diode?

6. Using an N-P-N transistor as an example, tell why the current gain of a junction transistor is less than 1.

7. Does an acceptor impurity result in an excess of holes or electrons in the crystal lattice?

8. Which basic transistor amplifier circuit gives current gain greater than one without current phase reversal?

9. What is the voltage gain of a transistor amplifier in grounded-base circuit when Rg equals 100, R_L equals 100,000, alpha equals .95 and i_e equals 100 microamperes?

10. What are four of the advantages of transistors over vacuum tubes for Radio work?

HONESTY

That old proverb, "*Honesty is the best policy,*" is just as true today as ever. Any firm which depends upon repeat business cannot exist for long without following this policy; any man who deals with other people cannot afford to disregard it.

Strict observance of the law will keep a man out of jail, but that does not necessarily make him an honest man. Honesty goes far beyond the law; it involves a careful regard for the rights of others, a truthfulness and sincerity in dealing with others, and a fairness and trustworthiness in matters involving property or business.

It is not enough to act so others will think you are honest; you yourself must know that you are playing the game fair and square if you are to enjoy that real satisfaction associated with absolute honesty.

Be honest, and your reputation will take care of itself. Let your spoken word, your slightest implied action be as good as your signature on a legal contract, and you will enjoy those things which no amount of money can buy—happiness, success, and the respect of your fellow men.

J. E. Smith.

PORTABLE AND AUTOMOBILE RECEIVERS

24B-2

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Study Schedule No. 24

☐ 1. Introduction . . . . Pages 1-2

Here you get a look at different types of battery-operated receivers.

☐ 2. Portable Receivers Using Vacuum Tubes . . . . Pages 3-9

Both simple portables and three-way portables are discussed in this section.

☐ 3. Portable Receivers Using Transistors . . . . Pages 9-17

We study a 6-tube transistor portable, then take up a receiver using a reflex circuit.

☐ 4. Vacuum-Tube Automobile Receivers . . . . Pages 18-24

You study an automobile receiver using a vibrator type of power supply.

☐ 5. Hybrid Auto Receivers . . . . Pages 24-28

Here we discuss an automobile receiver using both tubes and transistors.

☐ 6. Answer Lesson Questions.

☐ 7. Start Studying the Next Lesson.

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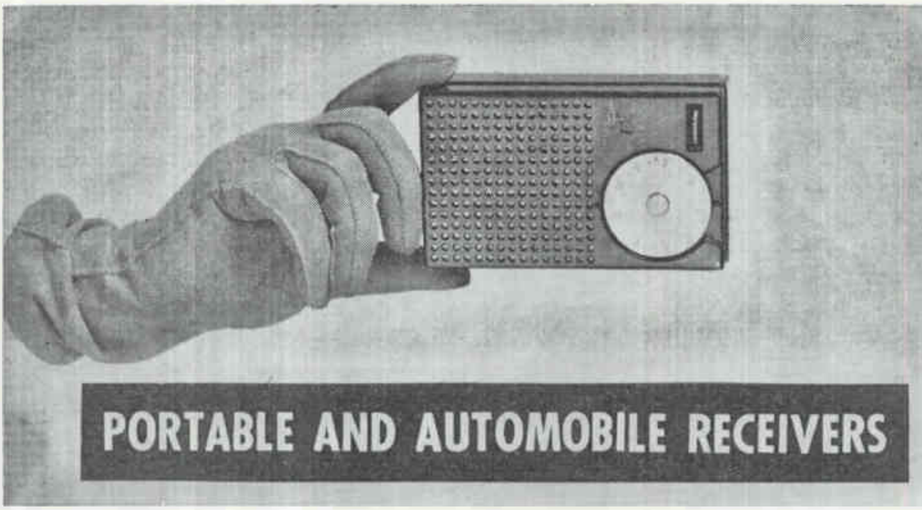


PORTABLE AND AUTOMOBILE RECEIVERS

IN THIS lesson we are going to discuss both portable and automobile receivers. We are discussing the two receivers together because both are battery-operated. Portable receivers obtain their power from batteries carried within the receiver; automobile receivers obtain their power from the storage battery in the automobile.

By present-day standards the early portable receivers were large and bulky. The receivers themselves did not weigh too much, but the total weight of the receiver and batteries was several times the weight of a modern portable.

In the early portable receivers, the parts and tubes used were the same size as the parts and tubes used for receivers operated from a power line. Later, miniature parts and tubes were used to reduce the size of the receiver, and midget portable receivers came on the market. However, even these midget portable receivers using vacuum tubes were much larger than the pocket-size portables using transistors that are now available.

Photo above Courtesy Regency

One of the most popular of the vacuum-tube portable receivers is the three-way portable. Many of these receivers are still in use today and it is likely that you will have to service some. A three-way portable is a receiver designed to operate from its own internal batteries or from either an ac or a dc power line. These sets are popular because they can be used in the home and operated from the power line. This is particularly useful if the receiver uses vacuum tubes, because tubes require so much current that the batteries will not last too long if the receiver is turned on early in the morning and operated all day long from batteries.

Modern portable receivers use transistors. Transistors have many advantages over vacuum tubes in portable receivers. Since transistors do not require any heater supply, one complete battery circuit can be eliminated. Transistors do not require much current, and furthermore they operate on low voltages. This means that even inexpensive batteries will last quite a long time.

Like portable receivers, automobile

receivers have progressed since they were first introduced. Early automobile receivers used the same tube types as home receivers. The voltage required to heat the tubes was obtained directly from the automobile's storage battery, and in the first auto sets the B supply voltage was obtained by means of a motor-generator that was also operated from the storage battery. The motor turned a generator, which generated the high dc voltage needed for the plates and screens of the various tubes.

The motor-generator arrangement in automobile receivers soon disappeared in favor of the vibrator. A vibrator is a device that is used to interrupt the dc circuit from the battery and at the same time cause current to flow through the primary winding of a power transformer, first in one direction and then in the other. Thus, a form of ac is applied to the primary of the transformer, the transformer steps this voltage up, the voltage is rectified, filtered, and then used to supply power to the plate and screens of the tubes.

A still later development in automobile receivers was tubes designed to operate from plate and screen voltages of 12 volts. These tubes appeared on the market shortly after automobile manufacturers began using 12-volt electrical systems. This tube type made it possible to eliminate vibrators in automobile receivers.

Another receiver that has appeared is known as the *hybrid* receiver. This is a receiver in which both tubes and transistors are used. In this type of receiver, tubes are usually used for the rf, mixer, i-f, and second detector stages, and transistors are used in the output stage and sometimes in the first audio stage.

All-transistor automobile receivers have also been manufactured. The advantage of these receivers over vacuum-tube receivers is that the current requirements are substantially lower since no heater current is required. This is a big advantage because the electrical system of the average modern automobile is pretty well loaded down with other accessories.

In this lesson we will first study a number of portable receivers and then we will look at automobile receivers so you will be familiar with the circuits used in these sets.

Portable Receivers Using Vacuum Tubes

Although modern portable receivers use transistors, there are still many portables using vacuum tubes. You can expect to service this type of receiver for a good many years. Therefore we will study several portable receivers using tubes.

A SIMPLE PORTABLE

A simple portable receiver that is designed for battery operation only is shown in Fig. 1. You will find this figure and other large figures stapled in the center of this book. Carefully open the staples and remove the two center sheets, then close the staples again. In this way, you will have the diagrams where you can refer to them easily. This receiver uses four tubes designed for use in portable receivers. These tubes have filaments instead of cathodes with a separate heater. The 1R5, 1T4, and 1S5 tubes operate from a filament voltage of about 1.5 volts and a filament current of .05 amp. The 3S4 tube is designed so that it can be operated with a filament voltage of either 3 volts or 1.5 volts and a filament current of either .05 or .1 amp, depending on how the filament is connected. Notice that there is a center-tap connection on the filament of this tube that divides the filament in two. When the two halves are connected in series, the tube requires a filament voltage of 3 volts and a filament current of .05 amp. If the two halves of the tube filament are connected in parallel, then it requires a filament voltage of only 1.5 volts, but will consume a current of .1 amp.

The filaments of the 1T4, 1S5, and 1R5 tubes are connected in series across a 4.5-volt filament battery, which is called the A battery. This is labeled 37 in Fig. 1. The two halves of the filament of the 3S4 are connected in series, so the tube requires a filament voltage of 3 volts. To get this voltage from the 4.5-volt A battery, a 27-ohm resistor is connected in series with the filament. In this set we have two filament strings, one made up of the filaments of the 1R5, 1T4, and 1S5 tubes, and the other made up of the filament of the 3S4 in series with the 27-ohm resistor. In some portables you will find the tubes connected in a single series string. If the tubes in this set had been connected this way, they would need a filament battery with a voltage of 7.5 volts. In some receivers the filaments are all connected in parallel. When they are connected in parallel they are operated from a 1.5-volt battery. In that case, the filament of the 3S4 tube would be connected with the two halves in parallel instead of in series as they are in this receiver.

The tubes used in this receiver are extremely delicate. The filament current of .05 amp is quite low. In order to get the tube filament to heat with such a low current, it must be made of rather thin, fragile wire. Thus, the tubes are not capable of withstanding great physical shock. Furthermore the filament, because it is delicate, is easily burned out. Many servicemen have learned to their grief, that a test probe that slipped for just an instant and shorted the B supply voltage to the filament circuit could burn out all the tubes in a receiver of this type.

The signal circuits in this receiver are not very different from the signal circuits in the receivers we have discussed previously, and therefore we will not go into a detailed analysis of them. However, there are some differences in the dc circuits, so let's look at them.

Since the filaments of the 1T4, 1S5, and 1R5 tubes are connected in series, there is a potential between the filament and the grid. For example, notice the 1R5 tube. One end of the filament of the 1R5 connects to ground or B-, and the other end connects to the filament of the 1S5. These connections are shown in the lower right-hand corner of the diagram, rather than being run all the way up to the tubes. The current flowing through the filament of the 1R5 will produce a voltage drop across it, so that the potential difference between B- and the end of the filament connected to it is zero, but the potential difference between the other end of the filament and B- will be 1.5 volts. Similarly, the potential difference between one side of the 1S5 filament and B- will be 1.5 volts, and the potential difference between the other side of the filament and B- will be 3 volts. The potential difference between one side of the 1T4 filament and B- will be 3 volts, and between the other side of the filament and B- will be 4.5 volts.

Because there is this potential difference, the grid returns on most of these stages cannot be brought back to B-. If the grid circuit were returned directly to B-, the bias placed on the tube by the voltage between B- and the filament would be so high that the flow of plate current through the tube would be cut off.

Notice that the return from the grid circuit of the 1T4 i-f amplifier in this receiver is connected to the filament of the tube through the secondary of the input i-f transformer and the 3.3-meg resistor 20. The potential difference between the grid and the side of the filament to which the grid return is connected will be zero, but the other side of the filament will be 1.5 volts positive with respect to the grid; or, in other words, the grid will be 1.5 volts negative with respect to that side of the filament.

Also notice that there is no avc voltage applied to this tube. Because the filament is positive with respect to B-, an avc voltage applied to the grid would put too high a bias on the tube, and plate current would be cut off.

However, since the 1R5 is at the end of the string closest to B-, the potential difference between its filament and B- is moderate, and avc voltage can be applied to its grid.

Another point to notice in this filament string is the 1000-ohm resistor, 27. Let's see what it is for. With the filament of three tubes connected in series as they are in this receiver, the filament current will be .05 amp in all three tubes. However, since the filaments emit electrons, the plate and screen currents from each tube must come from the filament. In the diagram, the B battery, labeled 38, is connected to B- through the 820-ohm resistor, 26. The plate and screen current for the 1R5 tube flows from B- to the filament, and then from the filament through the tube to the plate and screen of the tube. This actually increases the filament current of the 1R5 tube somewhat above the .05 amp required to heat the filament.

If we allowed the B supply current for all the tubes to flow through the 1R5 tube, the current flowing through the filament of this tube would be substantially higher than it should be. To overcome this difficulty, the 1000-ohm resistor is connected from the junction of the 1S5 and 1T4 filaments to B-. The purpose of this resistor is to maintain the filament current of the 1R5 and 1S5 tubes at the correct value and to provide a path for the B supply current flowing through the 1S5 and 1T4 tubes to flow from B- to the filament of these tubes without having to flow through the other tubes in the filament string. The .1 and .05-mfd capacitors are signal by-pass capacitors. They are used to provide a path for signal currents from B- to the filaments.

The two most common defects found in servicing these receivers are weak batteries and defective tubes. To check a battery in a portable receiver you should connect the battery to the receiver, and with the receiver turned off, connect a voltmeter across the battery. Notice the reading on the voltmeter. The voltmeter should indicate that the battery has its rated voltage. In other words, if the voltage you are measuring is the A battery voltage and it is supposed to be 4.5 volts with the receiver turned off, the battery voltage should be 4.5 volts. Next, turn the receiver on, and if you find that the battery voltage drops below 4.1 volts, the battery is exhausted and should be replaced. If the battery voltage, particularly the A battery voltage is low, the tube filaments will not heat as they should. This will often mean that the oscillator will fail to oscillate.

The second defect we mentioned was defective tubes. This is often due to the fact that the tubes are quite fragile and they have simply been handled too roughly and shorts have developed between the elements, or perhaps a current surge through the set has burned out the filament of one or more of the tubes. Sometimes you can burn out the filament of one of these tubes simply by rapidly turning the receiver on and off several times.

Another common defect in this type of receiver is the failure of the 1R5 tube to oscillate. Often this happens even though the battery voltages are normal and the tube checks good in a tube tester. You can check the 1R5 tube to see if it is oscillating by measuring the voltage across the oscillator grid resistor. This is the 100K resistor connected between the No. 1 grid and the filament of the 1R5 tube. If the oscillator is operating, there will be a voltage across this resistor, and the grid end will be negative. If you find that the oscillator is not working but the operating voltages throughout the receiver appear to be normal, it would be worthwhile to try a new 1R5 tube, even though the old one may test good. If you run into this situation, simply put the new 1R5 tube in the receiver and save the old one; it might work entirely satisfactorily in the next receiver you service.

A THREE-WAY PORTABLE

A schematic diagram of a three-way portable receiver is shown in Fig. 2, which is on the same sheet as Fig. 1. Notice that this receiver is quite similar to the receiver shown in Fig. 1. The big difference is the addition of a half-wave rectifier tube and a filter network. A switch is provided to select the type of operation. In the position shown, the switch is in the power line position.

In three-way portables this switch is often inside the receiver cabinet. Frequently it is actuated simply by plugging the line-cord plug into a receptacle in the receiver. When you do this you automatically throw the switch to the battery position and the set can be used as a portable. When the plug is removed from this receptacle the switch is automatically thrown to the power-line position so you can go ahead and plug it into a wall outlet and operate the receiver from the power line.

Since the main difference between this circuit and the circuits discussed previously is in the power supply, we will limit our discussion to the power supply. Notice that the rectifier is a 117Z3 tube. This is a half-wave rectifier tube with a heater designed to operate from a 117-volt power line. Thus, the tube heater is connected directly across the power line. The filter network used in the receiver actually consists of two separate networks, one for the A supply which operates the filaments of the various tubes, and one for the B supply for the plate and screen currents. The input filter capacitor for both supplies is the 80-mfd capacitor marked 6A. The filter network for the B supply consists of a 1500-ohm resistor 32 and the 30-mfd output filter capacitor marked 6C. The filter network for the A supply consists of the 40-mfd capacitor 6B and the 1100-ohm resistor between 6A and 6B.

The filament circuit is quite interesting. These tubes all have extremely delicate filaments. They can be operated only from dc, so they are operated from the output of the rectifier tube. The 1100-ohm resistor connected between the sections 6A and 6B of the filter capacitor is a combination voltage-dropping and filter resistor. The purpose of this resistor is to work in conjunction with the 40-mfd filter capacitor 6B to filter the pulsating dc across the input filter capacitor to pure dc and at the same time to help reduce the output voltage from the rectifier tube to the voltage needed by the tube filaments. These filaments are all connected in series and require a filament voltage of 7.5 volts across the series string. The output from the rectifier tube across the input filter capacitor is usually about 120 volts. Therefore some means of dropping this voltage must be provided. The two 1100-ohm resistors marked 31 are used for this purpose. These resistors are connected in series, making a total resistance of 2200 ohms. When the filament current of .05 amp flows through them, the output voltage from the rectifier tube will be dropped so that the total voltage across the four tubes connected in series will be about 7.5 volts.

Servicing Procedures. One of the first rules a serviceman should learn when working on three-way portables is: *Never remove any of the tubes from their sockets while the receiver is turned on.* To see why, let's examine this series filament circuit more closely. Notice the 40-mfd filter capacitor 6B. It is connected at the junction of two 1100-ohm resistors. Since these resistors are of equal size, you can expect the voltage drop across them to be about the same. The voltage drop across each resistor will be somewhere around 50 volts. As long as current is flowing in the circuit, we will have this voltage drop across these resistors. Now suppose you were servicing this receiver with the power turned on and you pulled the 3Q4 tube from its socket. Doing this would open the series circuit and there would be no current flow through the two 1100-ohm resistors. This means that the 40-mfd filter capacitor 6B would charge up to a value almost equal to the peak ac line voltage. This means that instead of having about 50 or 60 volts across the capacitor, the charge would build up to 150 volts or more. Then, if you plug the 3Q4 tube back into its socket with 150 volts across this capacitor, there will be such a high current surge through the filaments of the tubes that you will burn out all of the tubes in the receiver. So remember not to remove any tube in a three-way portable with the power on.

A burned out filament in one of the tubes can cause the same difficulty. For example, suppose you had this receiver for servicing and the filament of the 3Q4 tube was burned out. When you first started to work on the set you might plug it in and turn it on to see if it would work. Doing this would charge the filter capacitor, just as removing the tube would do. As soon as you found out that the receiver did not work, the next step might be to check the tubes and you would discover that the 3Q4 tube was burned out. Now if you simply installed a new tube in the set, you would still have the charge on the capacitor, and when you put the new tube in you would burn it and the other three tubes out. Therefore, if you should plug in such a receiver and find out it doesn't work, before you replace any of the tubes, discharge the filter capacitors in the set. You can do this by simply shorting the cathode of the rectifier tube to B- with a screwdriver, holding the screwdriver in place long enough to let the capacitor discharge. Of course, the set should be turned off when you do this. After you have discharged the filter capacitors, then you can replace any defective tubes and try the receiver again.

Another complaint that the serviceman frequently receives about this type of receiver is that when the set is operated from batteries, it will start playing almost as soon as it is turned on, but when it is operated from the power line, it takes a couple of minutes before it starts to work. Actually, this is an exaggeration and the set owner just thinks that it takes much longer to start operating when it is operated from a power line than it should. This is not a defect in the receiver. The battery type tubes used in the set have a very light filament and the filament will heat almost instantly. Therefore when the receiver is operated from batteries it will start playing almost as soon as it is turned on. On the other hand, when the set is operated from the power line, the cathode of the 117Z3 tube will have to have time to heat. This usually takes about 25 or 30 seconds, but compared to the rapid, almost instantaneous, starting of the receiver on batteries it seems like a long time. A circuit that is sometimes used to overcome this difficulty is shown in Fig. 3, which is on the back of Figs. 1 and 2. This is a schematic diagram of a three-way portable receiver using a selenium rectifier instead of a vacuum tube rectifier.

The signal circuits in this receiver are similar to those used in receivers we have already discussed, so we will not go through them again. We will, however, take a look at the B supply circuit and the filament circuit.

The selenium rectifier is used in a half-wave rectifier circuit similar to the half-wave rectifier circuits using vacuum tubes that we have already discussed. With this arrangement, the side of the power line that is shown on the lower side of the plug in the drawing will be connected to B-. Current will flow in on this side of the power line to terminal d of switch S2, which is the power-line battery switch. It is shown in position for power-line operation. Current will flow through the switch to terminal e, and then through the On-Off switch S1 to B-, indicated by the heavy black line. The current will then flow through the load, which consists of the plate and screen circuits of the various tubes plus the filaments of the tubes, back through the filter network and through the rectifier to the other side of the power line.

Notice the rectifier symbol. Current flows from the flat side into the side represented by the triangle, that is, from the side marked with a plus sign to the side marked with the minus sign.

The B supply filter network consists of the 30-mfd input filter capacitor C17B, the 2700-ohm filter resistor R16, and the 20-mfd output filter capacitor C17A. The filament filter network consists of the 1380-ohm resistor R17A and the 20-mfd filter capacitor C17C. The two 1380-ohm resistors R17A and R17B are used for voltage dropping as in the preceding receiver.

The filaments of the tubes in this receiver are connected in series, both for operation from batteries and for operation from the power line. We can trace the filament circuits from the section of switch S2 shown just to the right of resistor R17B. You will see a lead going from this switch to pin 7 of the 3V4. The connection from pin 5 is for the B-supply current and has nothing to do with the filament circuit. At pin 1 of the 3V4 you see a lead going to pin 7 of the 1U4. At pin 1 of the 1U4 there is a lead going to pin 7 of the 1R5. Pin 1 of the 1R5 has a lead to pin 1 of the 1U5, and pin 7 of the 1U5 is connected to B-.

For battery operation the various sections of S2 move to the right, connecting the A and B batteries into the circuit.

Sometimes in these three-way portable receivers you will find the receiver will operate from batteries but will fail to operate from the power line. This, of course, indicates a power-supply defect. The trouble could be due to a defective selenium rectifier or to defective filter capacitors. If the capacity of the filter capacitors changes, the operating voltages in the set will be somewhat lower than normal. When this happens, the set usually fails to work because the 1R5 tube fails to oscillate. You will also run into situations where the receiver will operate from the power line but fails to operate from batteries. This is often an indication that the batteries are exhausted. Of course, the remedy for this situation is to replace the batteries.

Sometimes a receiver may operate from the power line but does not operate from batteries, even though the battery voltages are normal. When the set is operated from the power line, sometimes the operating voltages in the set are a little higher than they are when it is operated from batteries, even though the batteries are new. The oscillator section of the 1R5 tube may oscillate with the slightly higher voltages obtained from the power line, but fail to oscillate with the lower voltages obtained from the battery. Then it is a good idea to try a new 1R5 tube in the receiver.

SUMMARY

The big difference between portable receivers and the receivers we have studied previously is in the tubes used in portable receivers. The tubes used in these receivers are specially designed for such use. They are filament-type tubes that operate on a comparatively low filament current. It is easy to burn out these tubes and you must work on these sets with considerable care to avoid any current surges through the set that might result if you accidentally let a test probe slip.

Remember the important rule we mentioned for servicing three-way portable receivers—*never remove any of the tubes from the set while it is plugged into the power line and turned on.*

Portable Receivers Using Transistors

In modern portable receivers, transistors have completely replaced vacuum tubes. Transistors are ideally suited for use in portables because they do not require heater current, they are rugged, and they can be operated from a comparatively low voltage source.

In modern portable receivers special miniature parts are used along with the transistors. You will find that the i-f transformer in a portable receiver is much smaller than the i-f transformer in a broadcast-band receiver designed for use in the home. Other parts such as the output transformer, tuning capacitor, and oscillator coil are also usually smaller than the similar components in receivers designed for use from the power line. All these miniature parts along with the small size of transistors make it possible to manufacture portable receivers so small that they can easily be slipped into a man's shirt pocket.

Many portable receivers use etched circuit boards. The etched circuit board is made by gluing a thin sheet of copper to a phenolic board. The electrical connections to the various parts in the receiver are then printed on the board, using an acid-resistant ink which covers the copper beneath it. The phenolic board with copper and the printing on it is then immersed in a chemical solution that eats away all of the copper that is not protected by the acid-resistant ink. The board is then removed from the solution, washed, and the ink is then removed. A copper pattern will be left on the board, that takes the place of connecting wires.

This board is then dried and punched on a hydraulic punch. The punch puts holes in the board through which the various parts can be mounted and soldered to the copper. Thus the receiver can be constructed without any wires; all the electrical connections between the various parts are made by the copper left on the circuit board.

A SIX-TRANSISTOR RECEIVER

A schematic diagram of a portable receiver using six transistors is shown in Fig. 4, on the same sheet as Fig. 3. The circuits used in this receiver are typical of those found in modern portable receivers. Let's review these circuits quickly. You have already studied most of these circuits and should be familiar with them; now we will see how they are used together in a complete receiver.

The input signal for this receiver is picked up by an antenna known as a Ferrite antenna. It consists of a coil wound on a core made of a powdered iron material called Ferrite. It has a very high Q, and hence the antenna has a high Q. Even a small Ferrite antenna is capable of comparatively high signal pickup.

In the receiver shown in Fig. 4 the Ferrite antenna has two windings on it, a primary winding and a secondary winding. The primary winding is tuned to resonance by the capacitor C18, which is connected across it. The capacitor is one section of the gang-tuning capacitor with a trimmer, which is marked T on the diagram, connected across it. The primary winding of the antenna is inductively coupled to the secondary winding. One side of the secondary winding is connected to ground, and the other side to the base of the transistor used in the converter circuit.

The 2N411 transistor shown in the converter circuit performs the dual function of mixer and oscillator. The oscillator signal is fed into the emitter circuit and is mixed in the transistor with the incoming local signal. In the converter, two new signals are produced, one equal to the sum of the frequencies of the incoming signal and the oscillator signal, and the other equal to the difference in frequency between them. As in the other superheterodyne receivers we have studied, the input i-f transformer T2 has its primary tuned to resonance at the difference frequency.

You will notice a crystal diode, marked CR2 and labeled "overload diode," connected to the collector circuit of the converter stage. We'll come back to this diode later and explain what it does and how it is used.

The signal flowing through the primary winding of T2 induces a voltage in the secondary. This voltage is applied to the base of the first i-f transistor and to ground through the .05-mfd capacitor C4. The emitter of the first i-f stage is connected to ground through the .05-mfd capacitor C5. Since these capacitors have low reactances at the i-f signal frequency, we have the signal effectively applied between the base and emitter.

The signal is amplified by the first i-f transistor, and fed to the primary winding of the interstage i-f transformer T3. Notice that the primary winding of this transformer is tapped, and the B supply voltage is applied to the tap, which is terminal 6 of the transformer. The voltages at the opposite ends, terminals 3 and 4, of the primary winding will be 180 degrees out of phase. The signal from terminal 3 is fed through the 6.8-mmf capacitor C7 back to the base of the first i-f transistor to cancel out any signal fed from the collector circuit back into the input circuit through the transistor. You will remember that this is a neutralizing circuit, and it is needed in order to prevent the stage from going into oscillation.

The signal current flowing through the primary of T3 induces a voltage in the secondary, and this voltage is applied to the second i-f transistor. One side of the secondary winding connects to the base, and the other to ground through the 10-mfd capacitor C12. The emitter of the second i-f transistor is connected to ground through the 45-mfd capacitor C10, so we have the signal applied between the base and the emitter of the second i-f amplifier. The signal is amplified by the second i-f amplifier and fed to the output i-f transformer T4. Notice that the second i-f amplifier is neutralized by the signal fed from terminal 3 of the output i-f transformer T4, through the 3.3-mmf capacitor C9 to the base of the transistor.

Connected in the secondary circuit of the output i-f transformer T4, we have the detector diode CR1. When the side of this diode that is connected to terminal 2 of the secondary is positive, the diode will conduct, and current will flow from ground through the volume control R13, through the 560-ohm resistor R21, through the diode detector. Current will then flow through the secondary of the output i-f transformer T4, back to the secondary of T2, through the base-emitter junction of the first i-f transistor, through the 680-ohm resistor R6, and back to ground.

This circuit back through the first i-f transistor provides avc for the first i-f stage. Notice that the negative voltage on the base of the first transistor is slightly higher than the negative voltage on the emitter. We have .92 volt negative on the base and .76 volt negative on the emitter. This means that the base is negative with respect to the emitter. This is as it should be with a PNP transistor such as the type 2N409 used in this stage. You will remember that to forward-bias an emitter-base junction, we need a negative voltage on the base and a positive voltage on the emitter. Although both voltages shown on the diagram are negative with respect to ground, the emitter is positive with respect to the base.

When a signal is picked up and current flows through the diode CR1, the strength of the current flowing will depend upon the strength of the signal. If the signal is strong, the current will be reasonably strong. This current, in flowing through the 680-ohm resistor R6 to get back to ground, will develop a voltage drop across it which will make the emitter end of the resistor negative. This will increase the negative voltage on the emitter, which will decrease the forward bias across the emitter-base junction. When this happens, the number of holes moving from the emitter through the base to the collector will decrease, and hence the collector current will decrease. When the collector current decreases, the voltage drop across the 1000-ohm resistor R8 will decrease. This means the negative voltage on the collector will increase, because this voltage is equal to the battery voltage minus the voltage drop across R8.

Now let's look at the overload diode CR2. One side of this diode is connected to the collector circuit of the converter stage, and terminal 4 of T2. The other side of it is connected to the junction of the 1000-ohm resistor R8, the .05-mfd capacitor C8, and terminal 6 of T3. This junction is held at signal ground potential by the .05-mfd capacitor C8. Terminal 6 of T2 is also at signal ground potential because it is bypassed by the .05-mfd capacitor C6, therefore the overload diode is effectively connected between terminals 4 and 6 of T2.

This diode normally has a reverse bias on it so it does not conduct. This bias is due to the fact that the collector voltage on the converter is more negative than the collector voltage on the first i-f stage; therefore, the side of the diode CR2 that is connected to the converter circuit is negative, and the other side is positive; under these conditions the diode does not conduct. However, if a strong signal is picked up, we found that the current flowing through R6 changes the voltage on the emitter, which in turn changes the collector current in the first i-f stage. This causes the voltage across R8 to decrease, which makes the collector voltage increase. This means that the reverse bias on the overload diode decreases or may disappear entirely. When this happens, the overload diode conducts, and when it does, it loads the primary of T2, reducing the Q and hence the signal developed across it. This will reduce the signal fed to the first i-f stage.

AVC voltage is also applied to the second i-f amplifier. The current flowing through the detector diode circuit must flow through the volume control and in doing so develops a voltage across the volume control, making terminal 3 positive. This voltage is fed through the 2700-ohm filter resistor R12 and the 10-mfd filter capacitor C12 back to the base of the second i-f transistor. The positive voltage drives the voltage on the base of this transistor in a positive direction, and hence reduces the forward emitter-base bias. This reduces the flow of holes from the emitter to the collector and hence the power gain in the transistor.

The audio signal across the part of the volume control between terminals 1 and 2 is fed between the base and emitter of the first audio amplifier. You will remember that the signal voltage will cause the emitter-base forward bias to vary, and this will cause a large variation ir the number of holes crossing the emitter-base junction. This in turn will cause the number of holes reaching the collector to vary, and hence the electrons flowing through the external circuit to the collector will vary. This varying current will produce an amplified signal in the collector output circuit across the primary winding of the driver transformer T5. The secondary winding of T5 is connected to two transistors which are used in a push-pull class B output stage. The output from these two transistors is combined in the output transformer T6 and fed to a loudspeaker.

You might wonder why a class B output stage is used in a portable receiver. The purpose is to reduce the current drain on the batteries. In a class A amplifier the tube or transistor is biased at the center of its characteristic curve so the current flows at all times. In the class B stage, a tube or transistor is biased practically at cut-off and current flows through the tube or transistor only when the signal is applied to it. Thus in the class B output stage used in this receiver, there is very little current flow through the transistors until an audio signal is applied to them. Thus, the power consumed by the transistors is considerably less than it would be if they were used in a class A amplifier circuit where the same average current would flow at all times.

The circuits used in this receiver are typical of those that you will find in transistorized portable receivers. Some sets are smaller than this and use fewer transistors. Some receivers have only a single i-f amplifier. Often in receivers with only a single i-f amplifier, specially selected transistors with a high gain are used in order to get enough sensitivity.

Not all transistor portable receivers use a push-pull output stage. Some use a single-ended stage. Of course, the power output from a single-ended stage in a portable receiver is usually substantially less than the power output that is available from a push-pull stage. However, some portable receivers are very small and use speakers less than three inches in diameter. With small speakers of this type, you can't use a great deal of power anyway, because it would simply overload the speaker, and distortion would result. In these receivers a single-ended output stage is usually quite adequate.

In a single-ended stage, a driver transformer is not always used between the first audio stage and the output stage. Sometimes the stage is resistance-capacitance coupled. This arrangement usually is not quite as good as using a transformer, but it is more economical, so many manufacturers have adopted it.

Another circuit that has been used by some manufacturers is what is known as a reflex circuit. This is quite an interesting circuit, so let's look at a receiver using a reflex circuit.

A REFLEX PORTABLE

The basic idea in a reflex circuit is to make one stage do two jobs; usually in portable receivers, to make one of the amplifiers work both as an i-f amplifier and as an audio amplifier. The signal is fed through the i-f amplifier, and then it is fed to the detector. After the signal is detected, the audio signal is then fed back to the same amplifier and amplified by it and then fed to the audio output stage. Because the signal is fed back in this way through the stage a second time, it is called a reflex circuit. You might at first think the signals would get mixed up, but remember, one signal is an i-f signal and the other an audio signal, so it is not too difficult to keep them separated.

A schematic diagram of a transistor receiver using a reflex circuit is shown in Fig. 5. Most of the circuits used in this receiver are not very different from those used in the receivers we discussed previously. The transistors are PNP transistors. Notice that there is an overload diode marked CR2. This diode is connected from terminal 1 of the input i-f transformer T1 to the terminal feeding the supply voltage to the collector circuit of the first i-f amplifier. Again, under normal conditions this diode has a reverse bias on it so it does not conduct. However, the avc voltage is fed through the 1.2K resistor R5 back to the secondary of T1, through the secondary to the base of the first i-f amplifier. When a strong signal is received, considerable positive avc voltage is developed, and this is fed to the base of the i-f amplifier. This positive voltage reduces the negative voltage and hence the forward bias of the emitter-base junction. This reduction in forward bias reduces the flow of holes through the transistor to the collector. This in turn reduces the number of electrons flowing to the collector, and hence the current through the 2.7K resistor R9 decreases. This causes the voltage drop across R9 to decrease, and the collector voltage on the first i-f transistor to increase. This reduces or eliminates the reverse bias on the overload diode and since, insofar as the signal is concerned, it is directly across the primary of the input i-f transformer, it loads it, reducing its Q, and hence the output from the

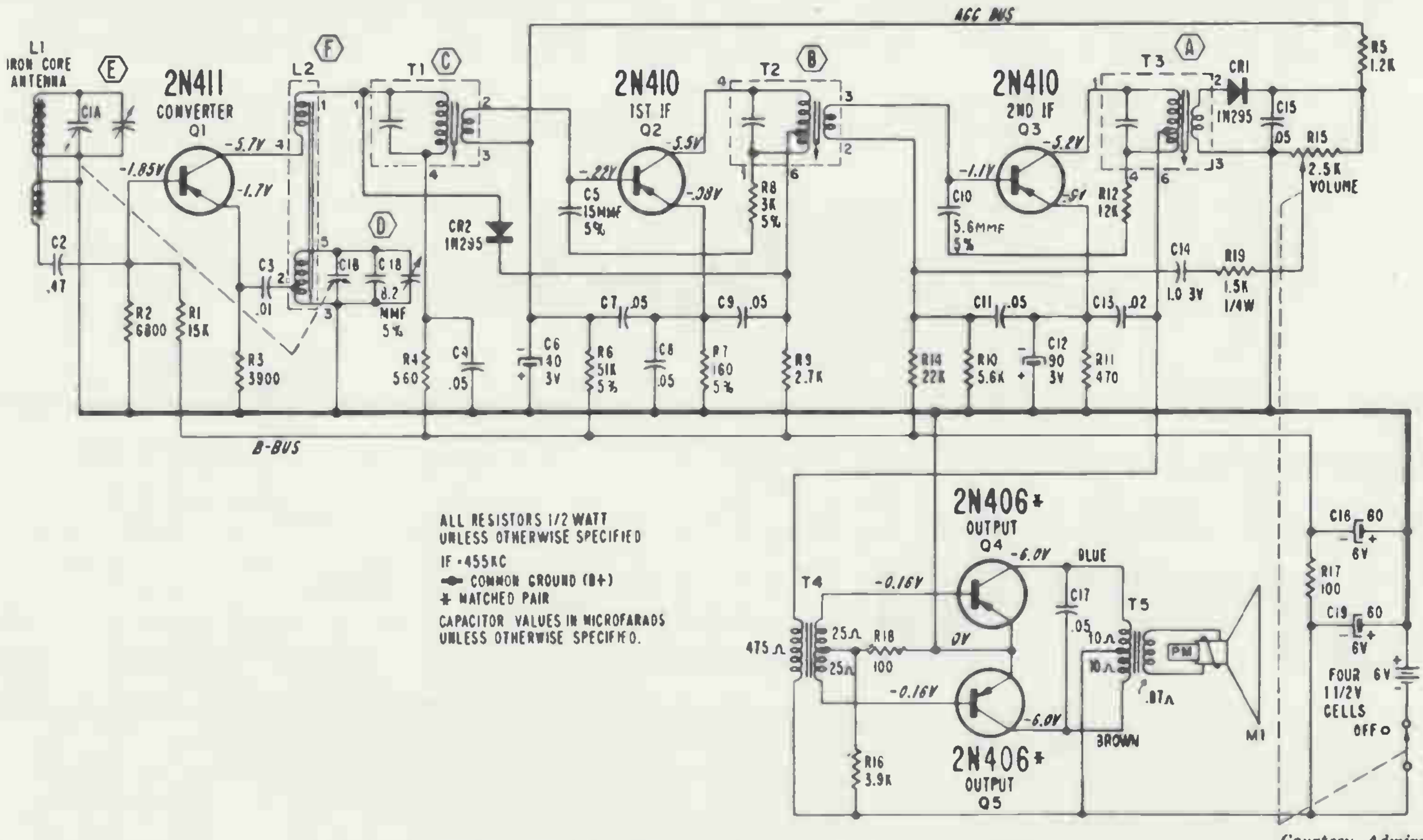
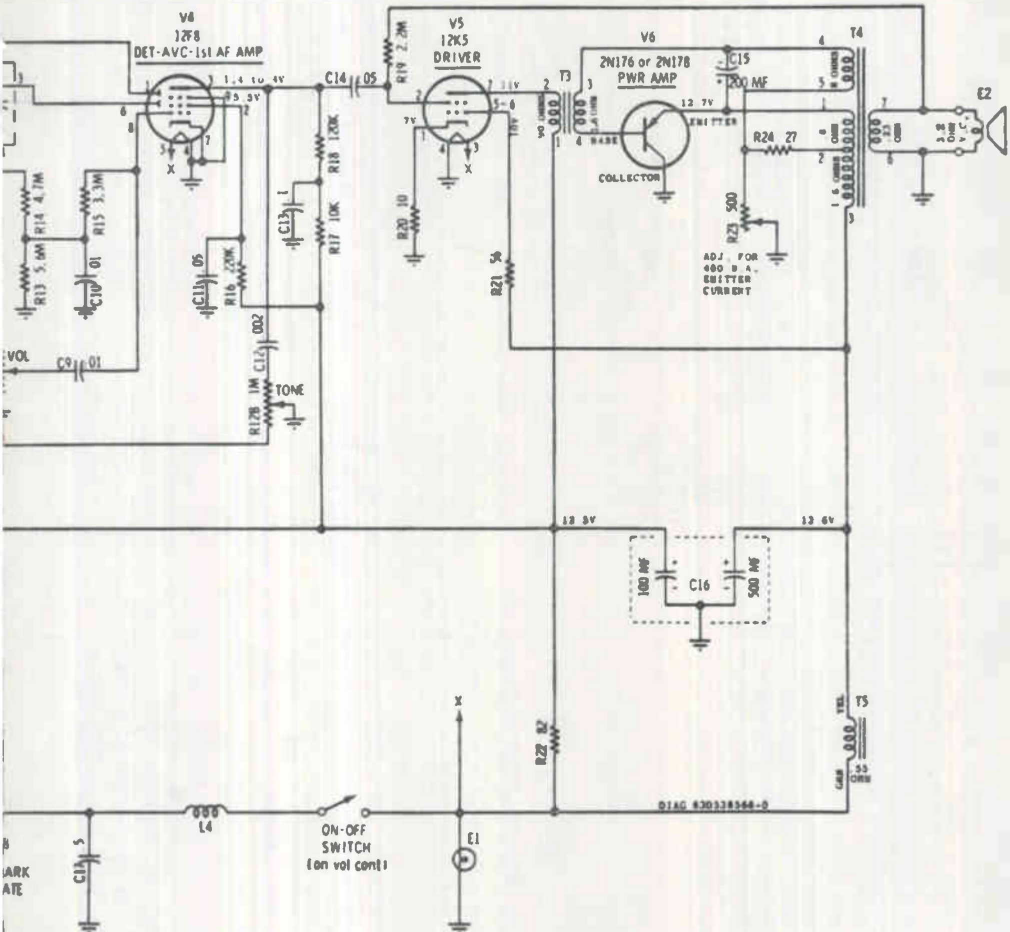


FIG. 5. A transistor portable using a reflex circuit in the second i-f stage.



Courtesy Motorola

with four tubes and one transistor.

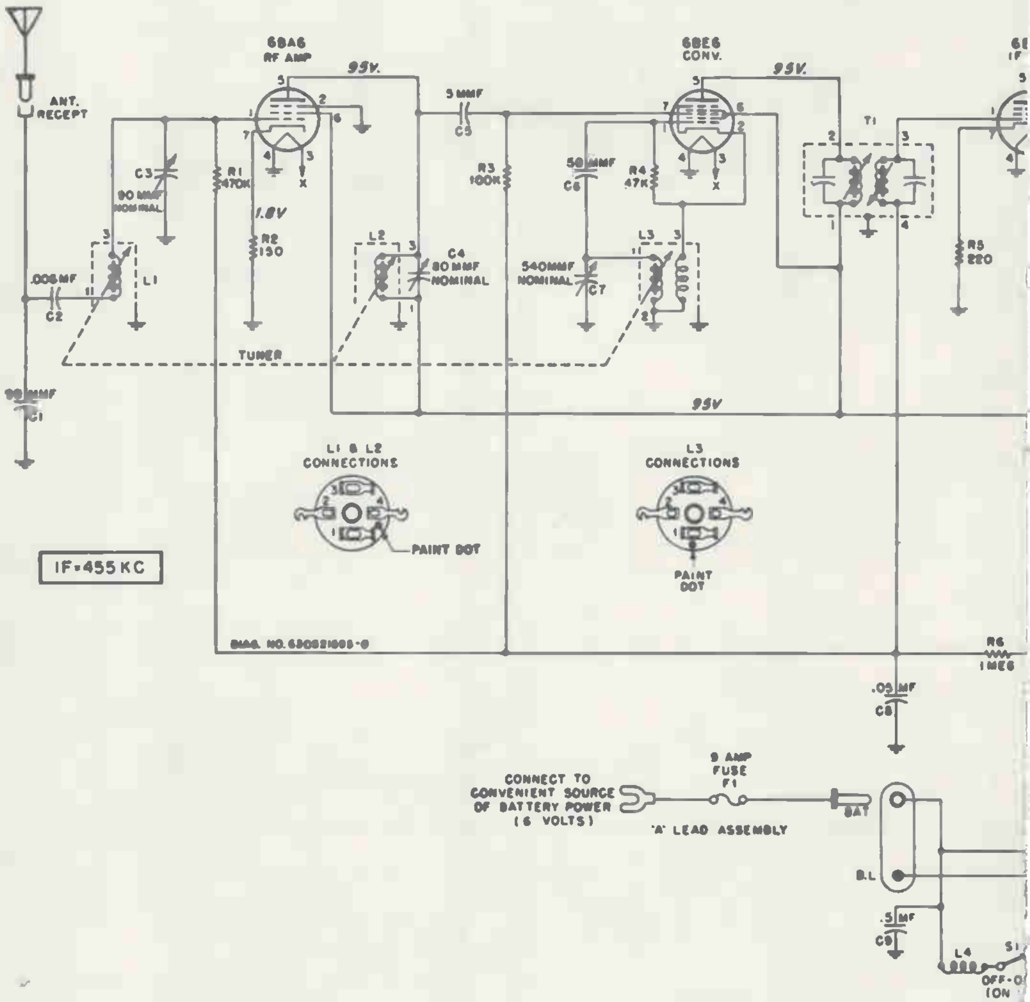
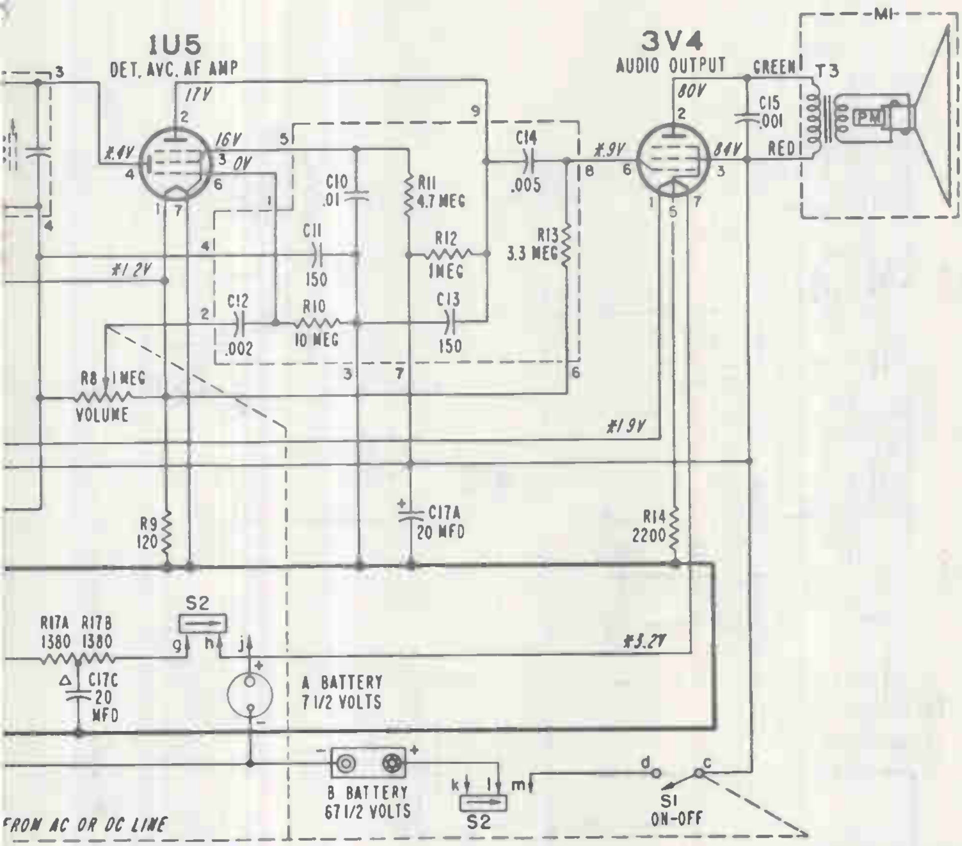
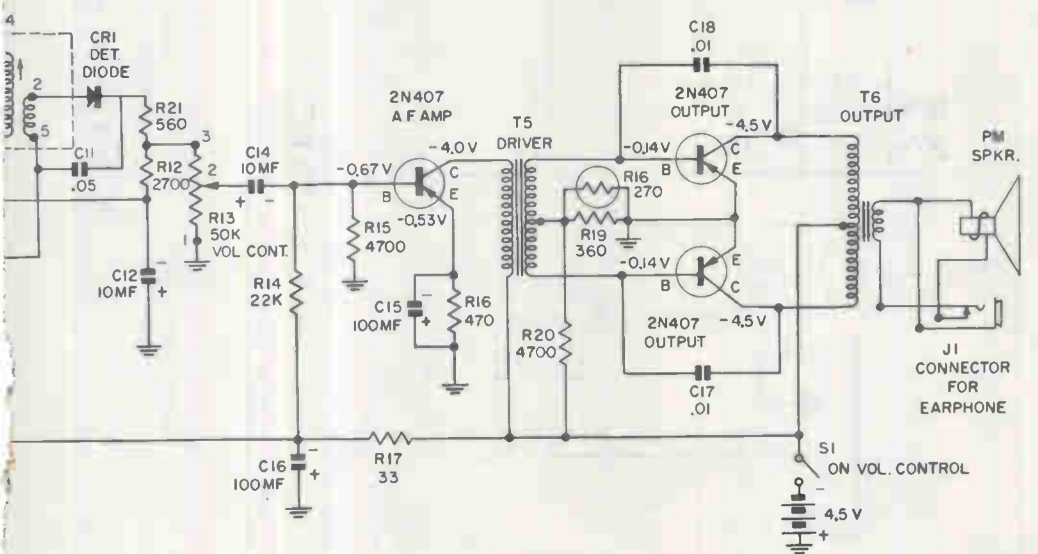


FIG. 6. An automobile receiver using,



using a selenium rectifier.

Courtesy Admiral



sistor portable.

Courtesy RCA

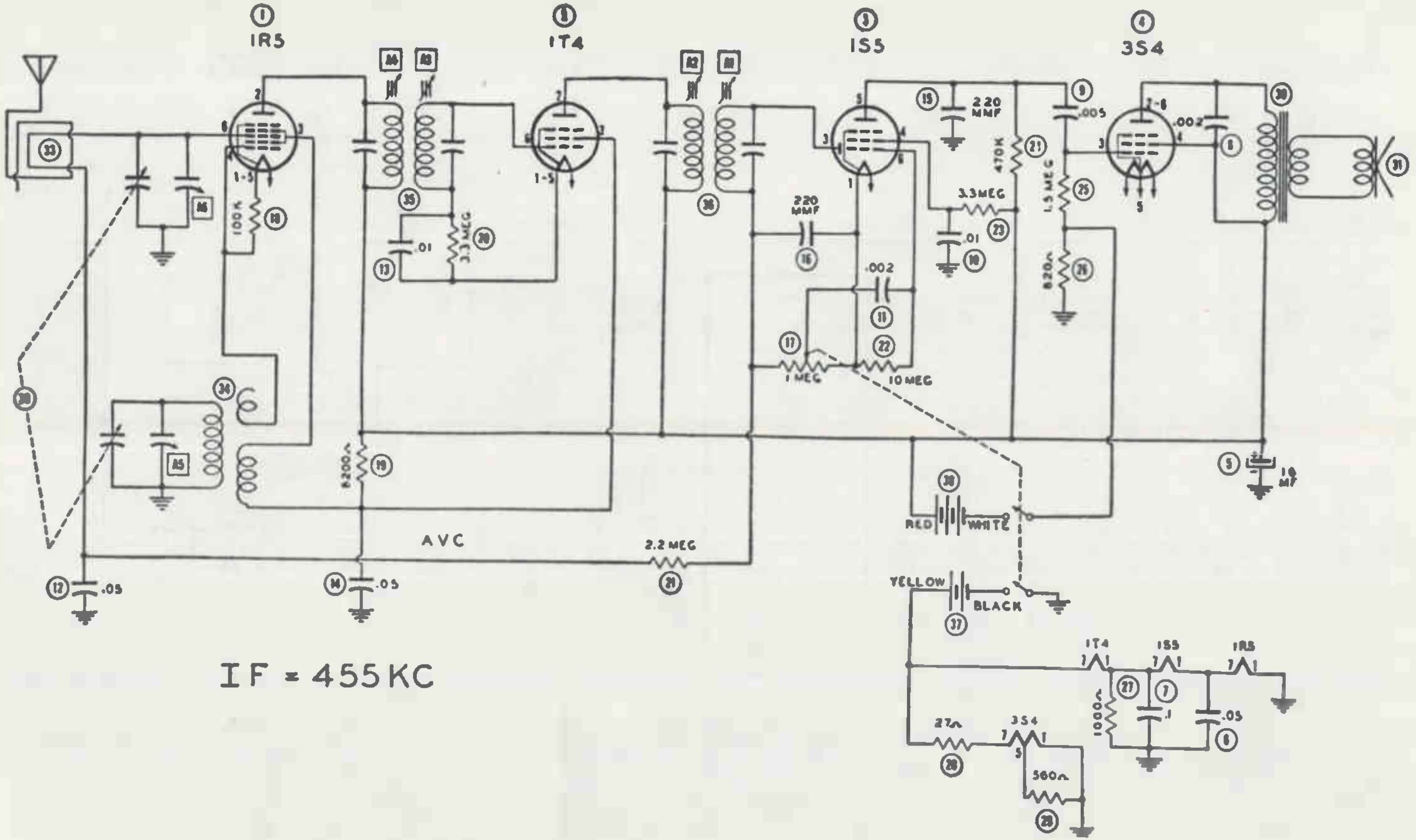
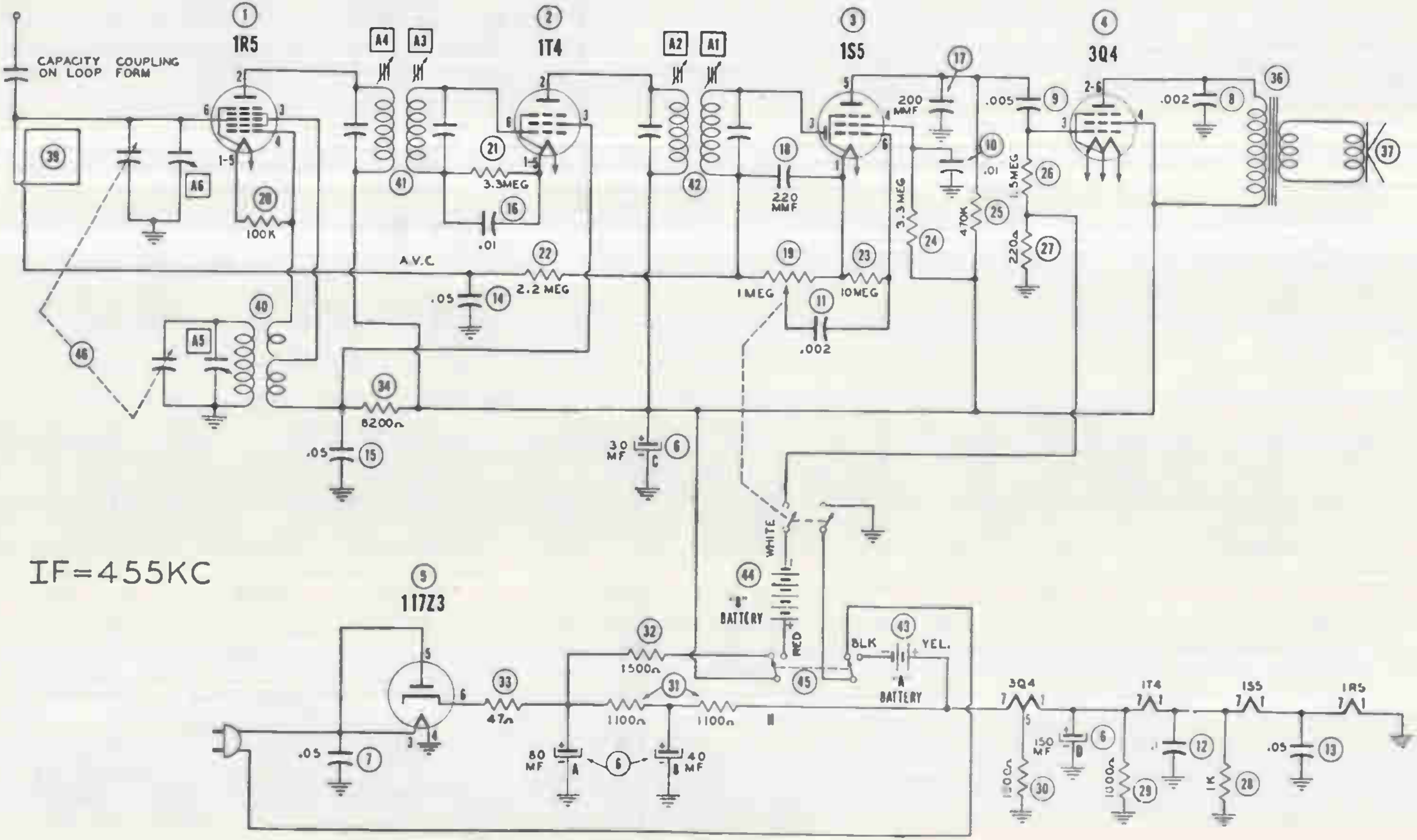


FIG. 1. A portable receiver, designed for operation on batteries only.

Courtesy Emerson



Courtesy Emerson

FIG. 2. A three-way portable receiver.

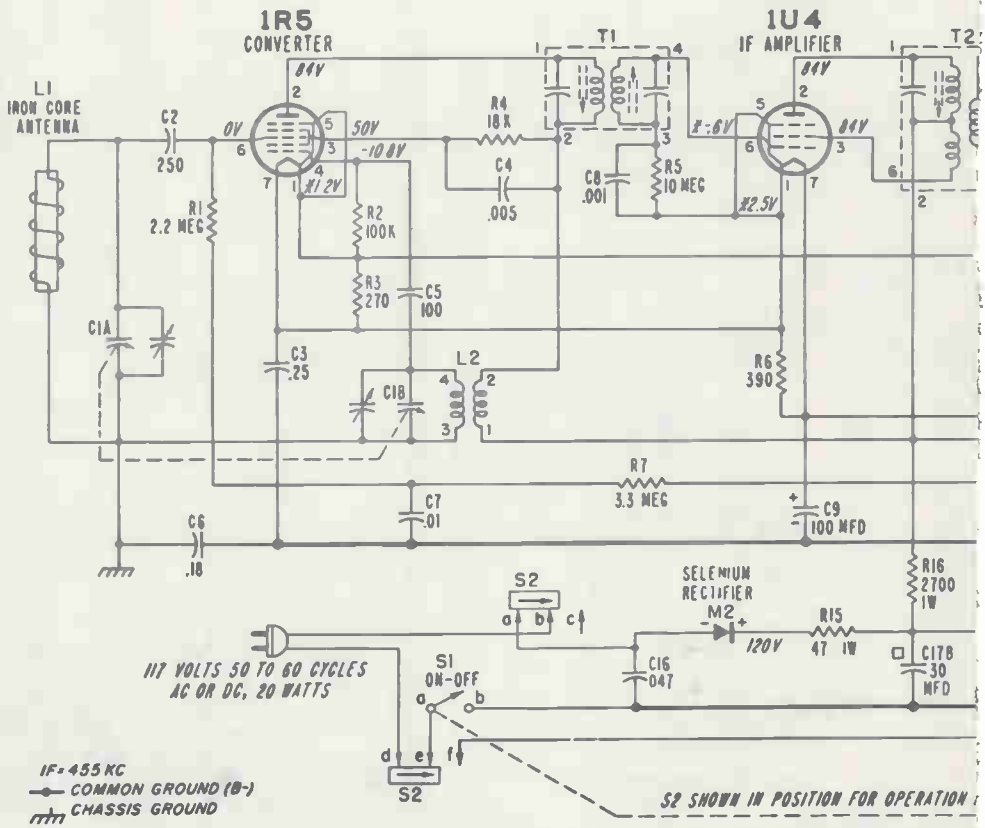


FIG. 3. A three-way portable

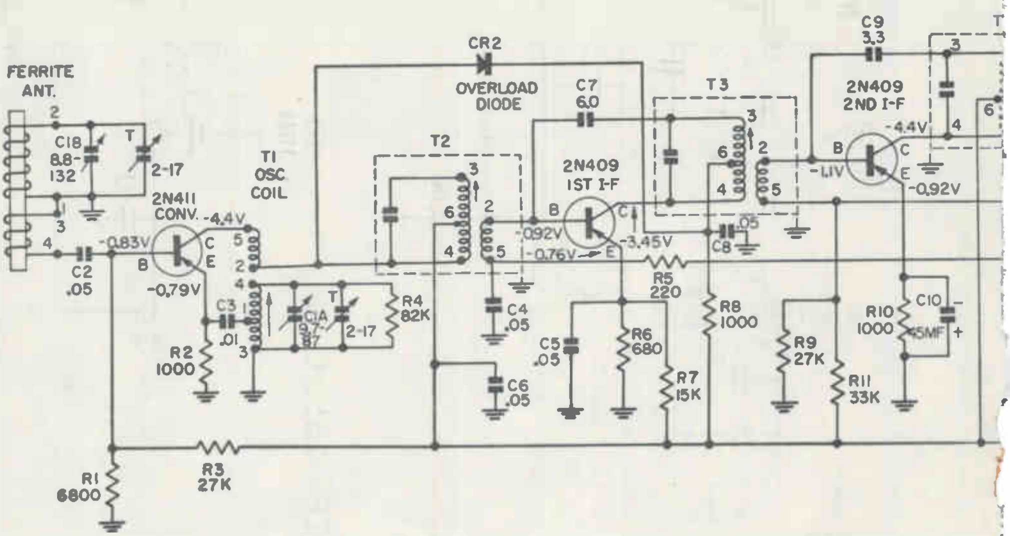
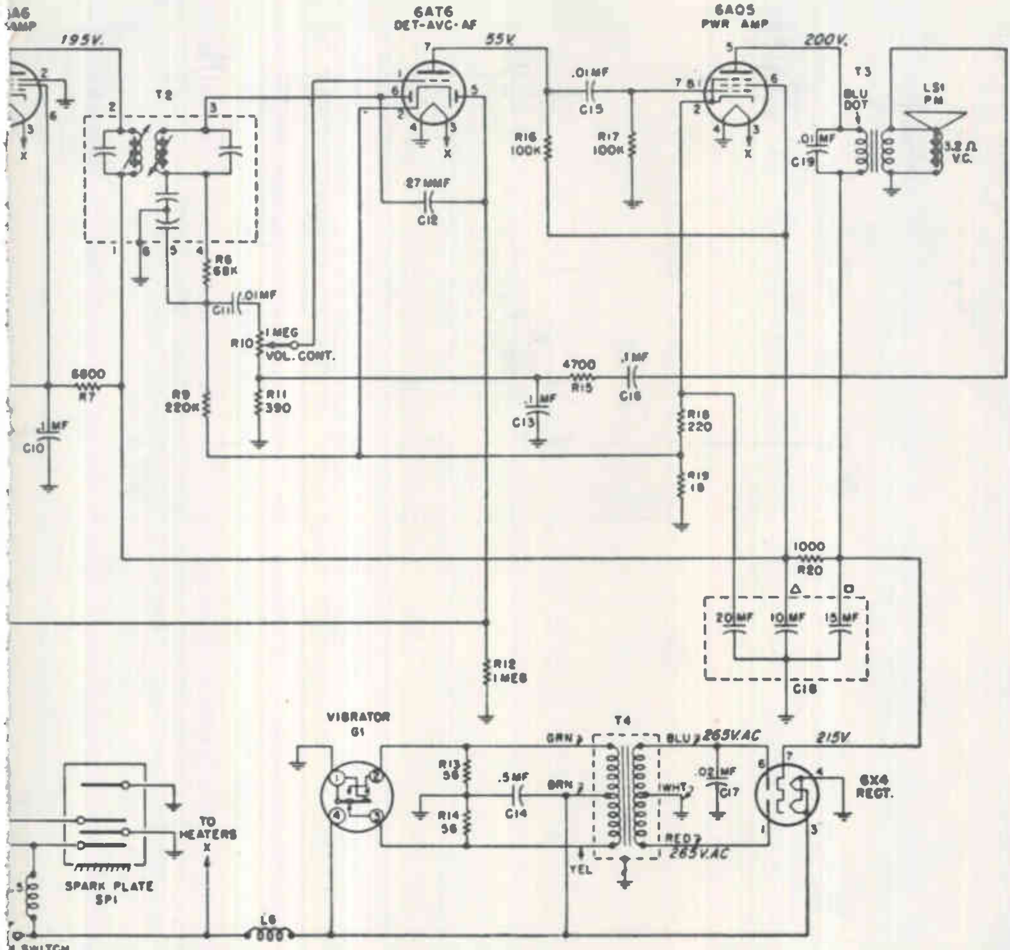


FIG. 4. A 6-tran



Courtesy Motorola

a vibrator type of power supply.

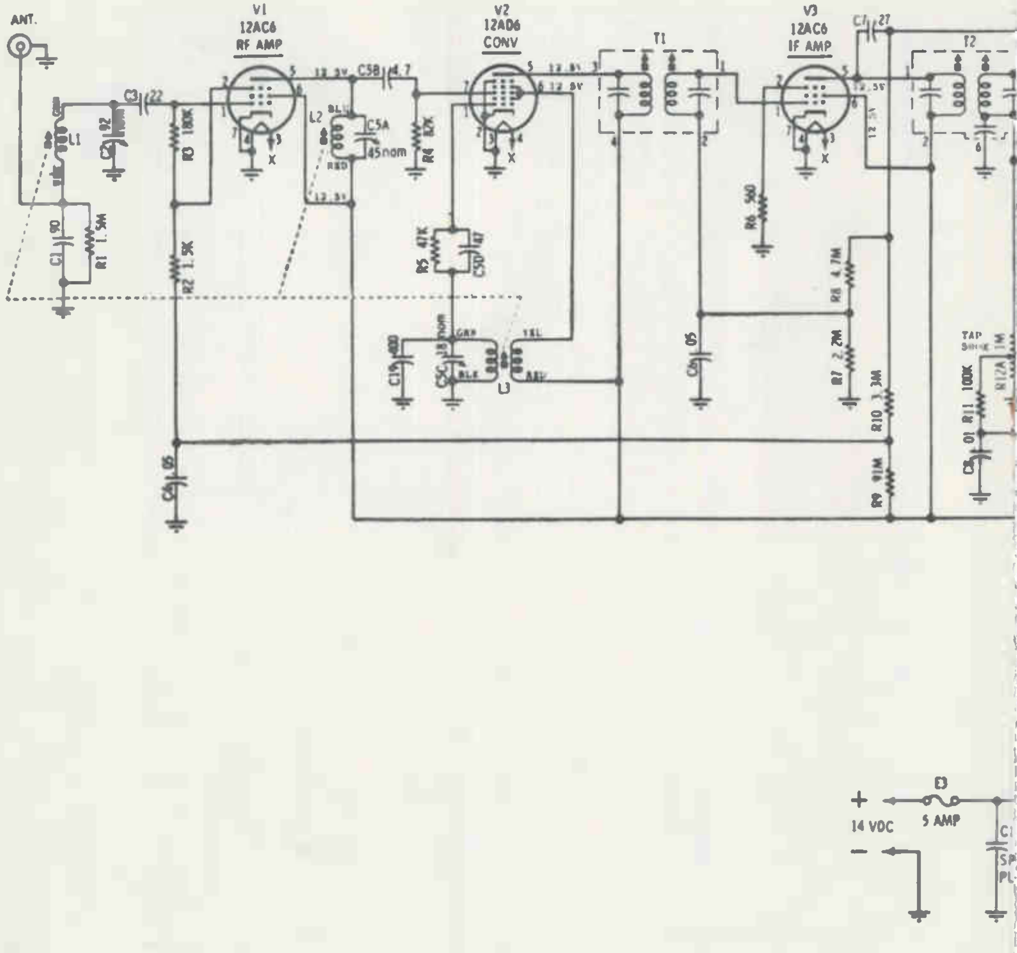


FIG. 8. A hybrid automobile radio,

transformer. Incidentally, notice that for the PNP transistors the avc voltage developed is positive; it is quite different from the avc voltage developed in vacuum tube receivers, which is always negative.

Insofar as the converter and first i-f stage of this receiver are concerned they are practically identical to those in the preceding receiver. In the converter stage the rf signal is mixed with the oscillator signal, and the i-f is produced. The i-f signal is amplified by the first i-f stage and fed to the second i-f amplifier. Now let's go through the second i-f amplifier and detector circuits to see how the second i-f amplifier is used to amplify both the i-f signal and also the audio signal from the output of the second detector.

The amplified signal from the first i-f stage is developed across the interstage i-f transformer T2. There will be an i-f signal voltage developed between terminals 2 and 3 of the secondary winding of T2. Terminal 3 is connected directly to the base of the second i-f transistor, and terminal 2 is connected to the emitter through the .05-mfd capacitor C11. Thus, the signal is applied between the emitter and the base of the transistor. The i-f signal is amplified by this transistor. The amplified signal is developed across the primary of the output transformer T3.

Notice that the second i-f stage is neutralized by the signal fed from terminal 4 of the output i-f transformer through the 12K resistor R12 and the 5.6-mmf capacitor C10 back into the base of the transistor. The signal fed through this circuit will cancel out any signal energy fed from the collector back into the input circuit through the transistor itself.

The amplified i-f signal current flowing through the primary winding of the output transformer T3 will induce a voltage in the secondary. When the polarity of the i-f signal voltage developed in the secondary is such that terminal 2 of the secondary is positive, terminal 3 will be negative, and current will flow from terminal 3 through the 2.5K volume control R15, through the diode detector CR1, through the secondary of T3, and back to terminal 3. The strength of this current will vary according to the modulation on the rf signal. Thus, an audio signal voltage will be developed across the volume control and across the .05-mfd capacitor C15. We are concerned with the audio signal voltage developed across the volume control.

Notice that the side of the volume control that connects to the .05-mfd capacitor C15 and terminal 3 of the output i-f transformer is grounded. The audio signal voltage is taken from the side of the volume control that is grounded and the adjustable arm on the potentiometer, and applied to the base and emitter of the second i-f amplifier. The further the adjustable arm is turned toward the end of the volume control that connects to the germanium diode, the greater the audio signal voltage will be. In any case, the audio signal voltage is fed from the adjustable arm, through the 1.5K resistor R19 and through the 1-mfd capacitor C14 to terminal 2 of the secondary winding of the interstage i-f transformer T2. The secondary of T2 has a very low impedance at the audio-signal frequency, so the audio signal is fed through the secondary winding of this transformer to the base of the transistor just as though there were a direct connection to the base. The emitter of the second i-f transistor is operated at ground potential for both the audio and i-f signals, because it is grounded through the 90-mfd capacitor C12. Therefore, since the end of the volume control is also grounded, we have the audio signal applied between the base and the emitter of the second i-f amplifier.

This audio signal applied between the base and the emitter of this transistor will cause an audio variation in the holes flowing from the emitter to the collector. Thus we will have an audio variation in the current flowing through the primary of T3. This current flows from the negative terminal of the battery (in the lower right corner), through the primary winding of the input audio transformer T4 to terminal 6 on the output i-f transformer to terminal 1, from terminal 1 to the collector of the second i-f transistor. Thus a varying audio current flows through the primary winding of the input audio transformer T4. This will induce an audio signal voltage in the secondary of T4 and this signal voltage is applied to the bases of the two transistors used in the push-pull output stage. The collector currents are combined in the primary winding of the output transformer T5, and the varying current through this winding will induce a voltage in the secondary of T5, which in turn will cause a current to flow through the transformer secondary and through the speaker voice coil.

Now the question that immediately comes to mind is why the two signals being amplified by the second i-f stage do not interfere with each other. As far as the audio signal is concerned, it will not cause any trouble by flowing through one winding of the i-f transformers T2 and T3, because they have such a low impedance at audio frequencies that the audio signal flowing through one winding will not induce any voltage in the other winding. As far as the i-f signal is concerned, the signal will not flow from terminal 2 of the interstage i-f transformer T2 back into the detector circuit because terminal 2 of this transformer is effectively at i-f signal ground potential. It is grounded, insofar as the i-f signal is concerned, through the .05-mfd capacitor C11 and the 90-mfd capacitor C12. It is not grounded as far as the audio signal is concerned, because the reactance of the .05-mfd capacitor C11 at audio frequencies is high compared to the low input impedance of the transistor. Similarly, the output circuit of the transistor amplifier is grounded insofar as the i-f signal is concerned, because terminal 6 is connected to ground through the .02-mfd capacitor C13 and the 90-mfd capacitor C12. So the i-f will not flow through the primary of T4.

However, in spite of these precautions to keep the two signals separated, there is some feed-through in a reflex circuit. The problem is not due to the signals getting mixed up, but rather to the fact that the second i-f amplifier is not perfectly linear. You will remember that we said that a non-linear device will act as a detector. Because there is some nonlinearity in the transistor, a certain amount of detection will occur. Thus there will be a weak audio signal developed in the second i-f stage which will flow through the primary winding of T4. The signal will then be amplified by the output transistors. Under normal operating conditions when the volume control is turned up to a reasonable level this does not cause any trouble, because the audio signal being fed from the detector back to the second i-f stage and then amplified by it, is usually so much stronger than the audio signal being produced by the second i-f amplifier acting as the detector, that the desired signal overrides the audio signal being produced in the second i-f stage. However, if you turn the volume control to a very low volume position it may cause distortion, and even if the volume is turned down completely there will usually still be some sound coming from the speaker. This is due to detection in the second i-f amplifier.

A number of manufacturers have put out sets using reflex circuits. The advantage of this type of receiver over the set using conventional stages is that one transistor can be omitted. Thus the five-transistor receiver shown in Fig. 5 will give you essentially the same performance as a receiver using six transistors in which no reflex circuits were used. The disadvantage of this type of receiver is in the feed-through that occurs due to detection in the i-f amplifier that is serving both as an i-f amplifier and an audio amplifier.

SUMMARY

Most modern portable receivers use transistors rather than vacuum tubes. Transistors are used because of their modest voltage and current requirements.

Transistor portables are generally smaller than vacuum tube portables. They can be made much smaller because transistors themselves are small, and because special miniature components are usually used in them. Also heat is not a big problem in these sets and therefore the parts can be put very close together.

Most transistor receivers use an etched circuit board. The etched circuit board is a phenolic board on which copper that has been put on the board makes the connections between parts so that no wires or leads are required to connect the various components together.

Portables may have as few as four transistors, but it is not uncommon for them to have 6 or more. Portable receivers using transistors are often made very small. Some of the smaller portables can actually be slipped into a man's shirt pocket. Some transistor portables are made somewhat larger in order to accommodate a better speaker to get better tone.

Often there will be two transistors used in a push-pull output stage in these receivers. The transistors used in the output stage are usually called a "matched pair." This means that the transistors are selected to have nearly identical characteristics in order to give best results in the receiver. If it should be necessary to replace one of these two transistors, you may find that you have to replace both of the transistors in the output stage with another matched pair. Most transistor manufacturers supply output transistors in matched pairs so the serviceman can replace both transistors in the output stage when he must do so.

Vacuum-Tube Automobile Receivers

Even though modern automobile receivers do not use vibrators, you can expect to service receivers using vibrators for many years. People who have radios in their cars usually want to keep the radio in operation as long as they have the car. Even when the original owner sells the car, he usually sells the radio along with it. Some cars are driven for many years before they are scrapped, so you can expect to service many old automobile radios.

Automobile receivers are designed to operate from the automobile electrical system. Most modern cars have 12-volt electrical systems, but older cars have 6-volt electrical systems. You can expect to get automobile receivers designed for 12-volt operation, and also receivers designed for 6-volt operation. If the receiver uses tubes, the tube types indicate the voltage the receiver operates from. If the tubes are all 6-volt tubes, then the receiver is designed for operation from a 6-volt electrical system, whereas if the receiver uses 12-volt tubes, then it is designed for operation on a 12-volt system.

In general, automobile receivers are capable of far superior performance to that of the average radio sold for home use. Automobile radios cost more money than ac-dc home receivers do, and since the receiver manufacturer is able to get more money for an auto receiver, he can afford to use better parts and to build a better receiver.

A schematic diagram of a typical automobile receiver designed for operation from a 6-volt electrical system is shown in Fig. 6. Notice that the tubes used in the set are all 6-volt tubes; that is, they operate with a heater voltage of 6.3 volts. This receiver has a number of circuits that you have not seen before, so we will go through a description of the various circuits and trace the signal through the receiver.

THE SIGNAL CIRCUITS

Automobile receivers are designed to operate from short antennas. Because the antenna is short, and because the signal picked up by the antenna is often not very strong, the receiver itself will usually have a fairly high gain. An rf amplifier stage is used between the antenna and converter in most automobile receivers in order to get good sensitivity and selectivity from the receivers.

In the circuit shown in Fig. 6, the signals picked up by the antenna flow through the 90-mmf capacitor C1 to ground. In parallel with the 90-mmf capacitor C1 we have the combination of the .006 mfd capacitor C2, the antenna coil L1, and the 90-mmf capacitor C3, forming a series resonant circuit. This circuit is tuned to one frequency by adjusting the inductance of L1. The inductance is adjusted when you tune in a station so that the circuit is resonant at the frequency to which the receiver is tuned.

You will remember that one of the characteristics of a series resonant circuit is that it has a very low resistance at the resonant frequency. Thus the signal picked up by the antenna will produce a current flow through C2, which has a very low reactance at the signal frequency, and then through the series resonant circuit. The signal current flowing through the series resonant circuit will produce a resonant voltage step up across L1 and across C3.

The voltage across C3 is applied between the grid and cathode of the 6BA6 rf amplifier. One side of C3 is connected directly to the grid and the other side of C3 is connected to the cathode of the tube through ground and the 150-ohm cathode resistor R2. Thus, we have the signal applied between the grid and the cathode of the 6BA6 tube.

The signal is amplified by this tube. In the plate circuit we have a parallel resonant circuit consisting of L2 and C4. This circuit is tuned to resonance by varying the inductance of L2. Notice that L1 and L2 are ganged so that they will be tuned to resonance at the same time.

You will remember that a parallel resonant circuit acts like a high resistance at resonance. Thus in the plate circuit of the 6BA6 rf amplifier we have a high resistance at the resonant frequency. This will result in a large signal voltage being developed across the parallel resonant circuit. Notice that one side of the parallel resonant circuit connects through the 5-mmf capacitor C5 to the number 3 grid of the 6BE6 converter tube. The other side of the parallel resonant circuit is connected to ground, insofar as the signal is concerned, through the .1-mfd capacitor C10. The cathode of the 6BE6 tube connects to ground through one winding on the oscillator coil. Thus the signal produced across the parallel resonant circuit in the plate circuit of the rf amplifier is applied between the grid and cathode of the 6BE6 converter tube.

In the converter stage we have a pentagrid mixer tube, which performs the two functions of generating a local signal and mixing this local signal with the signal from the rf amplifier. The oscillator coil L3 has its tank circuit tuned to resonance by C7. Notice that the oscillator coil L3 is a variable inductance, and this inductance is ganged to L1 and L2. The resonant frequency of the oscillator circuit is adjusted so that it operates at a frequency of 455 kc above the frequency to which L1 and L2 are tuned. Thus the oscillator signal is mixed in the converter stage to produce a 455-kc signal in the plate circuit of the 6BE6 converter tube.

The 455-kc signal flowing through the primary winding of the i-f transformer T1 induces a voltage in the secondary winding, and this voltage is applied between the grid and cathode of the 6BA6 i-f tube. The voltage is applied directly to the grid, and to the cathode through the .05-mfd capacitor C8 and through the 220-ohm cathode resistor R5.

The signal is amplified in the 6BA6 tube, and the signal current flowing through the primary of the output i-f transformer T2 induces a voltage in the secondary of this transformer. This voltage is applied to the diode plate connected to the number 6 pin of the 6AT6 detector-avc-audio amplifier. When this plate is positive, current will flow from the cathode of the tube to the diode plate, through the secondary of the i-f transformer, through the 68K resistor R8, through the 220K resistor R9 and back to the cathode of the tube. An audio signal voltage will be produced across the 220K resistor R9.

Notice that the cathode of the 6AT6 tube is not brought directly to ground. Instead, it connects to ground through the 18-ohm resistor R19. Current flowing through the triode section of the 6AT6 tube and through the 6AQ5 tube must flow from ground through R19 to the cathode of the 6AT6 and through both R19 and R18 to the cathode of the 6AQ5. In flowing through R19 these two currents will produce a voltage drop across this resistor having a polarity such that the end that connects to the cathode of the 6AT6 tube will be positive. Thus the cathode of the tube is positive with respect to ground. As far as the detector action is concerned, this does not cause any difficulty because the 220K detector load resistor R9 is connected back to the cathode of the 6AT6 tube. Therefore, insofar as the detector section of the tube is concerned, there will be no potential difference between pin 6 of the tube and the cathode unless there is a signal applied to the detector circuit.

However, notice that from pin 6 of the tube to pin 5, which is the other diode plate, there is a 27-mmf capacitor C12. The signal from the secondary of the output i-f transformer is fed to the diode plate that connects to the number 5 pin through the capacitor. This diode plate connects to ground through the 1-meg resistor R12. Thus with no signal applied, the diode plate will have no voltage applied to it, and will therefore be at ground potential, but the cathode will be slightly positive. This means that the diode plate will be negative with respect to the cathode.

If a weak rf signal is picked up by the receiver it will be amplified and then fed through the 27-mmf capacitor C12 to the diode plate connected to pin number 5. If the amplitude of this rf signal is low, it will not be enough to drive the plate positive with respect to the cathode, and there will be no current flow from the cathode to this diode plate. On the other hand, if the signal is strong enough, then the plate connected to the number 5 pin will be driven positive with respect to the cathode. When this happens, current will flow from the cathode to the number 5 pin and through the 1-meg resistor R12 to ground, and then through the 18-ohm resistor R19 back to the cathode of the tube. In flowing through R12, the current will develop a voltage having a polarity such that the end that connects to the number 5 pin is negative. This voltage is used as the avc voltage. It is filtered by the combination of the 1-meg resistor R6 and the .05-mfd capacitor C8, and then fed to the grid of the rf tube through the 470K resistor R1, to the control grid of the mixer through the 100K resistor R3, and to the grid of the i-f amplifier through the secondary of the input i-f transformer.

The important difference to notice in this i-f system is first that the avc voltage is not developed by the same diode that is used as the detector. One diode in the 6AT6 tube works as the detector, the other develops the avc voltage. The second important thing to notice is that the avc diode is biased so that it does not begin to work until the signal reaches a certain strength. In other words there is no avc voltage developed on very weak signals; the avc voltage will be developed only when the signal is strong enough to overcome the bias placed on the avc diode. This type of avc is called *delayed avc.*

Now, tracing the audio signal, we found that the audio signal was developed across the 220K resistor R9. This signal is fed through the .01-mfd coupling capacitor C11, through the volume control, and through R11 to ground. Since the cathode of the tube is operated slightly positive with respect to ground, the grid return is made directly back to ground so that the cathode will be positive with respect to the grid, or in other words, the grid negative with respect to the cathode. Thus, the bias voltage for the triode section of the 6AT6 tube is developed across the 18-ohm resistor R19.

The audio signal fed to the grid of the 6AT6 tube is amplified by the tube. The amplified signal current flows through the 100K plate load resistor R16, producing an audio signal voltage across it. The end of R16 that connects to the plate of the 6AT6 is connected to the grid of the 6AQ5 through the .01-mfd capacitor C15. The other end of R16 is connected to ground through the 10-mfd section of the filter capacitor C18. The cathode of the 6AQ5 is connected to ground through the 20-mfd section of the filter capacitor C18; thus the signal voltage developed across R16 is applied between the cathode and grid of the 6AQ5.

The signal will be amplified by the 6AQ5, which is a power amplifier, and the current variations flowing through the primary of the output transformer will induce a voltage in the secondary. This voltage will cause current to flow through the voice coil to operate the speaker.

Notice that there is a ground connection on one side of the voice coil, and on the other side there is a lead going to the .1-mfd capacitor C16 and through this capacitor to the 4700-ohm resistor R15. The 4700-ohm resistor connects to the .1-mfd capacitor C13, which is grounded, and to the junction of R11 and the volume control R10. This is a feedback circuit which is used to eliminate distortion. This is called inverse feedback; it is a degenerative type of feedback which opposes the signal voltage across the volume control.

Let's trace out this feedback circuit and see how the signal fed back opposes the volume-control signal. Let's consider an ac signal across the volume control. Suppose at a given instant that this signal is positive with respect to ground. Thus we have a positive signal voltage applied to the grid of the triode section of the 6AT6 tube and this causes the current through the tube to increase. When the current through the triode tube increases, the voltage drop across R16 will increase, meaning that the voltage between the plate of the 6AT6 tube and ground will decrease. Thus a positive-going signal in the grid circuit produces a negative-going signal between the plate of the tube and ground. When this negative-going signal is applied to the grid of the 6AQ5 tube, it will cause the current through this tube to decrease. When this current decreases, the voltage drop across the primary of the output transformer T3 will decrease, meaning that the plate voltage on the 6AQ5 tube will increase. You will remember that you already knew that a vacuum tube inverts the signal phase 180 degrees. Here we have two stages, the 6AT6 inverts the signal phase so that a positive-going input signal produces a negative output signal. In the 6AQ5 the negative input signal produces a positive output signal so that in the plate circuit of the 6AQ5 tube we have the same signal phase as we had at the volume control.

Now you will remember that an induced voltage opposes the voltage producing it. Thus, if the signal is going positive at one end of the output transformer and the primary and secondary windings are wound in the same direction, then the signal at the same end of the secondary winding will be going negative. This is the arrangement we have here, and a negative-going signal is fed back to the volume control circuit. This signal subtracts from the input signal. You will remember that we have already discussed inverse feedback showing how it can eliminate distortion produced in an audio stage.

Incidentally, while we are discussing this circuit it might be well to point out that usually when an output transformer burns out, you do not have to be particularly concerned about the polarity of the secondary leads when you install a replacement. One of the primary leads is usually color-coded blue and the other red. The blue lead is connected to the plate of the tube and the red lead to B+. The secondary leads are usually enamel-covered wire without any insulation on them other than the enamel. These two leads are connected to the speaker voice coil. Ordinarily it does not make any difference which lead is connected to which side of the speaker voice coil. However, with this inverse feedback system, if you connect the secondary of the output transformer with the wrong polarity you'll have regenerative feedback instead of degenerative feedback and the chances are that the audio stages will go into oscillation. If you should happen to replace the transformer in a receiver using this type of circuit and the set goes into oscillation, the remedy is to reverse the secondary connections from the output transformer so that you'll get degenerative feedback instead of regenerative feedback.

THE POWER SUPPLY

The power supply used in this receiver is quite different from the power supplies you have seen in preceding receivers because it is designed to give a high dc output voltage from a low dc input voltage. Let's trace the circuit from the battery terminal on through the power supply.

The battery itself is not shown on the diagram, because it is not part of the radio. The connection to the battery is shown in the middle of the lower part of the diagram. Only one connection is used because one terminal of the storage battery in an automobile is connected to the frame of the car. Automobile radios are built in a metal case, so when the case is mounted in the car the connection to one side of the battery is automatically made. In most cars the negative terminal of the battery is grounded, but in some cars the positive terminal is grounded.

In this particular receiver the lead to the ungrounded battery terminal connects through a fuse to a receptacle on the receiver. At the other end of this receptacle is a label D.L. This is for a dial light, not shown on the diagram. Tracing the circuit from the terminal marked BAT we find a lead going to a device marked "spark plate." We'll come back to this in a minute. The lead also goes to the coil L4, and from L4 through the On-Off switch S1, through L6 to the center terminal on the primary winding of the power transformer T4. Current flows from the center tap on the primary winding through one half of the winding to the lead identified as

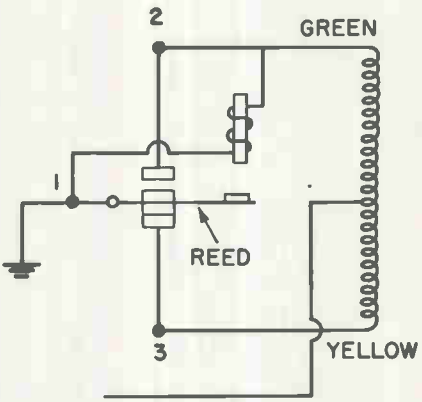


FIG. 7. How a vibrator works.

yellow, and from there to terminal 3 on the vibrator. From terminal 3 it flows to a contact in the vibrator which rests against a device called a reed. In the position shown in the diagram, terminal 3 makes contact with the reed so that current flows from terminal 3 to the reed and then to terminal 1 and to ground, which is connected to the other terminal of the battery.

The reed in a vibrator is made of a spring-type material. It is anchored on one end and is free to vibrate on the other end. A sketch of a vibrator circuit showing the contacts and the reed is shown in Fig. 7.

In this receiver, at the same time that current is flowing through the lower half of the primary winding of the power transformer, there is also a small current flowing through the upper half of the primary winding. This current flows through a coil in the vibrator connected between terminals 2 and 1. This coil is mounted near the reed. When the coil is energized, it becomes a magnet and attracts the reed over it. When the reed is pulled over to it, it hits the contact connected to terminal 2 on the vibrator. This shorts out the coil connected between terminals 2 and 1 and causes a much higher current to flow through the upper half of the primary, between the center tap and the terminal marked green. At the same time, since the current can no longer flow from terminal 3 of the vibrator to the reed, the circuit through the lower half of the transformer winding will be opened. When this happens, the magnetic field built up by the current in the lower half of the primary begins to collapse. This, of course, will induce a voltage which tries to oppose this collapse in the field.

The vibrator reed moves back and forth, making contact first to the terminal connected to terminal 3 and then to the terminal connected to terminal 2, and current flows first through the lower half of the primary winding and then through the upper half. Notice the current when it flows through the lower half of the winding will be flowing in the opposite direction to what it will be flowing when it flows through the upper half. Thus we have a current flowing first in one direction in the primary winding and then in the other direction. Since the primary winding is inductively coupled to the secondary winding, this change in current in the primary winding will induce a voltage in the secondary winding.

In the secondary circuit we have a full-wave rectifier. The rectified voltage is filtered by the filter network consisting of the 15-mfd input filter capacitor and the 10-mfd output filter capacitor along with the 1000-ohm filter resistor R20. The rectifier circuit and the filter network are similar to the full-wave circuits you have already studied.

Now let's go back to the part called a spark plate that is connected across the input circuit. The spark plate is, in effect, a special type of capacitor. Its purpose is to keep rf "hash," which is the name given to noise produced by the vibrator out of the automobile electrical system. Noise that gets into the electrical system would be radiated and picked up by the antenna and reproduced in the receiver. The coils L4, L5, and L6, are radio-frequency chokes which are also used to keep vibrator hash out of the electrical system.

The vibrator was usually considered one of the weak points in the older automobile radios. Vibrators sometimes stick, and once a vibrator sticks, the current flow through one half of the primary winding of the power transformer would become very high and usually blow the fuse in the receiver. This often happened as soon as the radio was turned on. In such a case, if you replace the fuse the set might work for a while and then perhaps the next time you turn it on the fuse will blow again. If you run into this type of trouble in an auto radio it is usually worthwhile to try a new vibrator.

Often vibrators became noisy because of burned contacts. When this happens the only remedy is to replace the vibrator.

SUMMARY

Practically all automobile receivers designed for operation from a 6-volt electrical system use a vibrator. You'll find some vibrator radios in cars with 12-volt electrical systems, but most radios in cars with 12-volt electrical systems use 12-volt tubes or transistors, or a combination of tubes and transistors. Let's look at one of these hybrid receivers.

A Hybrid Automobile Receiver

A hybrid automobile receiver is a receiver that uses both tubes and transistors. Tubes are usually used in the rf, mixer, i-f, and second detector stages. The output stage in a hybrid receiver is usually a transistor stage. The first audio stage may use either a tube or a transistor.

A typical hybrid receiver is shown in Fig. 8. Notice that a transistor is used in the output circuit, but all other stages in the receiver use vacuum tubes.

Let's look at the power supply and then the signal circuits.

THE POWER SUPPLY

Notice that the input of the receiver is supposed to connect across 14 volts dc. Let's see why it can be used with a 12-volt storage battery. First, let's consider a 6-volt battery. When we refer to a 6-volt storage battery we're speaking of a lead storage battery with 3 cells. Actually a fully charged lead cell has a voltage of about 2.2 volts, so the so-called 6-volt storage battery, which has three cells connected in series, actually has a voltage of about 6.6 volts when it is fully charged. Furthermore, in order to charge a 6-volt storage battery, the voltage developed by the generator in the automobile must be somewhat above 6.6 volts. When an automobile battery is being charged, the voltage is actually about 7 volts. In a 12-volt battery the actual battery voltage is over 13 volts when the battery is fully charged, and often is above 14 volts when the generator is charging the battery. However, since the practice of calling a storage battery with 3 cells a 6-volt battery is commonly accepted, the automobile manufacturers simply called a storage battery with 6 cells a 12-volt battery even though the normal voltage is over 12 volts.

The tubes used in this receiver are all designed to operate with a heater voltage of 12.6 volts. The voltage applied to these heaters is usually slightly over this value when the car is running and the battery is being charged. The heaters are operated by connecting them directly across the input from an automobile electrical system. Therefore all of the tube heaters are in parallel. Having slightly higher than normal heater voltage does not seem to have any noticeable effect on the tubes.

As far as the B supply is concerned, these tubes are designed for operation on low dc plate and screen voltages. There is no vibrator or any other device in the set to step up the voltage. The plates and screens are simply operated directly from the 12-volt supply. In the receiver you'll see a dual electrolytic capacitor marked C16. One section is a 100-mfd capacitor, and the other section a 500-mfd capacitor. The 500-mfd section is used in conjunction with the iron-core choke, labeled T5, as a filter in the screen circuit of the 12K5 driver tube and in the transistor output stage. The purpose of this filter choke and capacitor is to keep audio current variations out of the B supply circuit for the other tubes. The transistor operates on a low voltage. To produce a reasonable amount of audio power there must be a substantial current variation through the transistor. If there were no filter network to keep this variation out of the plate and screen circuits of the other tubes in the set, this could cause audio feedback, which might result in oscillation in the receiver. The 100-mfd section of the electrolytic capacitor is used as the filter of the plate circuit of the 12K5 driver and in the plate and screen circuits of the other tubes.

By comparing the power supply of this receiver with the power supply of the automobile receiver we discussed in the preceding example, you can immediately see the advantage of this type of receiver. Not only have we eliminated the vibrator, which was always a troublesome part, but also we have eliminated the power transformer and the rectifier tube. In doing so we have obtained not only a more economical power supply, but also one that is far more reliable and has fewer parts in it to break down.

You might wonder why one transistor is used in a receiver with five vacuum tubes. The answer to this question is not too difficult. In order to produce a reasonable amount of audio power from a radio receiver, we must have a reasonably high power input to the power-amplifier stage. In a radio receiver designed to operate from a power supply of 100 volts or more, we could have 10 watts input power to the power amplifier if the voltage is 100 volts and the current .1 amp. (You will remember that the power is equal to the product of the voltage times the current.) However, in a receiver designed to operate from an input voltage of around 12 volts, in order to have a power input of about 10 watts, we have to have a current of almost 1 amp in the power amplifier stage. It is difficult to build tubes that can handle such high current. Transistors are used in the output stages of hybrid receivers simply because it is easier to get the required audio output from a transistor operating on a low voltage than it is from a vacuum tube. On the other hand, the tubes work very nicely in the other stages; they usually have a higher gain than transistors, and in addition are more economical than transistors. Hence tubes are used in all stages except the output stage.

Now let's trace the signal circuits through this receiver, paying particular attention to those circuits that are different from circuits we have already discussed.

THE SIGNAL CIRCUITS

The input circuit and the rf amplifier used in this receiver are similar to circuits used in the automobile receiver we discussed in the preceding example. However, the converter stage is a little different. Notice that the 47K oscillator grid resistor R5 is connected in parallel with the 47-mmf grid capacitor C50. Usually the capacitor is connected from the oscillator grid to the oscillator tank circuit, and the grid resistor is connected from the oscillator grid to ground. However, insofar as the dc voltage developed across the grid resistor is concerned, it makes little difference whether it is connected from the grid of the tube directly to ground or in parallel with the grid capacitor. You'll notice that the circuit is completed to ground through the oscillator coil. Since the coil has a low resistance and the current flowing through the grid resistor is a dc current, this current flowing through the oscillator coil has very little effect on the operation of the oscillator circuit. In fact, if the connection for the oscillator grid resistor was changed so that it was connected directly from the oscillator grid to ground, you would not be able to notice any difference in performance of the receiver.

In most of the oscillator circuits we have seen previously, the oscillator feedback coil, which feeds the energy back into the oscillator tank circuit, has been located in the cathode circuit of the mixer. However, in this stage, it is connected in the circuit to the No. 2 and No. 4 grids. You will remember that in a pentagrid converter, such as the 12AD6 converter tube, the No. 2 grid serves as the oscillator plate, and the No. 4 grid serves as the screen grid. The screen-grid current flowing through the oscillator feedback winding has no effect on the operation of the oscillator. However, there will be a signal current from the oscillator plate, which is the No. 2 grid. This current will flow through the feedback winding on the oscillator coil and set up a field, which will be coupled to the oscillator tank coil. Energy from the tank coil will be fed back into the grid circuit in order to sustain the oscillation.

The i-f amplifier is similar to those we have discussed previously with the exception of the way the signal is taken off the plate circuit. The signal is fed through the 27-mmf capacitor C7 from the plate of the i-f tube to the diode plate that connects to the number 1 pin of the 12F8 detector-avc-first audio stage. This signal is used to develop the avc voltage for the receiver. Let's look at this circuit and see how it works.

First, tracing the circuit from the number 1 diode plate you will see that there are two dc paths. One is through the 4.7-meg resistor R8 and the 2.2-meg resistor R7 to ground. The other path is through the 3.3-meg resistor R10 and the 91-meg resistor R9 to B+. Thus we have a voltage-divider network consisting of R7, R8, R10, and R9 connected from B— to B+. However, because of the size of the resistors, particularly the 91-meg resistor R9, the current that flows through the divider is very small.

When the signal applied to the diode plate 1 swings positive, the plate will attract electrons from the cathode. These electrons will flow through R8 and R7 to ground and then back to the cathode of the 12F8. In flowing through R8 and R7, they will set up a voltage drop across these resistors having a polarity such that the junction of R8 and R10 will be negative with respeet to ground. The part of the negative avc voltage developed across R7 is fed to the 12AC6 i-f amplifier and used to control the gain of this stage. The voltage at the junction of R9 and R10 is fed to the grid of the 12AC6 rf amplifier to control the gain of this stage. As in other avc systems, the amplitude of the avc voltage developed will depend upon the signal strength. The stronger the signal, the greater the negative voltage that will be developed and fed back to the i-f and rf stages to control the gain of these stages.

There is another interesting circuit in the first audio stage of this receiver. Notice that the audio signal developed across the volume control is fed to the grid of the pentode section of the tube through the .01-mfd capacitor C9. The grid return of the stage, however, is not directly back to ground as in most first audio stages. Instead, the grid is connected through the 3.3-megohm grid resistor R15 to the junction of R13 and R14. To see why this circuit is used, let's consider the detector stage.

When the diode plate connected to the number 6 pin is driven positive by the signal, current flows from the cathode of the tube to this diode plate, through the secondary of the i-f transformer and then through the volume control back to the cathode. There will be a small current flow also through R13 and R14, but most of the current will flow through the volume control because its resistance is lower than the resistance of R13 and R14 in series. The electrons flowing through the volume control will develop a voltage across the control having a polarity such that the end of the control that connects to the i-f transformer is negative. This voltage is also present across R13 and R14 and the portion of the voltage appearing across R13 is applied to the grid of the pentode section of the 12F8. This is a true form of automatic volume control. The amplitude of the voltage across R13 will depend upon the strength of the signal. With a strong signal this voltage can be quite high and the negative voltage fed to the grid of the pentode section of the 12F8 will reduce the gain of the first audio stage. If the signal, on the other hand, is weak, there will be very little voltage developed across R13, and the pentode section can operate with maximum gain.

The advantage of an arrangement such as this is that if the strength of the signal suddenly changes, as it might when the car is passing under a bridge or traveling over mountains, not only will the gain of the rf and i-f stages be varied to compensate for the change in signal strength, but also the gain of the first audio stage will be automatically varied in order to keep the output volume from the receiver as close to constant as possible.

Notice the 12K5 driver stage. The signal is applied to the No. 2 grid rather than the No. 1 grid. The No. 1 grid is connected to B+. This is done to accelerate the electrons flowing from the cathode to the plate. This tube was designed specifically for this type of circuit when the plate voltage is low.

The output stage in this receiver uses a transistor. At first glance you might think that it is a common-collector circuit because the collector is grounded. However, this is not true; the circuit is a common-emitter circuit.

Transistors such as the one used in this receiver have the collector connected directly to the metal case in which the transistor is housed. The reason for this is to provide the best possible method of heat dissipation. Since a transistor operating on a low voltage must pass a comparatively high current in order to develop any appreciable amount of power, there must be some good method of getting rid of the heat produced within the transistor, or the junction temperature will become excessive and the transistor will be destroyed. In use, transistors of this type with the collector connected directly to the transistor case, are bolted directly to the radio chassis. This is called a heat sink, since it provides a means of getting rid of the heat developed in the transistor. This explains why the collector must be grounded in the receiver; the transistor itself is made in such a way that mounting it in place automatically connects the collector to ground.

If you should have occasion to service any of these receivers, do not try to operate them without the transistor bolted to the chassis. If you do so you probably will not get a good contact between the transistor and chassis and even though the contact might be good enough to allow an electrical connection, the chances are that heat will not be dissipated as rapidly as it should be, and the transistor may overheat and be destroyed.

LOOKING AHEAD

Some automobile manufacturers are using radios that have been completely transistorized. The advantage of this type of radio over one using vacuum tubes is that the current requirements of the receiver are lower than the current requirements of a hybrid receiver using tubes and transistors. With the automobile electrical systems already greatly overloaded by all of the accessories connected to them, reducing the current requirements of the radio presents a very real saving to the automobile manufacturers. However, in general, automobile receivers that use transistors throughout are more expensive than hybrid receivers, so some manufacturers are offering two sets, one a completely transistorized receiver and the other a hybrid receiver. It is quite likely that both types will be made for some time to come. You can expect to encounter many hybrid receivers in auto radio servicing.

We are not going to go into detail on an all-transistorized automobile receiver because they are practically identical to the portable transistor receivers. In fact, some manufacturers who have an all-transistor automobile receiver have made it so that it can be easily moved from the car and operated from a separate battery and used as a portable.

Lesson Questions

Be sure to number your Answer Sheet 24B-2.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What is a hybrid receiver?

2. Why is it so easy to burn out the filaments of battery-operated tubes like those used in the receiver shown in Fig. 1?

3. What important rule must a serviceman observe when working on three-way portable receivers?

4. Why will the receiver shown in Fig. 3 start operating almost immediately when it is turned on and operated from an ac power line, whereas the receiver shown in Fig. 2 will not start operating for about thirty seconds?

5. If you are servicing a set like the one shown in Fig. 3 and you find that the receiver will operate from the power line, but does not operate from batteries even though the battery voltages are normal, what tube would you suspect to be causing the trouble?

6. What is the purpose of the overload diode in the circuit shown in Fig. 4?

7. In the receiver shown in Fig. 5, which stage acts as the first audio stage?

8. What is the name given to the avc system used in the automobile receiver shown in Fig. 6?

9. If you are servicing an automobile receiver like the one shown in Fig. 6, and find that the fuse blows as soon as you turn the set on, what part might be causing the trouble?

10. In what type of circuit is the power transistor used in the power output stage in the receiver shown in Fig. 8?

HONESTY

That old proverb, "*Honesty is the best policy,*" is just as true today as ever. Any firm which depends upon repeat business cannot exist for long without following this policy; any man who deals with other people cannot afford to disregard it.

Strict observance of the law will keep a man out of jail, but that does not necessarily make him an honest man. Honesty goes far beyond the law; it involves a careful regard for the rights of others, a truthfulness and sincerity in dealing with others, and a fairness and trustworthiness in matters involving property or business.

It is not enough to act so others will think you are honest; you yourself must know that you are playing the game fair and square if you are to enjoy that real satisfaction associated with absolute honesty.

Be honest, and your reputation will take care of itself. Let your spoken word, your slightest implied action be as good as your signature on a legal contract, and you will enjoy those things which no amount of money can buy—happiness, success, and the respect of your fellow men.

J. E. Smith.

HOW TRANSISTORS ARE USED IN PRACTICAL CIRCUITS

25B
(Same as 25FR-4)

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE No. 25

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ 1. Introduction .... Page 1

☐ 2. Low-Frequency Amplifier Circuits .... Pages 2-7

In this section, you study basic single-stage transistor amplifiers and learn how they are adaptable to various circuit applications.

☐ 3. Multistage Transistor Amplifiers .... Pages 7-14

Various types of low-frequency amplifier circuits and coupling methods are described here. You also study circuits employing some of the unusual properties of transistors.

☐ 4. High-Frequency Amplifiers and Oscillator Circuits .. Pages 15-21

Transistors can be used to amplify high-frequency signals and to generate high and low-frequency signals. This section is devoted to a study of circuits of these types.

☐ 5. Transistor Radios .... Pages 21-25

Here you study actual circuits employed in transistorized receivers.

☐ 6. Transistor Servicing Methods .... Pages 26-28

Many servicing procedures used in vacuum tube receivers cannot be used to check and repair transistor circuits. In this section, you learn the precautions that should be taken when servicing transistorized equipment.

☐ 7. Answer Lesson Questions.

☐ 8. Start Studying the Next Lesson.

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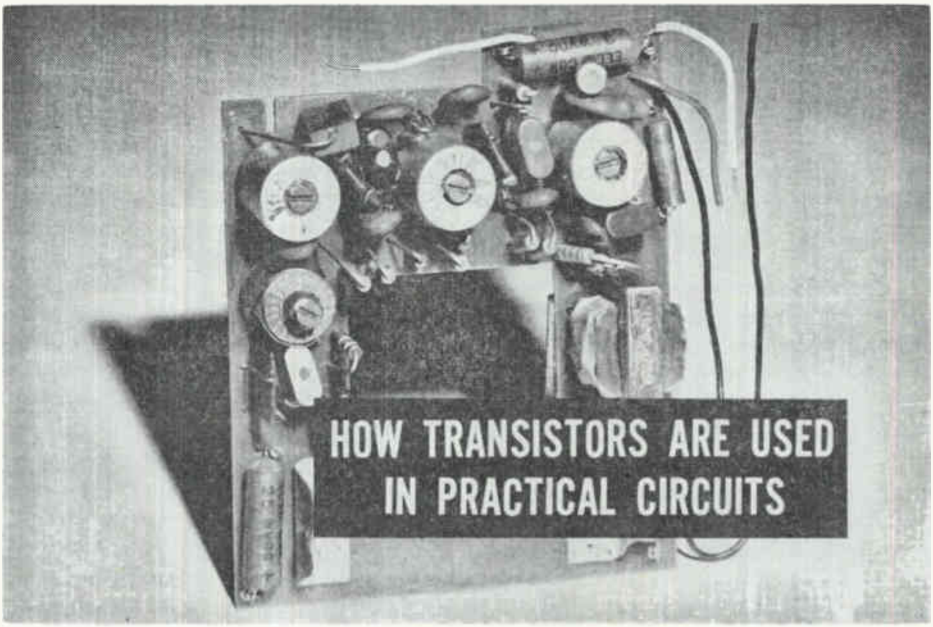


BECAUSE the transistor is a comparatively new development, few circuits have been designed that fully utilize their unusual characteristics. While most of the circuits in which transistors are now used are merely copies of vacuum tube circuits, this does not mean that no new circuits have been developed. As you will learn later, the unusual properties of the P-N-P and N-P-N junction transistors can be used, for example, to produce push-pull operation in a single-ended audio output stage without using input or output transformers.

Circuit designers have only begun to discover the possibilities of the transistor in all types of electronic equipment. Many new transistor types also will be developed which will produce even more unusual circuit actions. As you will learn, the two transistor types now being used, junction and point-contact, operate satisfactorily in many circuits which formerly used vacuum tubes, such as low- and high-frequency amplifiers and oscillators. In this lesson, we will describe examples of each type, and later we will briefly analyze the circuits in a typical transistorized radio. You will notice that there are variations in the transistor circuits as compared to corresponding vacuum tube circuits, but that the basic operation is the same.

The method of servicing transistorized equipment also will be described. To make the equipment as small as possible, the parts are miniaturized and mounted on a printed circuit board. The servicing methods are somewhat different from those used in an ordinary vacuum tube receiver.

Photo Courtesy I.D.B.A., Inc.

Low-Frequency Amplifier Circuits

In the previous lesson, you learned that transistors can be connected in three different ways. These are grounded-base, grounded-emitter, and grounded-collector. These three transistor circuits resemble the grounded-grid, grounded-cathode, and grounded-plate (cathode follower) vacuum tube circuits respectively.

This resemblance is limited however, to the input and output voltage phase relationships, the high input and low output impedances of the grounded-collector, and the low input, high output impedances of the grounded-base circuit. The greatest value of the similarity is in remembering the voltage phase relationship.

Any of the three circuit connections may be used as voltage amplifiers, such as in the audio systems of radio receivers, hearing aids, the sound section of television receivers, record players, public address amplifiers, and microphone and oscilloscope preamplifiers. However, because the characteristics of point-contact and junction transistors differ, one method may be more satisfactory than another—depending on the type of transistor used.

The input and output impedances of the transistor stages, as with vacuum tube stages, are important considerations in the design of all types of transistor circuits. For example, the input impedance of a grounded-base circuit is approximately 90 ohms, and the output impedance approximately 100,000 ohms. Because the impedances are low, impedance matching and maximum gain from the stage are difficult to obtain.

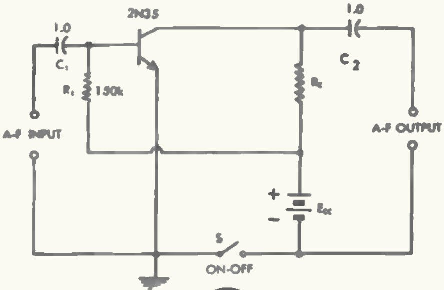
The input and output impedances of the grounded-emitter circuit are approximately 600 and 20,000 ohms, while the impedances of the grounded-collector circuit are approximately .1 megohm and 100 ohms. As you can see, these values, although still low, more nearly correspond to the impedances in the usual voltage amplifying circuits. The grounded-emitter circuit has a higher gain than a grounded-base circuit. Thus, the moderate values of the input and output impedances and the higher gain of the grounded-emitter circuit makes it more desirable for amplifier stages than either the grounded-base or grounded-collector circuit. Like the cathode-follower vacuum tube circuit, the grounded-collector transistor circuit has a high input impedance, a small power gain, but no voltage gain.

Before we discuss practical transistor circuits, let us study the three basic circuits in more detail and point out the main characteristics of each connection method. If you understand how these circuits work, you should have no trouble understanding the practical transistor circuits which we will discuss later in the lesson.

GROUNDED-EMITTER AMPLIFIER

A basic grounded-emitter amplifier is shown in Fig. 1A. This stage uses a Sylvania 2N35 general purpose N-P-N junction transistor. Typical operating conditions for the amplifier stage are shown in the chart in Fig. 1B. Notice first that the voltage gain of the stage depends upon the battery voltage and collector resistor values. The higher the voltage, the higher the collector or output resistor value that can be used. Thus, because the collector current change occurs through a higher resistance, a higher voltage gain will be produced in the output.

The value of the load resistor can-



A

Battery Voltage (E_{cc})	Current Drain (d-c μa)	Collector Resistor (ohms)	Input Impedance (ohms)	Input* Voltage (rms volts)	Output Voltage (rms volts)	Voltage Gain
1.5 v	100	6,500	625	0.005	0.16	32
3.0	200	7,500	350	0.011	0.60	54.6
4.5	225	6,500	500	0.0285	1.20	42.2
6.0	225	10,000	400	0.019	1.50	79
22.5	100	100,000	450	0.013	4.80	369

*Maximum value before output distortion.

B

FREQUENCY (CPS)	30	100	1000	5000	10,000	20,000
RESPONSE (% of Maximum Voltage Output)	97.5	98	100	97.5	87	36.6

C

Courtesy Sylvania Electric Products

FIG. 1. Grounded-emitter amplifier and performance data.

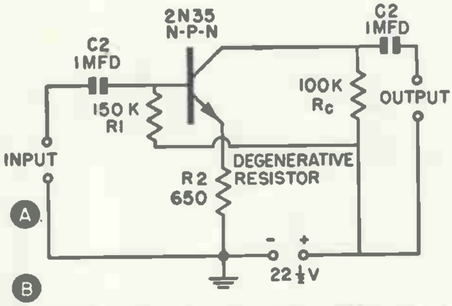
not be increased indefinitely to produce a higher output voltage. The reduction in collector voltage and the shunting effect of the transistor collector resistance tend to reduce the gain when the load resistance becomes too high. In this respect the transistor amplifier is similar to a resistance-coupled vacuum-tube amplifier. You will recall that the value of the plate load resistor also cannot be increased beyond a certain value because the increase in resistance causes a decrease in plate voltage. The shunting effect of the plate resistance on the high value load resistor is also more pronounced. Therefore, the effective output resistance of the vacuum tube stage can never be higher than the value of the plate resistance.

Referring again to the chart, notice that the transistor operates at a very low battery voltage. The input voltage value also is extremely small. As in any low-level voltage amplifier, too strong an input signal will overload the stage and cause distortion. Thus, the level of the input signal must always be kept within that recommended by the transistor manufacturer.

A higher input signal can be applied if the supply voltage is increased. We can use the two horizontal lines having a 6500-ohm load resistor as an example. With the same collector resistance value, notice that the maximum input voltage is higher for a battery voltage value of 4.5V than for 1.5V. In general, the higher the battery voltage and the lower the load resistor, the higher the input signal that can be applied without distortion.

There is a closer link between input and output circuits in a transistor stage than in a vacuum tube stage that does not employ feedback. Changes in the output circuit of the transistor stage will also affect the input impedance and the operating conditions. In the chart, note that the input impedance changes with the supply voltage and the collector, or load resistor values.

As stated previously, the input impedance of a transistor stage is much lower than that of a vacuum tube amplifier. Hence, the transistor circuit must be designed to maintain the frequency response and prevent loading the preceding stage too heavily. For example, in coupling between two vacuum-tube resistance-coupled stages, the grid circuit impedance of the second stage is generally so high that there is very little loading effect



FREQUENCY(CPS)	50	100	1000	5000	10,000	50,000
RESPONSE	99	100	100	94.7	85.5	27

FIG. 2. Grounded-emitter circuit with feedback.

on the first stage. In a two-stage transistor amplifier, however, the input impedance of the second stage may be very low and has a heavy loading effect on the preceding transistor. Some form of impedance coupling (from high impedance to low impedance) must be used between stages, or the output impedance of the first stage must be made to have a very low value. Various coupling methods will be discussed later.

In the usual vacuum tube stage, we are accustomed to using a high value of grid resistor between grid and cathode to serve as a light load on the preceding vacuum tube amplifier and as a grid return path. The input resistor used in this transistor stage has very little effect on the input impedance because of the low impedance of the transistor itself. Resistor R1 in Fig. 1A, has a much higher value than the input impedance of the stage. Its only purpose is to establish the proper base bias and to serve as a limiting resistor on the collector current.

As you learned in an earlier lesson, increasing the feedback in a vacuum tube amplifier produces an increase in input impedance. The same idea can be used in a transistor circuit to raise the input impedance to a more suitable value.

A degenerative circuit can be formed, as shown in Fig. 2, by adding a small series resistor, R2, between the emitter and ground. The action of the resistor is similar to the effect produced by an unbypassed cathode resistor in a vacuum tube circuit. A signal applied to the input of the transistor amplifier causes a change in emitter current through the series resistor R2. The current change develops a voltage variation across the resistor that is out of phase with the applied signal. Thus, the effective base-to-emitter voltage is less than the applied voltage.

Degeneration, as is to be expected, is helpful in equalizing the frequency response in any of the basic transistor circuits. In addition, with degeneration, a higher amplitude signal can be applied before the transistor stage is over-driven, but the stage gain is lower.

Frequency Response. The factors that affect the frequency response of a vacuum tube amplifier also affect the response of a transistor stage. The input impedance, the value of the series coupling capacitor, and any type bias or supply voltage filter combination influence the low frequency response, while the stray and internal capacities and the input and output impedances affect the high frequency response.

The degenerative circuit in Fig. 2, because of its higher input impedance, has a better low frequency response than the circuit in Fig. 1. In fact, degeneration can cause the input impedance to increase by a factor of 20 or more. However, to obtain the same output signal a higher input must be used, just as in a vacuum tube circuit.

When compared to a vacuum tube stage, the input impedance of a transistor stage is usually very low, even with degeneration. Thus, large value coupling capacitors must be used to prevent the loss of low frequencies. If a small-value coupling capacitor is used, the capacitor will present a high reactance (ac resistance) to low frequency signals, and the low frequency signals will develop across the coupling capacitor instead of across the input of the transistor stage. Therefore, a coupling capacitor, such as C1, must have a value of 1 microfarad or more. These values, of course, are much larger than those used in vacuum tube interstage coupling circuits.

The high frequency response of the transistor stage is determined by the total distributed capacity C_T in Fig. 3.

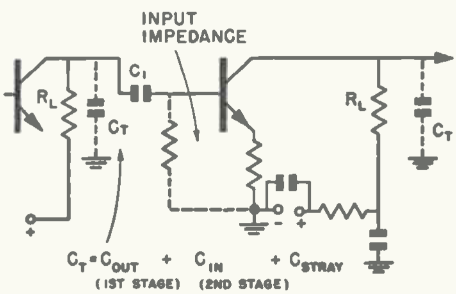


FIG. 3. Frequency response of a transistor stage.

You can understand how the distributed capacity attenuates high frequency signals when you remember that the reactance of a capacitor varies with frequency. You learned that the higher the frequency, the lower the reactance of a capacitor. At very high frequencies, the distributed capacity in a transistor begins to act like a partial short or shunt on the output circuit because of its low reactance (low ac resistance). Therefore, the transistor stage gain, as shown in Fig. 1C, decreases sharply as the frequency increases.

The high frequency response also depends on the circuit impedance, which in turn is determined by the operating point and the circuit constants, including transistor voltages and load resistor values. You know that the grid and plate voltages of a vacuum tube are adjusted so that the tube operates at a definite point on its characteristic curve. The transistor also is a biased device. Thus, its operating point also depends upon the voltages applied to the emitter and the collector. These voltage sources represent shunt and series impedances at the input and the output of the transistor stage.

The output impedance of a transistor stage has more influence on the high frequency response than the input impedance. The total load impedance across the output of the stage is determined by the parallel combination of the transistor output impedance, the external load resistor value, and the impedance of the circuit into which the transistor stage is working. Since the circuit that follows is often another transistor amplifier, the input impedance of this following stage will largely determine the load on the output of the preceding stage.

A low impedance load on the transistor output circuit permits a better high frequency response because a much lower value of reactance is necessary to cause high frequency degeneration. The disadvantage of a low impedance load, however, is that the transistor stage gain is lower, just as in the case of a vacuum tube resistance-coupled amplifier operating with a low value of plate load resistor. In general, the lower the resistive load in the transistor output circuit, the better the high frequency response; and the higher the load resistance value, the poorer the high frequency response.

Temperature Influence. The temperature of the surrounding air and of the transistor itself has a marked effect on the operation of all transistor circuits. When the temperature of the transistor rises, the number of intrinsic carriers is much greater, and the collector current rises sharply. Collector current increases of five to twenty times are not uncommon. Thus, the operating point of the transistor stage changes with temperature.

One of the methods used to correct for this temperature effect is the circuit of Fig. 4. The base bias is obtained from a voltage divider net composed of R1 and R3. The change in static collector current changes the voltage drop across R1. The resultant change in emitter current causes a change in static collector current that partially offsets the change due to temperature. By using the correct values for the four resistors and the supply voltage, the effect of temperature changes on the gain of the stage and the output current can be greatly reduced.

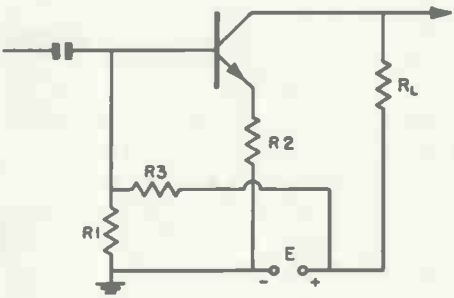


FIG. 4. Temperature-compensated transistor stage.

GROUNDED-BASE AMPLIFIER

The low input impedance of the grounded-base stage complicates matching with other circuits. Most vacuum tube circuits and components have much higher impedances than the input impedance presented by the grounded-base circuit.

An example of how the impedance characteristics of a grounded-base circuit can be used effectively in a practical voltage amplifying circuit is shown in Fig. 5. This is an intercom circuit in which the loudspeaker is used as a microphone. Because the input impedance is low, the loudspeaker voice coil can be used to drive the stage. The output impedance, although less than the output impedance of a vacuum tube stage, is still enough to feed directly to a following amplifier stage.

One advantage of the grounded-base circuit is that temperature variations do not affect the operating characteristics of the stage as much as in a grounded-emitter circuit. Thus, the grounded-base connection is used widely in both low frequency and high frequency transistor oscillators.

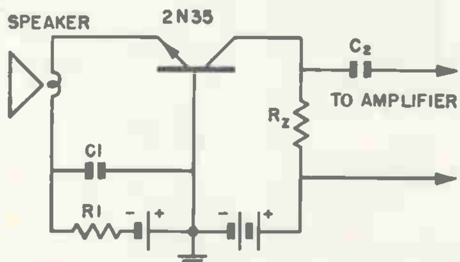
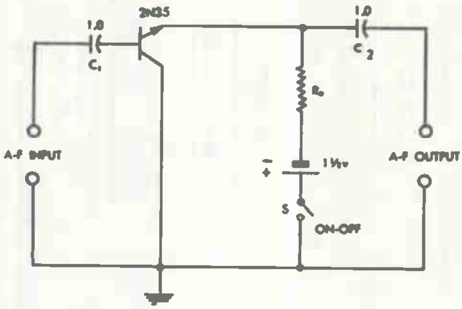


FIG. 5. Grounded-base amplifier.

GROUNDED-COLLECTOR AMPLIFIER

Fig. 6 shows one version of the grounded-collector circuit. Connected in this way, the stage requires no input resistor, no fixed base bias, and only one battery. The input resistance of the transistor itself serves as the resistive input load. Like the cathode-follower stage, the grounded-collector circuit is well suited for input and interstage coupling arrangements be-



Courtesy Sylvania Electric Products

FIG. 6. Grounded-collector stage.

cause of its high input impedance and impedance transforming properties. The input impedance, however, is seldom much more than 100,000 ohms as compared to several megohms for the cathode-follower circuit.

The circuit has a high current gain but low voltage and power gain. The current in the output circuit is out of phase with the current at the input. The voltage across the output is in phase with the input voltage. Point-contact transistors are unstable in this circuit and so are seldom used.

One important characteristic of the grounded-collector stage is that the input impedance changes with the value of the emitter load resistor. This again demonstrates the interaction between the input and output circuits of a transistor due to the nature of the semiconductor material. Therefore, interaction must be considered in the construction of all transistor circuits and in servicing electronic devices employing transistors.

Multistage Transistor Amplifiers

We have considered the transistor as it is employed in single stage amplifiers. Let us next study the methods and problems involved in multi-stage transistor amplifiers.

The similarities and differences between vacuum tubes and transistors are again seen in the methods used to couple one stage to another. Like vacuum tubes, transistors may be either resistance-coupled, transformer-coupled, or dc-coupled. There is a special method, called tandem coupling, that is used only with transistors. Of course, each method has its own characteristics and special features.

RESISTANCE-COUPLED STAGES

A three-stage resistance-coupled amplifier is shown in Fig. 7. Maximum voltage gain for each stage cannot be attained with this method of interstage coupling because the high impedance output of one stage must work into the low impedance input circuit of the next stage. Higher input impedances are obtained by using series resistors in the emitter circuits, high value collector load resistors, and maximum supply voltage. As in vacuum tube circuits, feedback and motorboating can be a problem unless the supply lines are properly filtered and decoupled. The resistor-capacitor combination in the supply line to the first stage serves as the decoupling network, while the capacitor connected across the battery terminals serves as the supply filter.

Volume and tone controls can also be used in transistor amplifiers. The volume control shown in Fig. 7 is in the form of a variable series resistor instead of the usual shunt control. With this arrangement, there is little change in frequency response with different settings of the volume control.

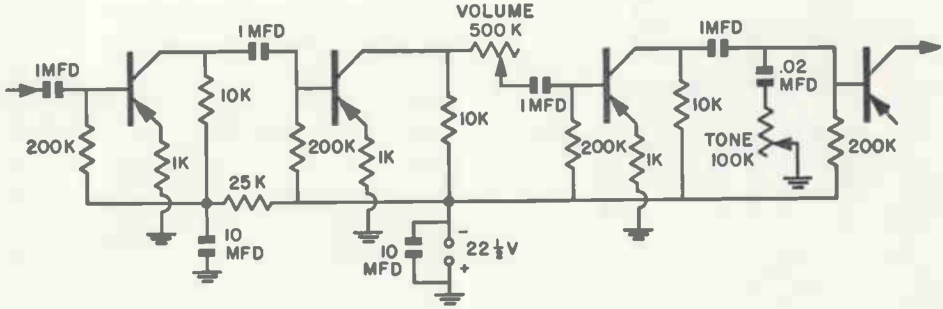


FIG. 7. Resistance-coupled transistor amplifier.

TRANSFORMER-COUPLED STAGES

The transformer-coupling method is well suited to transistor stages. As shown in Fig. 8, a step-down transformer can be used to match the low impedance input to the higher impedance output of the preceding stage. Consequently, each transistor works into a higher impedance, and it is possible to obtain a higher stage gain. Fewer transistor stages are required to obtain the same amount of gain as compared to the resistance-coupled amplifier. Note the use of a divider to obtain base bias and give some temperature stabilization.

In addition to the higher gain, it is also possible to use a lower supply voltage because there is only a very small voltage drop in the primary of the audio transformer. Thus, voltage can be supplied by smaller batteries. The resistance-coupled amplifier is often more desirable because the expensive transformers are not required. In many cases, it is better to add one or two transistors than the more costly transformers.

DC-COUPLED STAGES

Transistors can be dc-coupled, using the complementary characteristics of the P-N-P and N-P-N transistor types. As shown in Fig. 9, the collector of an N-P-N transistor can be directly connected to the base of a P-N-P

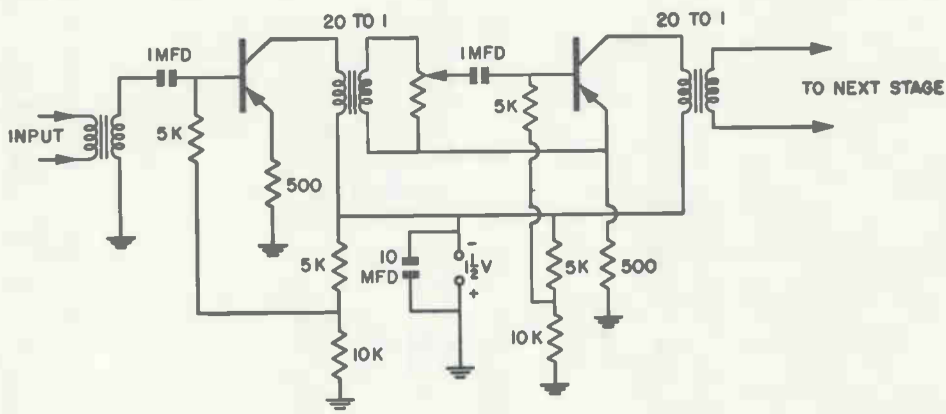


FIG. 8. Transformer-coupled transistor amplifier.

transistor; an interstage coupling network is not required and the frequency response of the amplifier can be extended down to almost dc.

You will recall that for an N-P-N transistor the electron flow is out from the collector, while the base current for a P-N-P junction transistor is into the base. The ratio between the collector and base currents depends on the operating point and the values of the parts in the circuit. If the operating collector current of the first stage is larger than the base current of the second stage, resistor R1 can be used to supply a path for the different current. Consequently, the collector current can exert proper control over the emitter current of the second stage.

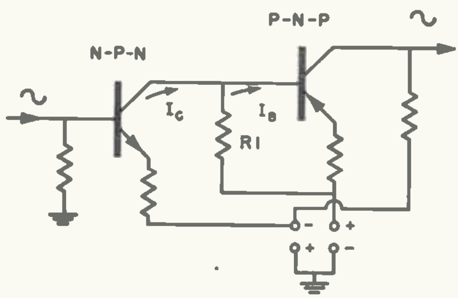


FIG. 9. DC amplifier.

To understand the operation of the dc amplifier, let us assume that the base voltage of the first stage is increasing. An increase in voltage causes an increase in emitter current. Since the transistor is an N-P-N type, electrons, or negative carriers, are released into the collector area. The collector current and voltage drop across R1 increase. Thus, the base voltage applied to the second transistor stage decreases (swings in negative direction).

The second transistor is a P-N-P type. Therefore, the more negative voltage on the base causes an increase in emitter current. The increased emitter current in the second transistor causes a motion of holes or positive particles into the collector region, resulting in an increase in collector current. This increased electron flow into the collector causes an increased voltage across the output load resistor. Notice that in this two-stage transistor amplifier, the amplified output signal is in phase with the input signal.

The dc amplifier is capable of responding to a dc as well as an ac change at its input. The transistor is basically a current amplifier. Therefore, a small direct current change at the input will produce an increased direct current change in the output circuit.

The fact that there are two basic types of transistors with electron flow in opposite directions (N-P-N and P-N-P) simplifies the battery problem and the design of dc amplifier systems. This dc coupling arrangement cannot be used with vacuum tube stages. To obtain an identical operation, one of the tubes would have to conduct electrons from plate to cathode.

TANDEM STAGES

We have seen that temperature variations in a transistor stage affect the operation of the stage. In low power amplifiers, stabilizing resistors in the form of voltage dividers can be placed across the supply voltage to maintain the bias. A disadvantage of this method, however, is that the divider resistors place a certain amount of power drain on the supply. The power loss becomes greater in the higher powered transistor stages. In transistor audio output stages, we must be concerned not only with the heat created by the surrounding parts, but also the heat that is created within the transistor itself. As the current increases, the temperature of the

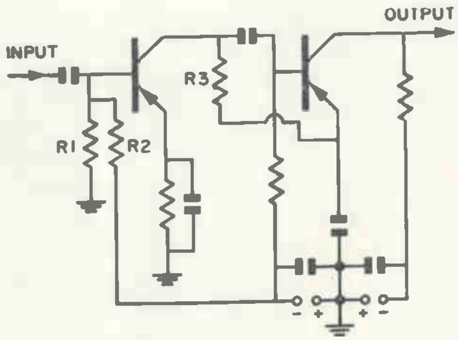


FIG. 10. Tandem stabilized amplifier.

transistor also increases. This, in turn, causes a further increase in the collector current unless adequate stabilization is provided.

Stabilization can be obtained by connecting transistor stages in a tandem arrangement. An example of a tandem amplifier is shown in Fig. 10. Notice that the emitter of the second stage obtains its current from the collector of the first stage. Thus, if the first stage is properly stabilized, in this case with resistors R1 and R2, its collector current will stabilize the second higher powered stage.

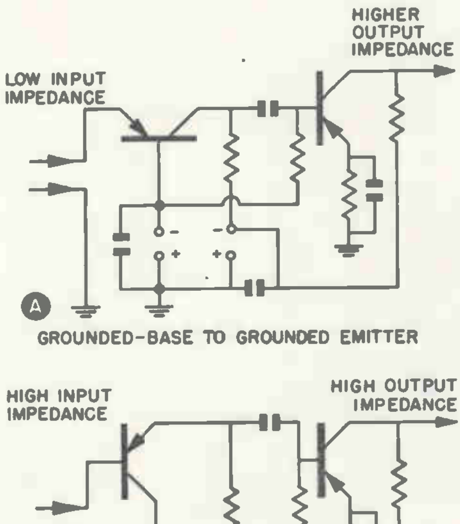
Connecting two transistor stages in tandem also establishes specific impedance and performance relations. If low input impedance, good gain, and high output impedance are desired, a grounded-base and a grounded-emitter stage can be connected in tandem as shown in Fig. 11A. Both stages will contribute gain. The grounded-base first stage has a low input impedance, while the grounded-emitter second stage provides good power gain and high output impedance.

You can use a grounded-collector stage to drive a grounded-emitter output, as illustrated in Fig. 11B. This combination will have both high input and output impedances. In this circuit, a grounded-collector first stage presents the high input impedance, while the ground-emitter stage has the necessary high gain and high output impedance. A moderate input impedance and a low output impedance can be obtained by driving a grounded-collector stage from a grounded-emitter stage. This method is used less than the other two connections.

TRANSISTOR POWER OUTPUT STAGES

Higher and higher powered transistors are being developed to drive increasingly larger loudspeaker systems. Like vacuum tubes, transistors can be used in single-ended and push-pull output stages, and be biased to operate class A, AB, or B.

In a transistor circuit the class of



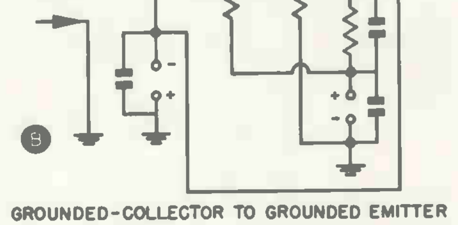


FIG. 11. Dual-stage transistor amplifiers.

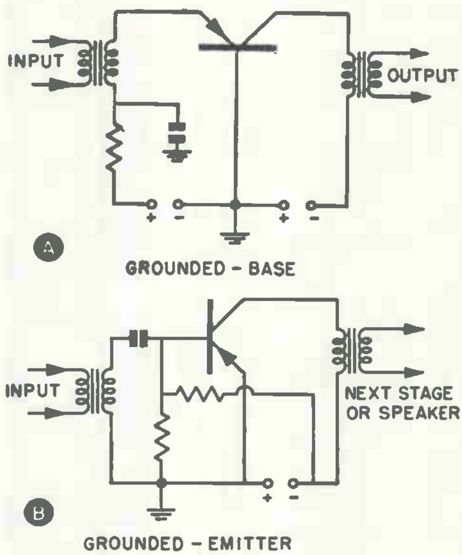


FIG. 12. Power-amplifier stages.

operation is determined by the supply voltage bias for the input circuit and the amplitude of the applied signal. As in vacuum tube circuits, to obtain linear operation for class AB or class B operation, you must connect two transistors in a push-pull arrangement.

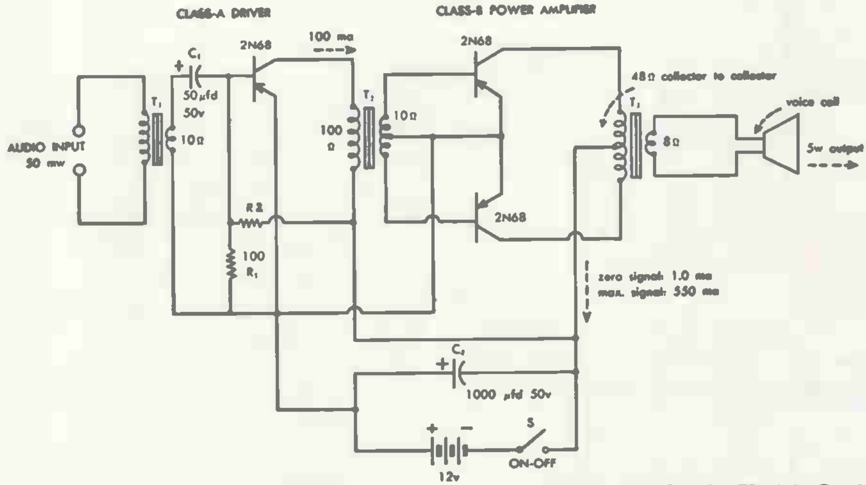
If a transistor power amplifier is to be operated class A, best results can be obtained by using the grounded-base arrangement shown in Fig. 12A. The chief advantage of using the grounded-base method is that it provides the best linearity and frequency response with fairly good power gain.

In the grounded-base circuit, the collector current changes linearly with the emitter current. Therefore, the collector output voltage follows exactly the changes in emitter current. However, because the transistor is basically a current controlled device, it is difficult to establish a linear relationship between the emitter voltage and the emitter current. Certain input conditions must be met to make certain that the applied signal voltage causes a linear change in the emitter current.

When the driving source at the input of a transistor power output stage has a very low impedance, it is easy to supply the necessary power required by the emitter input circuit and obtain a fairly high power ouput. However, a low impedance driving source causes a non-linear relationship between the emitter current and the applied emitter signal voltage. A higher impedance signal source provides a more linear operation, but introduces a loss in power gain. Thus, when the grounded-base circuit is operated class A, the source impedance must be adjusted to a compromise between best linearity and highest gain.

The impedance relationship again must be considered in the grounded-emitter circuit in Fig. 12B. The input transformer must provide a suitable match between the base-emitter transistor circuit and the input driving source. The output transformer must match the higher impedance collector circuit to the next stage or the loudspeaker; at the same time it must be able to handle the dc collector current.

Although the grounded-base arrangement has a better linearity and frequency response, it is less efficient and has a lower power output than the grounded-emitter connection. In addition, the grounded-base circuit requires two voltage supply sources, while the grounded-emitter circuit requires only one. Practical transistor power output stages are usually designed to deliver the maximum power gain at highest efficiency. Therefore, most of the power output stages use the grounded-emitter circuit biased for class B operation. The 5-watt amplifier shown in Fig. 13 is a good example. In this circuit, power gain is considered to be more important



Courtesy Sylvania Electric Products

FIG. 13. Five-watt audio amplifier.

than linearity and frequency response. Of course, any of the three basic circuit arrangements can be used in the push-pull class B output stage. In this case, the grounded-emitter circuit was chosen because its power gain is highest.

The audio amplifier shown in Fig. 13 employs three power transistors. The first stage is a single transistor class A driver that builds up the 50-milliwatt input power to an adequate level for driving the class B output stage. The driver stage is suitably biased and stabilized with the voltage divider network consisting of resistors R1 and R2 connected across the supply. Notice that a constant 100 milliampere collector current flows in the class A driver stage.

The output stage consists of two 2N68 transistors connected in a push-pull arrangement. No dc bias voltage is applied between the base and the emitters, thus biasing the stage for class B operation. With no signal applied, the total collector current is 1 milliampere. When the maximum signal is fed to the output stage, the collector current rises to 550 milliamperes.

In our study of push-pull vacuum tube output circuits, we learned that even harmonics cancel in the output circuit and that there is almost no phase shift in the output frequencies. Therefore, much of the distortion that would appear at the output of a class B vacuum tube stage is cancelled in push-pull operation. However, in a transistor output stage operating push-pull, a complete harmonic cancellation does not occur because of the phase shift which varies with the frequency.

PHASE INVERTER

Phase inversion is obtained in the circuit shown in Fig. 13 with an interstage transformer. However, a simple phase inverter circuit can be constructed using a single transistor, as shown in Fig. 14.

The transistor performs well as a phase inverter, having characteristics similar to a triode vacuum tube phase inverter with plate and cathode output. It can also be used in the pulse and waveform inversion circuits of TV receivers.

As you know, the emitter and collector voltages of a transistor stage are out of phase with each other. This phase relationship is used in the phase inverter circuit to obtain two outputs of equal amplitude but opposite polarity.

When a positive-going signal is applied to the base of the N-P-N transistor, it causes an increase in emitter current and a more positive voltage to be developed across the emitter resistor R1. At the same time, the motion of electrons into the collector region causes an increase in collector current. This current, in flowing out of the collector and down through resistor R2, develops a more negative voltage output on the collector side. By properly balancing the values of resistors R1 and R2, the two opposite polarity output signals can be made to have equal amplitudes. However, as in the vacuum tube phase inverter stage, it may be necessary to use resistor values that are not identical.

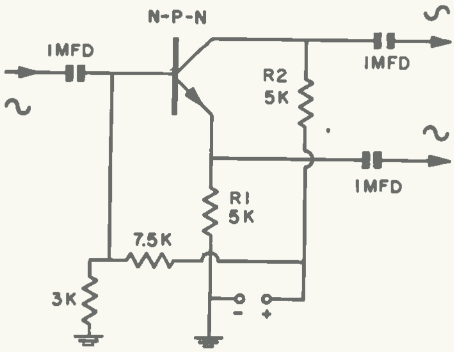


FIG. 14. Transistor phase inverter.

COMPLEMENTARY SYMMETRY

In an earlier discussion, you learned that the N-P-N and P-N-P junction transistors have similar but opposite characteristics. This is referred to as the symmetrical property of the two types of transistors. When using the transistors in the same circuit, as in the push-pull output stage of Fig. 15, we obtain results that are unlike any vacuum tube operation.

By studying the circuit diagram you will notice that neither a push-pull input transformer nor a push-pull output transformer is used to obtain a push-pull output. In fact, the circuit is single-ended. The circuit is arranged so that the N-P-N and the P-N-P transistors complement each other; the N-P-N transistor supplies the negative peaks of the output signal voltage, while the P-N-P section develops positive alternations.

To get a more thorough understanding of the complementary operations of the transistors, let us consider the action of the stage when a signal voltage is simultaneously applied to the bases of the two units. When a positive alternation is applied to the base of the P-N-P transistor, there is no change in the emitter current

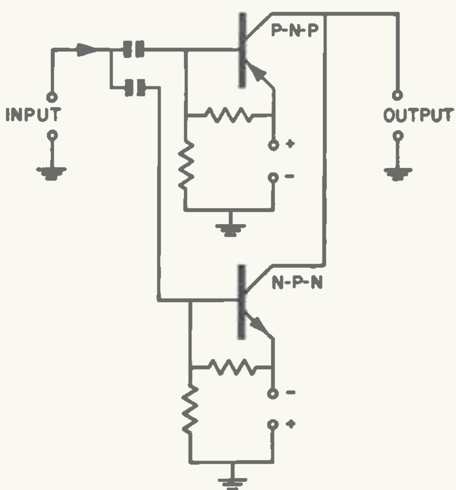


FIG. 15. Amplifier using complementary symmetry transistors.

because the stage has been biased class B (near cut-off). When a negative alternation is applied, however, the emitter current increases. The collector current also increases and develops a more positive voltage across the load. This is the positive alternation of the output signal as shown in Fig. 16A.

A complementary action occurs at the N-P-N transistor. When a negative alternation is applied to the lower transistor, there is no change in emitter current because the emitter again has been biased near cut-off. A positive alternation on the base, however, results in an increase in emitter current. Again the increase in emitter current causes an increase in collector current, but in this transistor, the collector current flow is in the opposite direction. Thus, a negative voltage is developed across the output load, as shown in Fig. 16B. Because both collectors are connected together, the individual outputs are combined, as shown in Fig. 16C, and both alternations of the input signal are reproduced across the output as an amplified signal.

Thus, push-pull operation is obtained merely by paralleling the collector output circuits without the need for push-pull transformers. The output impedance of the parallel combination is low enough so that the output can be resistance-coupled or transformer-coupled to the following circuit. It is also possible to connect the impedance load (voice coil) of a hearing aid ear piece or small loudspeaker directly in the collector circuit.

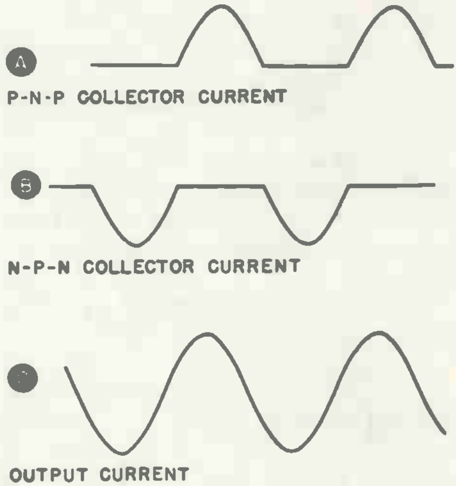


FIG. 16. Waveforms of push-pull amplifier.

The two transistors used in a single-ended push-pull amplifier must be carefully chosen to have identical but opposite characteristics. In other words, they must be symmetrical so that the positive and negative alternations of the output signal have equal amplitudes and identical shapes. At the same time, the units must be complementary and develop signals of opposite polarity. This method of operation is often called complementary symmetry. It is a type of operation that cannot be duplicated in a vacuum tube circuit.

High Frequency Amplifiers and Oscillator Circuits

Transistors can be used to replace vacuum tubes in amplifying high frequency signals up to the VHF range. This is especially important in TV receiver circuits, because they are designed to operate in the high frequency range.

When we discuss typical high frequency circuits in this section, you may not be familiar with all their vacuum tube counterparts, particularly the corresponding circuits used in TV receivers. These circuits will be taken up later in the course. However, you do not have to completely understand how the corresponding vacuum tube circuits work to be able to understand the transistor circuits.

It is important to note that point-contact transistors will amplify higher frequency signals than will junction transistors; but because of their construction, they are not as stable as the junction types. Junction units have been developed that have very good response up to several megacycles. Thus, they can be used effectively in many TV circuits. In the next few years the response of both point-contact and junction transistors will undoubtedly be improved to make the units even more useful in high frequency amplifiers and oscillator circuits.

VIDEO AMPLIFIERS

The video amplifier section of a TV receiver builds up the signal containing the picture information (the video signal) until it is strong enough to be applied to the control grid of the picture tube. The frequency of the video signal, of course, is much higher than an audio signal. Thus, the transistor used in a stage of this type should be able to amplify the entire band of frequencies, up to 4 or 5 megacycles, without introducing phase or amplitude distortion.

Phase distortion is a more serious problem in transistors operating at high frequencies than in vacuum tubes because of the physical construction of the transistor itself. This type of distortion occurs when signals of different frequencies take different amounts of time to pass through the transistor material.

The transistor video amplifier also should have a linear frequency-amplitude response over the entire band. As in a vacuum tube circuit, linear response is obtained by using special external low and high frequency compensating circuits.

A typical video detector and amplifier consisting of three transistors is shown in Fig. 17. The first stage functions as a combination video detector and amplifier. Notice that there is no bias between the emitter and the base. Thus, the emitter-base circuit is actually a diode detector. The detected signal, because it is coupled internally through the transistor to the collector circuit, is amplified by transistor action. The signal at the output is coupled through a capacitor to the base of the first video amplifier stage.

The transistor in the first video amplifier stage is connected as a grounded-emitter. This connection method premits a good voltage gain and at the same time, presents a moderate impedance to the output of the detector stage. Also, because it has a moderate output impedance, the

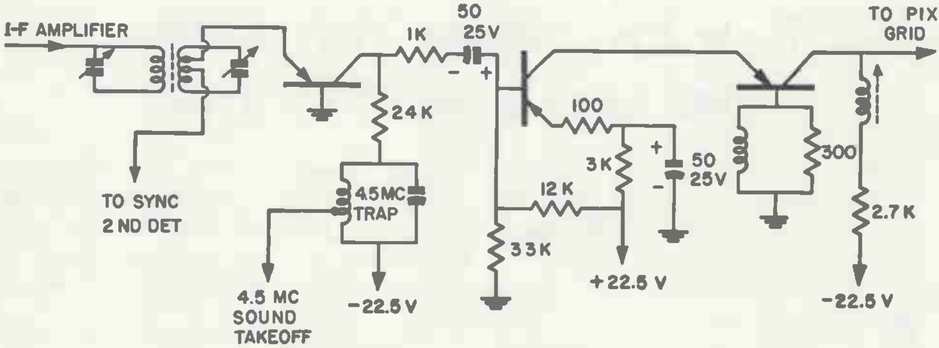


FIG. 17. Video amplifier.

grounded-emitter stage can be directly-coupled to the grounded-base output stage.

The video output stage employs special frequency compensating circuits. The high frequency signal components are boosted by the shunt peaking coil in the collector circuit and by the high frequency feedback in the transistor base circuit. In amplifier stages that pass high frequency signals, high frequency degeneration is caused by shunt capacity. The shunt capacity in the transistor video stages is a combination of the transistor capacities and the stray capacities in the component parts and wiring. To minimize the shunt capacity, the shunt load impedances must be kept to a low value. Thus, the values of the diode detector load and the collector output load resistors are just a few thousand ohms, as compared to the tens of thousands of ohms used in the audio amplifiers discussed in the previous section.

The low frequencies present in a video signal also can be lost because of the low input and output impedances of the transistor circuits. Therefore, as you learned earlier, the coupling and filter capacitors must be much larger than those employed in similar vacuum tube circuits.

HIGH FREQUENCY TUNED AMPLIFIERS

Transistors can be employed in narrow band and wide band rf and i-f amplifier systems up to frequencies in the VHF region. A typical tuned amplifier using Raytheon CK761 or CK762 high-frequency junction transistors is shown in Fig. 18.

A transistor tuned amplifier is similar to a vacuum tube amplifier in some respects, but different in others. Because the input and output impedances are lower than in vacuum tube stages, matching methods must be used to obtain the benefits of the high Q resonant circuits. Also, you have learned that feedback between the output and input circuits is much higher in a transistor than in a vacuum tube. To prevent interaction between the stages when two or more transistor stages are used as high frequency amplifiers, capacitors such as C1 and C2, must be used to neutralize the feedback. Triode vacuum tubes also must be neutralized when they are used to amplify high frequency signals.

The interstage transformer T2 is designed to match the input and output impedances of the transistor stages. the resonant primary circuit is made to have a high Q, and the collec-

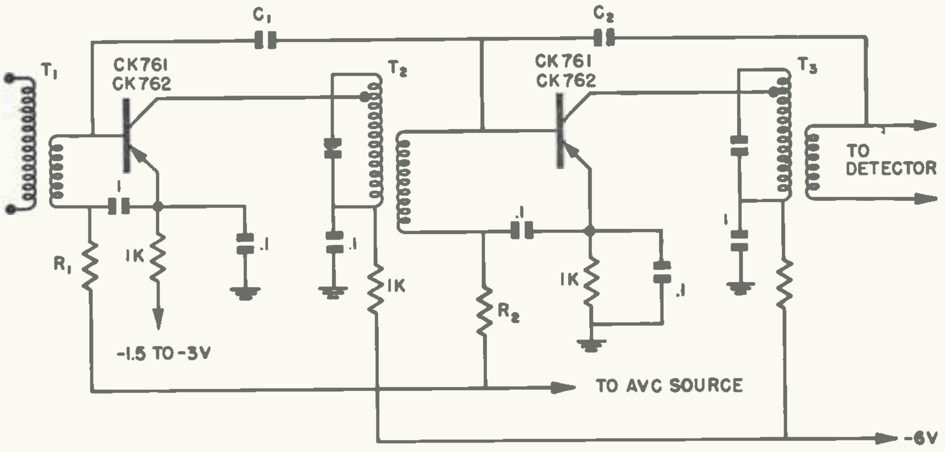


FIG. 18. Raytheon two-stage transistor i-f amplifier.

tor is tapped down on the coil to provide an impedance match between the collector and the resonant tuned circuit. To match the low input impedance of the second stage, there is an impedance step-down ratio between the tuned primary and the untuned secondary coils.

Because grounded-emitter stages are used in this i-f amplifier, only one battery is needed to supply the potentials to the various stages. Of course, decoupling networks and filters are needed in the supply and avc lines to prevent interaction between the transistor stages, just as when vacuum tubes are used.

The same type junction transistor can be used in the high-frequency

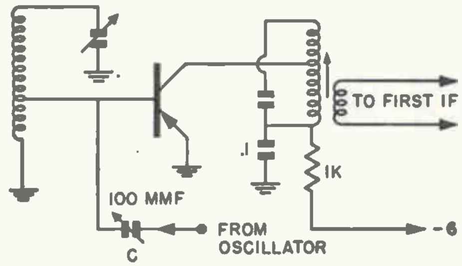


FIG. 19. Raytheon transistor mixer.

mixer circuit in Fig. 19. The oscillator and signal voltages are injected at the transistor base. No bias is applied between the base and the emitter. Thus, the transistor operates on the nonlinear portion of its characteristic curve, as is required for good mixing action. The strength of the local oscillator signal applied to the stage can be controlled by varying the value of the coupling capacitor C.

A typical wide band i-f amplifier stage is shown in Fig. 20. It uses a point-contact transistor connected in a grounded-base arrangement. To obtain good stability and proper impedance match in a cascaded, high-frequency amplifier, it is customary to use the grounded-base circuit for point-contact transistors. The grounded-emitter circuit, on the other hand, is more commonly used for junction transistors operating at high frequencies.

The band width of the i-f amplifier is established by the low impedance input of the grounded-base circuit and the loads in the emitter and collector circuits. Again, in the wide band transistor system, the impedances must be matched to obtain maximum signal at the output. The grounded-base transistor has a rather high output impedance, and therefore, the impedance matching network to the low-impedance emitter circuit of the following stage, often consists of just a tap-off in the collector tuned circuit.

A number of other methods of matching impedances between two grounded-base or grounded-emitter transistor stages are shown in Fig. 21. The coupling method in Fig. 21A is in the form of a capacitive impedance divider. In this arrangement, the two series capacitors are a part of the tuned circuit and have values that properly match the low impedance input of the following stage. As you can see in the illustration, the signal is taken off between the capacitors.

A double-tuned transformer can be used to match the output and input circuits of the transistor stages. The tapped coil in Fig. 21B matches the output of the collector to the primary resonant circuit. In the secondary tuned circuit, the signal is removed from the capacitive impedance divider at a low impedance point to match the base-emitter circuit of the following stage.

Fig. 21C is an example of a series-resonant circuit that can be used to transfer maximum signal between the collector output of one stage and the low impedance input of the next stage. A pi-coupled impedance matching circuit is shown in Fig. 21D. The collector of the first stage acts as if it were operating into a parallel-resonant circuit. By properly choosing the values of the coil and capacitors to match the impedances of the two stages, maximum signal can be transferred between the collector of the first stage and the emitter of the second.

From this you can see that the transistor can be employed to perform all the basic vacuum tube operations in circuits handling sinusoidal waves. Transistor circuits can be designed to amplify low- or high-frequency signals, and either a wide band or a narrow band of frequencies. The units are especially adaptable as mixers and

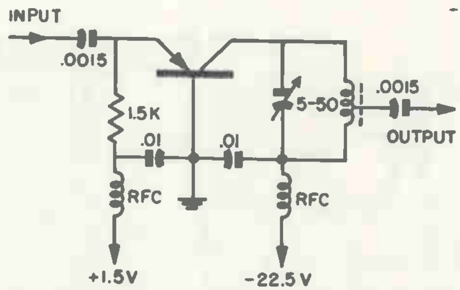


FIG. 20. Transistor wideband i-f amplifier.

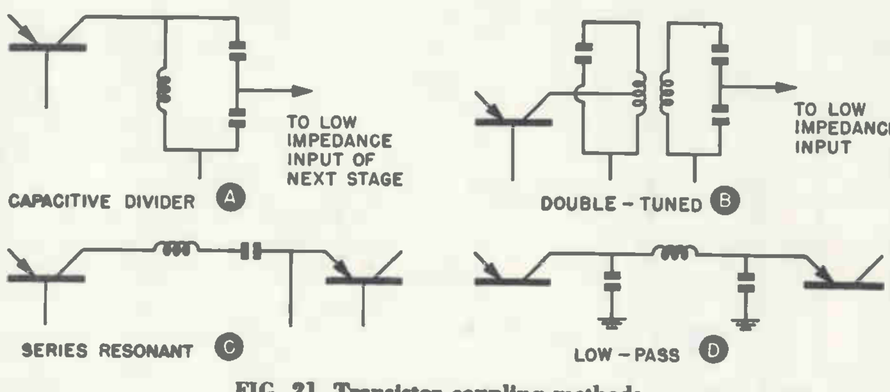


FIG. 21. Transistor coupling methods.

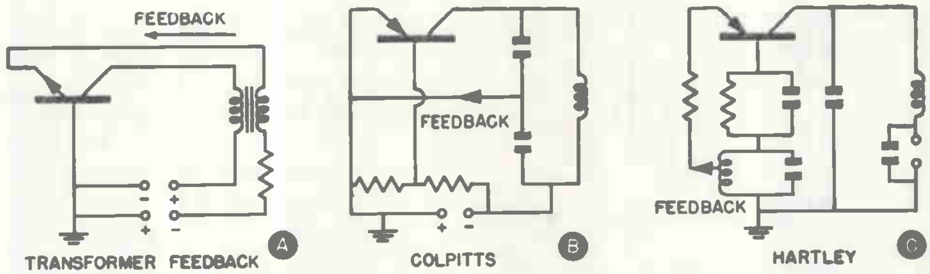


FIG. 22. Basic transistor oscillators.

demodulators. At the present time, the high frequency response of transistors is somewhat limited. However, as they are developed further, they will be able to amplify higher and higher frequencies.

TRANSISTOR OSCILLATORS

Transistors can be used in oscillator and generator circuits to produce low- or high-frequency signals having sinusoidal or non-sinusoidal waveforms. Transistor oscillators again can be compared to vacuum tube oscillators. For example, transistors can be used in Hartley, Colpitts, crystal, and self-excited oscillator circuits. You will notice that the transistor circuits operate almost the same as the corresponding vacuum tube circuits.

You learned in your study of vacuum tube oscillators that oscillations are supported by feeding part of the output voltage back to the grid. The feedback voltage reinforces the grid signal and overcomes the grid circuit losses. The same arrangement is used in transistor oscillator circuits. Part of the transistor output current is fed back to the input to reinforce the input current.

Basic transistor oscillator circuits are shown in Fig. 22. In the basic feedback circuit in Fig. 22A, an increase in the emitter-base current causes an increase in the collector current. Since this is a grounded-base circuit, the output current is in phase with the input current. The collector output current change is transformer-coupled to the secondary of the feedback transformer. The polarity of the transformer windings is such that the current fed back to the emitter circuit is in phase with the input signal current and reinforces the original base-emitter current. The emitter current, in turn, increases and causes a further increase in the collector current. Thus, continuous oscillations are set up in the circuit.

Feedback can be obtained by using the same methods employed in Hartley, Colpitts, or modified types of vacuum tube oscillators. A Colpitts version, using a capacitive divider to obtain the feedback energy, is shown in Fig. 22B. In a Hartley transistor oscillator (Fig. 22C), the feedback is taken from the coil in the base circuit. The oscillator bias is controlled by the value of the resistor in the emitter circuit and the collector voltage. In the same manner, the oscillations in a vacuum tube circuit of this type are controlled by the value of the grid resistor and the plate supply potential.

TYPICAL OSCILLATORS

A typical transistorized audio frequency oscillator is shown in Fig. 23. The transformer acts as an auto-

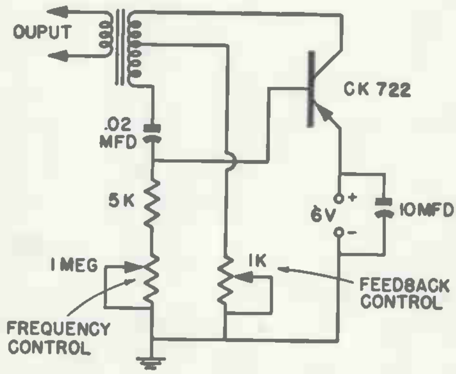


FIG. 23. Audio oscillator using transistor.

transformer with one half of the winding connected between the collector and ground. The second half of the winding acts as a feedback link through the capacitor to the base of the junction transistor. The frequency is controlled by the potentiometer in the base circuit, and the oscillator signal is removed from across the output winding of the audio transformer.

This circuit is designed to produce audio frequency signals. However, it can be made to oscillate at higher frequencies by replacing the transformer with a resonant circuit.

Point-contact transistors can be made to oscillate at frequencies in the VHF range. Remember that there is a current gain in a point-contact transistor; the collector current is higher than the emitter current. Therefore, in the VHF oscillator circuit in Fig. 24A, oscillation is maintained by using a base feedback arrangement. The emitter bias is determined by the series emitter resistor and the base resistor. Notice that the oscillator signal is removed from the small link near the resonant circuit.

A transistorized crystal oscillator circuit is shown in Fig. 24B. Notice that the collector circuit contains the coil-capacitor tuned circuit, while the crystal is connected in the feedback path between the collector and the emitter circuits. Notice also that the base is grounded and that the emitter bias is obtained across the series emitter resistor. The rf choke is used to keep the emitter above ground potential.

The circuits of Fig. 24 show two different methods of producing oscillations. The circuit in Fig. 24A makes use of the current gain of a point-contact transistor. In-phase currents from both emitter and collector flow through a common high impedance in the base. In Fig. 24B a low impedance,

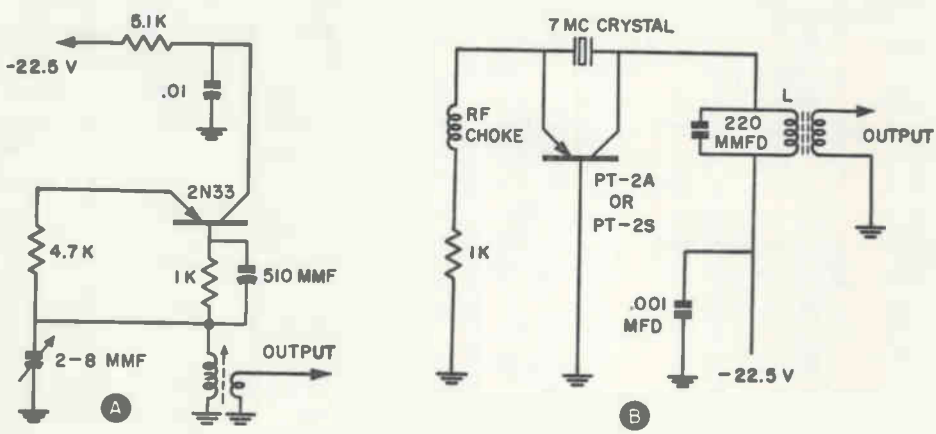


FIG. 24. High-frequency oscillators using point-contact transistors.

series resonant mode of the crystal, is used to provide direct feedback from collector to emitter. This circuit works with either point-contact or junction transistors.

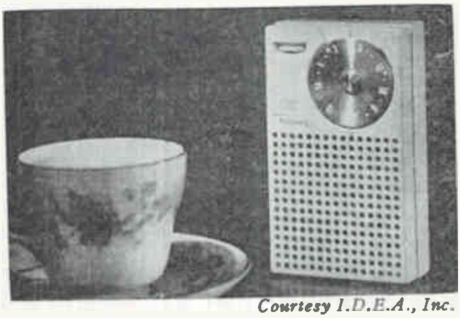
The crystal oscillator resembles the Pierce oscillator used with vacuum tubes. There is no vacuum tube counterpart for the oscillator in Fig. 24A. This circuit depends on current gains greater than one. A vacuum tube does not have current gain.

Remember the principle of this VHF oscillator. Any transistor circuit with a current gain greater than one and having a high resistance or impedance in the base circuit is unstable and will tend to break into oscillation.

The amplifier and oscillator circuits that we have described in this section are only a few of the many possible circuits in which transistors can be used. Their small physical size and low power requirements make them ideal for use in many pieces of equipment. They will probably replace vacuum tubes in various sections of TV receivers. This, of course, will reduce the size and the cost of the equipment. Further development will produce transistors that are able to perform many more jobs more efficiently than the units now on the market.

Transistor Radios

Transistors are out of the experimental stage, as indicated by the number of partially and completely transistorized receivers now on the market. A typical example of such a personal broadcast receiver is the Regency TR-1 shown in Fig. 25.



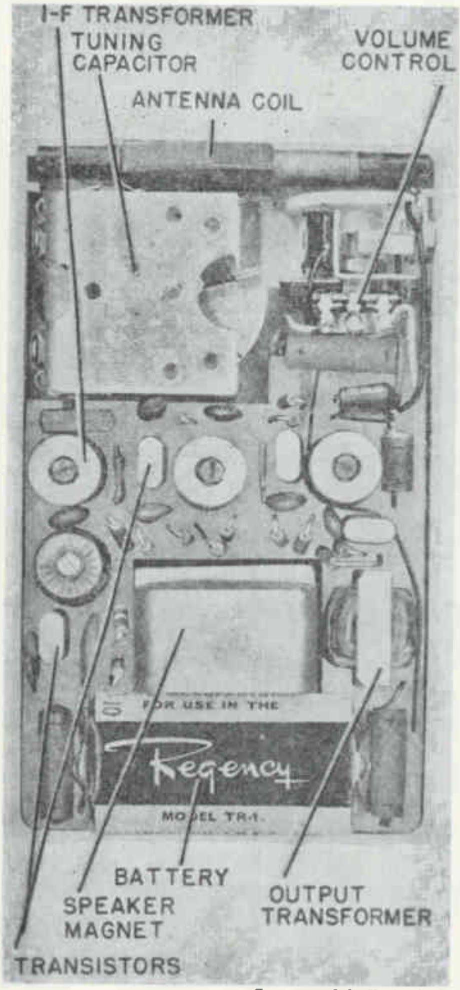
Courtesy I.D.E.A., Inc.

FIG. 25. Regency transistor receiver.

This receiver employs four transistors and a crystal diode, to produce a performance that is equal to many battery-type, five-tube portable radios. To construct a radio with such small dimensions, the components, including capacitors, resistors, transformers, i-f coils, speaker, and tuning capacitor, have to be made very small (miniaturized). It is possible to miniaturize parts in transistor circuits because of the very low battery voltage and small current drain.

The parts in the Regency transistor radio are mounted on a printed-circuit wiring board. The mounting holes in the board are close together. Therefore, as you will notice in Fig. 26, many of the resistors and capacitors must be mounted vertically. The leads from each component pass through holes in the board and are soldered into position, thus replacing the maze of wires needed in a regular receiver.

Let us consider the operation of this receiver by referring to the schematic diagram in Fig. 27. Notice that it employs four N-P-N transistors in grounded-emitter circuits. The transistors can be seen in Fig. 26. The antenna and mixer input coil has a ferrite core to provide a high-Q tuned circuit. By properly designing and



Courtesy I.D.E.A., Inc.

FIG. 26. Chassis view of the transistor radio with the back cover removed.

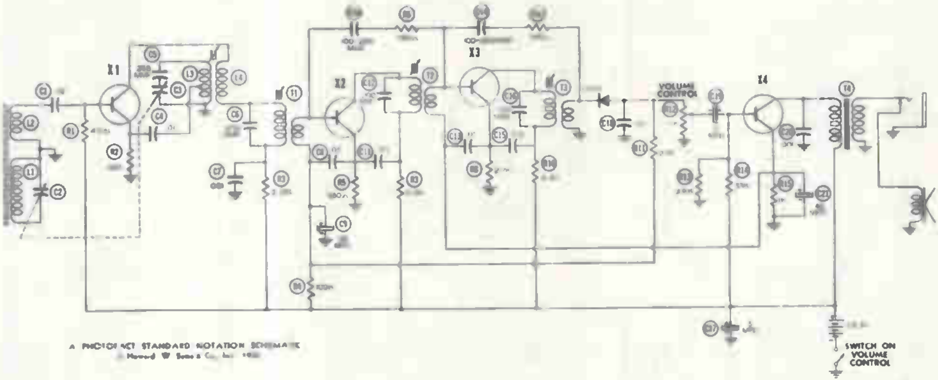
locating this coil, hand-capacity and directional effects can be almost entirely eliminated. The input transformer is an impedance-matching device, the top winding acting as a step-down winding to match the low impedance input of the first transistor.

MIXER-OSCILLATOR CIRCUIT

The operation of the first transistor stage is similar to the converter section of an ordinary superheterodyne receiver. The received signal is injected at the transistor base, while the signal from the local oscillator is removed from a tap on the oscillator coil winding L3 and applied to the emitter. Winding L4 feeds part of the oscillator signal to the collector. Of course, proper bias is applied to the various elements to obtain proper mixing action. After being mixed in the transistor, the signals from the collector are applied to the primary of the first i-f transformer T1. This tuned resonant circuit, which is adjusted to accept only the difference, or i-f frequency of 262 kc, passes the i-f signal to the input of the first i-f amplifier.

An example of a transistor radio using separate transistors in the mixer and local oscillator circuits is shown in Fig. 28. The input tuned circuit of the mixer stage, containing transistor V1, consists of a ferrite core, loop antenna and capacitors C1a and C1b. Notice that the base-emitter circuit impedance is matched by tapping the antenna coil at the proper point. To obtain the most efficient mixing and conversion gain, the base-to-emitter circuit is unbiased.

The local oscillator circuit is a Hartley-like arrangement. By using the auto-transformer, the tuned circuit can be made to have the proper Q, and the transformer winding can be tapped to provide correct feedback voltage and impedance relationships. The local oscillator signal from the separate transformer winding is fed through capacitor C3 to the base of transistor V1. In this way, both signals are mixed and transformer-coupled to the i-f amplifier system. Notice again that the collector impedance is matched by tapping into the coil in the output tuned circuit.



Courtesy Howard W. Sams & Co., Inc.

FIG. 27. Schematic diagram of the Regency TR-1 transistor radio.

I-F AMPLIFIER CIRCUIT

A two-stage transistor i-f amplifier is used in the receiver shown in Fig. 27. The i-f transformers use tuned primaries and untuned secondaries. The impedance step-down ratio between the windings properly matches the collector circuit of one stage to the low impedance base-emitter circuit of the next. Series emitter resistors stabilize the i-f amplifier and prevent the input impedance from being too low.

As mentioned earlier, high frequency transistor amplifier stages, like vacuum tube triode amplifiers, must be neutralized. Neutralizing networks consisting of series resistor-capacitor combinations R6-C10 and R9-C14 link the secondary of each i-f transformer back to the base of the preceding transistor. The values of C10 and C14 are chosen to match the characteristics of the individual transistors.

DEMODULATOR CIRCUIT

Demodulation in this receiver is performed by the crystal diode. The diode rectifies the i-f signal, capacitor C18 filters the rf frequencies, and the audio information appears across load resistor R12. Notice the very low value for this volume control load resistor. This low value is necessary to properly match into the low impedance base circuit of the audio amplifier stage.

An avc circuit also is associated with the diode detector. The avc voltage is filtered by resistor R11 and large value capacitor C9 and is applied to the base of the first i-f transistor. When the incoming signal strength increases, the crystal diode develops a higher dc component. This current reduces the voltage on capacitor C9. The reduced voltage in the transistor base circuit causes a decrease in the positive emitter current, and in turn, a decrease in the i-f amplifier gain. Since N-P-N transistors are used, negative avc is applied to the base. If P-N-P transistors were used, negative avc would be applied to the emitter.

AUDIO OUTPUT CIRCUIT

The audio information is fed through capacitor C19 to the base circuit of the output transistor. The bias for the transistor base is obtained through resistor R14. R14 and R13, as explained earlier, form a voltage divider network to stabilize the base bias and prevent temperature varia-

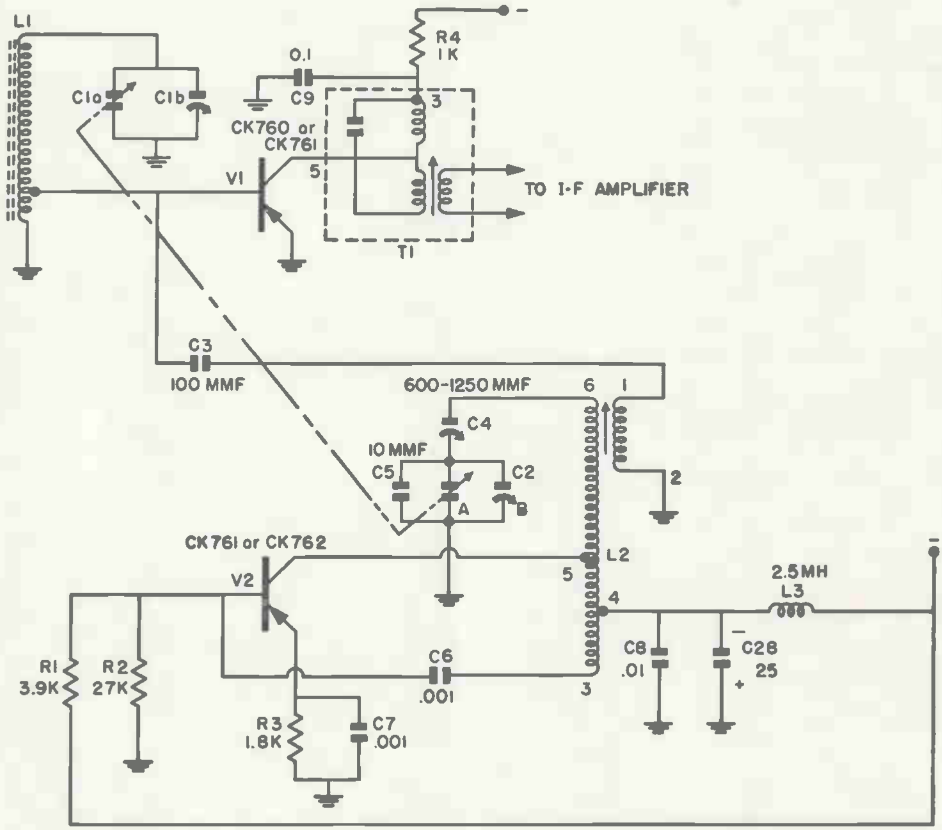


FIG. 28. Raytheon mixer-oscillator stages.

tions from affecting the output stage operation. The emitter current flow through R15 places a charge on capacitor C21 which, in turn, establishes the emitter bias. This positive voltage also is used as the base bias for the second i-f amplifier stage.

A small output transformer matches the approximately 10,000-ohm output impedance of the collector circuit to the 10- to 15-ohm impedance of the small 2¾ inch speaker. Instead of using the speaker, the plug of a hearing aid type earphone can be inserted into the output jack. Of course, when the plug is inserted, the speaker is removed from operation.

Since grounded-emitter circuits are used in each stage, a single 22½-volt hearing aid battery will supply the necessary bias voltages to operate the complete receiver. The average current drawn is approximately 4 ma. Therefore, the expected life of this tiny battery is about 20 to 30 hours.

A higher power audio output stage, shown in Fig. 29, is used in a Raytheon transistorized receiver. The two transistors in the push-pull class B output stage are able to deliver approximately a 100-milliwatt output to feed a 4-inch round speaker. The battery drain, of course, is much higher than in the circuit in Fig. 27. For maximum rated output, the current in the output circuit is approximately 27 ma. The current drain, of course, decreases as the output is decreased. The no-signal current is approximately 1 ma.

Instead of using a crystal diode, transistor V5 demodulates the rf signal and amplifies the recovered audio information. The diode-acting part of the transistor is between base and the grounded emitter. The recovered audio is taken off the collector and supplied through a resistance-coupled network to the base of the audio driver V6. The audio driver is biased class A and supplies sufficient power to drive the class B output stage. A step-down transformer matches the high impedance output of the driver to the low impedance input of the push-pull stage.

The class B emitter circuits in the output stage are biased to near cut-off by the voltage divider consisting of resistors R22 and R24. The collector output of the push-pull stage drives the output transformer which serves as an impedance match between the approximately 1000-ohm output impedance of the class B stage to the 3.2-ohm loudspeaker. A feedback link connects the secondary of the output transformer with the input of the audio amplifier to improve the frequency response.

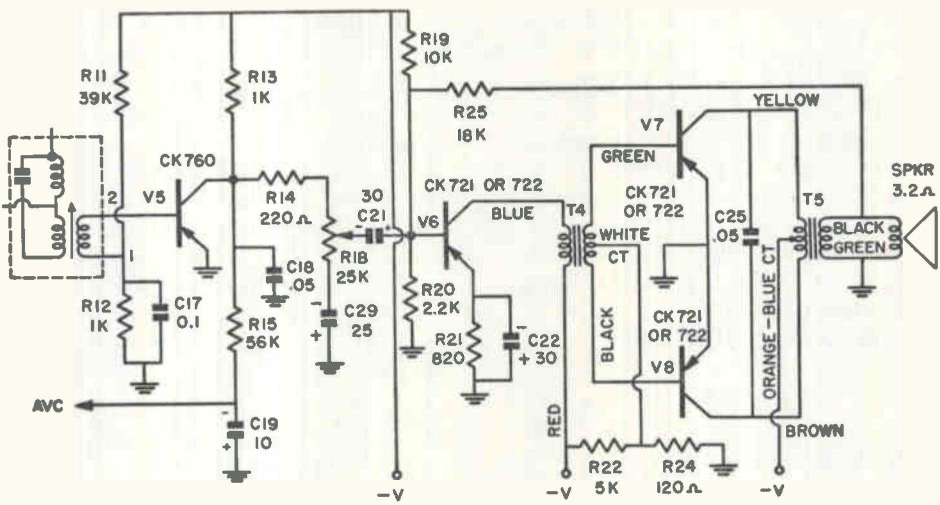


FIG. 29. Raytheon audio amplifier.

Transistor Servicing Techniques

When a vacuum tube receiver is brought to you for repair, you would usually check the tubes before looking for trouble elsewhere in the set. Transistors, on the other hand, have a very long useful life; there is no filament to burn out and no fragile electrodes to become open or short-circuited. Therefore, the chief cause of trouble in transistorized equipment will be defects in the batteries, electrolytic capacitors, and other circuit components rather than in the transistors themselves.

Transistors need not be operated exclusively from battery power. A rectified ac supply will work as well, provided it is well filtered. However, there are many problems involved in obtaining an adequately filtered supply. Transistorized equipment consumes such a small amount of power that it has become common practice to use batteries in preference to an ac-operated supply.

Now let us consider the precautions that should be followed in servicing transistorized equipment.

BATTERIES

Battery voltage can be checked with an ordinary dc voltmeter. A 1000 ohm-per-volt meter is better for this check than a high resistance meter. If a high resistance meter or vtvm is used, add an external resistor to load the batteries. However, a number of precautions should be taken in measuring or replacing the supply batteries. Above all, be certain *never to insert the battery with improper polarity*. It is possible that incorrect polarity will damage the transistors or the electrolytic capacitors. Electrolytic capacitors are polarized; and to keep them small, they must have very low voltage ratings.

Since the small batteries used in most transistorized units have a limited power capacity, a short in the circuit will quickly drain the battery. Therefore, when a battery has become weak faster than normal, check the receiver to see if some circuit component is defective. A check of this type can be made in two ways. You can disconnect one of the battery terminals and connect a current meter in series with the supply voltage line. The current reading should be within the limits set by the manufacturer for the transistorized device being serviced. A higher current drain indicates a defect in the unit. Of course, the defect should be located before the battery is replaced.

Another method of checking battery load is to remove the battery and measure the actual resistance of the load. As you have learned in earlier lessons, an ohmmeter itself contains a battery, and a certain percentage of this battery potential is present across the ohmmeter leads. In electronic devices operating at higher voltages, this small amount of voltage is unimportant. However, in low voltage transistor circuits the ohmmeter voltage and polarity must be considered.

The polarity of this small voltage can be checked with a dc voltmeter. Then, when the ohmmeter is attached to the transistor unit to measure the resistance, the lead polarity should be the same as the polarity of the battery terminals in the transistor unit. For example, if the red ohmmeter lead is positive with respect to the black ohmmeter lead, attach the red lead of the ohmmeter to the positive terminal of the battery holder and the black lead to the negative terminal of the battery holder.

An improper connection of ohmmeter leads will apply a reverse potential to the low voltage rating electrolytic capacitors. If it does not damage the capacitors, the meter reading that you obtain will be the low reverse resistance instead of the true load on the transistor batteries. Also, a reverse potential may damage the transistors. Therefore, some manufacturers advise removing the transistors from the equipment before checking with an ohmmeter.

ELECTROLYTIC CAPACITORS

A second possible source of trouble in transistorized units is the electrolytic capacitors. Those across the battery source itself have very high capacity. Therefore, if these capacitors are defective, the voltage will not be filtered properly. The ac variations in the transistor unit can cause the battery potential to vary and cause oscillations and instability in the transistor circuits.

A capacitor can be either shorted or open. If it is open, there will be no filtering; oscillation and instability will occur in the transistor receiver. If a filter capacitor is either shorted, acting as a low resistance shunt, or is intermittently shorted, the receiver sensitivity will be lost and the battery will be drained quickly.

It might at first seem that because of the very low voltages used in a transistor unit that electrolytic capacitors would not cause trouble. Although the capacity is larger, the working voltage is very small, usually 6 to 50 volts, to reduce the physical size of the capacitor and permit more compact design. By comparison, these miniature capacitors have the same tendency to break down at a low voltage as a capacitor having a higher working voltage does in a higher voltage circuit.

Many capacitor checkers apply a high voltage across the capacitor. This type of check cannot be employed to check miniaturized capacitors used in transistor circuits.

TEST INSTRUMENTS

We have mentioned the importance of connecting test instruments properly so as not to cause damage or improper readings. Signal generators of the usual type also present problems when used to service transistorized equipment. For example, there is usually a small amount of hum in the output of the ordinary signal generator. Because the transistors operate at very weak signal levels, this small percentage of hum can cause a substantial disturbance in the transistorized unit. Therefore, direct signal injection is seldom used. Instead, a small loop consisting of several turns of wire can be used to inject a test signal into the antenna coil of a

Courtesy General Electric

A pocket-size transistor tester.

transistor receiver.

A small, pocket-size tester is available for checking transistors. It will test for short circuits, opens, leakage and current gain, and being designed for transistor use, will test them safely and easily.

SOLDERING AND REPLACEMENT METHODS

More care must be taken in replacing parts in transistorized equipment than in vacuum tube equipment. For example, excess heat will damage the transistors and the small components used in transistor circuits. When soldering and doing replacement work, keep the heat concentrated as much as possible at the soldering junction, and apply the heat only for a short period of time. In fact, it is always advisable to have a large piece of metal somewhere between the nearest component and the solder junction. This can be either a metal tool or metal strip to conduct the heat away from the pigtail lead that connects to a miniaturized part.

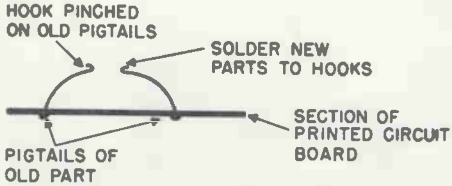


FIG. 30. Replacement of parts in a printed circuit.

Special precautions must be taken in doing work near printed circuit wiring boards. Excessive heat can cause the printed conductors to separate from the board. Likewise, small pieces of solder may fall on the printed conductors and cause shorts and capacitive shunts. Therefore, wipe all excess solder off the joints with a cloth or a small wire brush.

In replacing component parts in a printed circuit unit, a standard recommended procedure is to cut the pigtails of the defective part as near as possible to the defective component itself. This is shown in Fig. 30. The new part can then be soldered to these leads, thus eliminating possible damage to the printed circuit board.

LOOKING AHEAD

In this lesson, we have shown how transistors may be used in practical circuits. These circuits, for the most part, were merely transistorized versions of vacuum tube circuits. However, as more development work is done in this phase of electronics, you can expect to see many new transistor types and circuit applications. For example, experimental tetrode and multi-segment transistors have been recently developed which have some of the characteristics of multi-element vacuum tubes. This is an indication of the advancements that have already been made. Of even more importance to you as a radio-TV serviceman, is the fact that transistors will be used more and more frequently in all types of electronic equipment. With the basic knowledge that you now have, you should have no trouble in repairing transistor circuits, even though they may be somewhat different from those we described in this lesson.

Lesson Questions

Be sure to number your Answer Sheet 25B.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. How may the input impedance of a grounded-emitter transistor amplifier be increased?
2. How would you check the load placed on a battery by a transistor circuit?
3. (a) Which of the three basic transistor circuits most resembles common vacuum tube circuits in operation? (b) Which circuit provides the highest input impedance?
4. What effect does increasing the supply voltage have on the input impedance?
5. What method of coupling is best between two like transistor stages? Why?
6. What effect does the value of the input resistor have on the input impedance of a grounded-emitter stage?
7. What are the effects on a grounded-emitter stage of placing a resistor in the emitter lead?
8. What is the purpose of obtaining base bias through a resistive voltage divider?
9. Why are transistor mixers and detectors operated at zero emitter bias?
10. (a) What basic circuit is generally used in high frequency amplifiers using point-contact transistors? (b) using junction transistors?

ACTION SPEAKS FOR ITSELF

***Be sure you are right, then go ahead*—this has been the motto of many of the world's great men.**

In most cases you know instinctively what is right, your decision being based upon your past training, your experience, your common sense and your conscience. In these cases, *act!* Waste no valuable time arguing with others who know less than you; waste no time trying to "pound" your ideas into a cynical world—take the initiative yourself.

It is a thousand times better to *do things* and let your deeds speak for themselves than to spend time explaining why your proposed course of action is right. Friends can hinder your success if you take time to justify your actions to each one of them.

If you need advice—if you are not exactly certain you are right, then go to men who are capable of giving authoritative answers to your questions. You'll find that successful men are glad to answer serious, well-planned questions. Analyze their advice in connection with your own experiences, make your decision, then act!

Give this plan a tryout. You will accomplish a great deal more work, and you will be a lot happier.

J. E. Smith

LIGHT SENSITIVE CELLS FOR CONTROL CIRCUITS

26B

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE No. 26

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ **1. Introduction** .... **Pages 1-2**

☐ **2. How Light is Measured** .... **Pages 2-5**

In this section you will learn how photocells are put to work, and how light is measured.

☐ **3. How Light Controls Electricity** .... **Pages 6-20**

Here you will learn how each of the three basic types of photocells controls the flow of current in a circuit. A section on manufacturers' ratings teaches you how to select the right photocell for any job.

☐ **4. Light Sources** .... **Pages 21-24**

Simple lens and reflector systems are used to control light and increase the reliability of photoelectric systems.

☐ **5. Photocell Applications** .... **Pages 25-36**

When a photocell is used for control, its output must be coupled to a relay or amplifier. The type of output circuit depends on the use. You will learn to adjust and service these photocell circuits.

☐ **6. Answer Lesson questions.**

☐ **7. Start studying the next Lesson.**

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LIGHT-SENSITIVE CELLS FOR CONTROL CIRCUITS

IN LEARNING to service radio and TV sets, you have studied basic electronic principles. So far in this course, these principles have been applied only to radio and TV circuits. Now you will learn how these principles and many of the same circuits are used for control and measurement.

In this lesson you will study the operation and uses of photocells. A photocell is a device which converts light level changes into voltage or current changes in an electrical circuit.

All of us have daily contact with equipment of this type. Television is one example; talking movies another. There are automatic door openers, automatic headlight dimmers, burglar alarms, and exposure meters. Photocells turn on street lights at night and on dark days. They switch on lighted signs and billboards along the highway. They are used to count traffic on a highway and to open garage doors when an automobile turns into the driveway at night. In a machine shop, equipment is turned off if the operator's hands or feet enter a danger zone. There are hundreds of everyday uses for light control devices.

Servicemen are often called on to install or to maintain this type of equipment. It is definitely not radio; but it is electronic. The average person expects the serviceman to be familiar with all the mysteries of electronics. This is all to the good. You will receive good publicity from any such specialized installation. Your customers will have increased respect for your ability and the profit is good with a very small investment.

Photocell installations may be divided into three main parts. The basic block diagram is shown in Fig. 1. The units are the light source, the photocell, and the control unit or meter. In most cases an amplifier must be between the photocell and the control unit. The control unit may be an ordinary electric meter, a mechanical counter, or a relay.

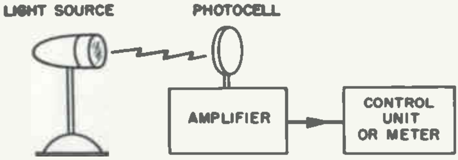


FIG. 1. Basic units of a photoelectric installation.

The light source is one of the main parts of a photoelectric system. Before we take up the study of photocells, we must know the terms used in measuring light. Ratings of photocells are given in terms of light intensity and color.

How Light is Measured

Light is energy in the form of electromagnetic radiation. Light waves are the same as radio waves but much higher in frequency. Green light, for example, has a frequency of about 580,000,000 megacycles, or a wavelength of 20 millionths of an inch. Since such figures are hard to work with and are impossible to visualize, another unit, called the Angstrom, is used in light measurements. The Angstrom unit (abbreviated "A") is one hundred-millionth of a centimeter. Using this measure, green light has a wavelength of 5200 Angstroms. Another unit that is used in measuring light wavelengths is the millimicron, which equals 10 Angstrom units. Thus, green light could also be shown as having a wavelength of 520 millimicrons.

The human eye receives and detects wavelengths from about 4000A to 7000A. Photocells have been made which will work above, below, and within the light sensitive range of the human eye. Fig. 2 is a graph of the response of the human eye compared to the responses of three typical photocells. The markings S-1, S-3, and S-5 refer to the different types of cathode coatings used in these cells. Notice that the three photocells have peak sensitivity at different wavelengths above and below the visible spectrum, but all of them are sensitive to light in the visible spectrum to a certain extent. The colors in the visible spectrum are shown on the wavelength scale below the graph.

MEASUREMENT OF ILLUMINATION

To be able to select, install and properly service a photocell system, you must know four terms used in measuring light intensity.

The first term is *candlepower*. Candlepower is a measure of the intensity of a light source. It is measured by comparison with the light of a standard source. Originally, a special whale oil candle was the standard source, and from this candle the name is obtained. Light output is given in terms of the number of candles needed to give the same amount of light as the source being measured. A four-candlepower light, for instance, gives the same amount of light as four standard candles.

The second term is *foot-candle*. The foot-candle is used to measure the intensity of the light falling on a point. One foot-candle is the intensity of the light which would shine on an object one foot from a one-candle-power source. You can find the number of foot-candles at any point by dividing the candlepower of the light source by the square of the distance from the source. For example, to find the light at a distance of two feet from a four-candlepower source, square the distance, 2 x 2 = 4. Now divide the distance squared, 4, into the candle-power of the source. 4 ÷ 4 is one foot-candle.

The third term is the *lumen*. The lumen measures the total amount of light or light flux which falls on a surface. One lumen is the amount of light which falls on a one square foot surface at right angles to the light rays when the light intensity is one foot-candle. Light flux is generally expressed as lumens per square foot, which is numerically equal to foot-candles. The amount of light in lumens falling on an object will increase as the surface of the object increases, as the intensity of the light source increases, and as the distance between the object and the light source decreases. Thus, a surface of three square feet located two feet from a four-candlepower source receives three lumens of light, or one lumen per square foot. Photocells are usually rated by the amount of current output per lumen of light striking the photocell. The drawing, Fig. 3, shows the relationship between these three terms.

To determine the light flux in lumens falling on any object, divide the candlepower rating of the source by the square of the distance in feet between the source and the object, then multiply by the area of the surface in square feet. For instance, suppose you needed to know the total

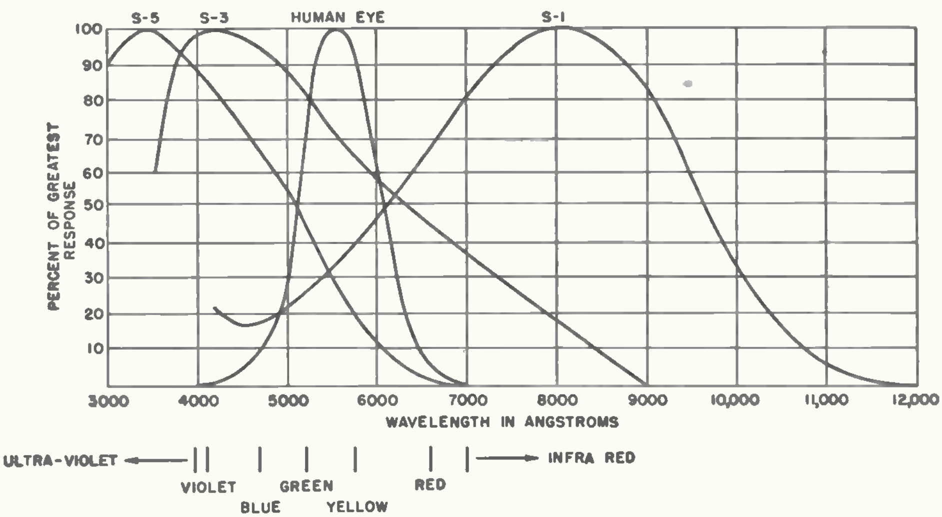


FIG. 2. Color sensitivity of the human eye compared with three typical photocells.

light falling on a photocell with a sensitive surface of two square inches that was located two feet from an eight-candlepower lamp. The distance is 2 feet; the square of the distance will, therefore, be 2 x 2 = 4 sq. ft. Eight candlepower divided by 4 gives

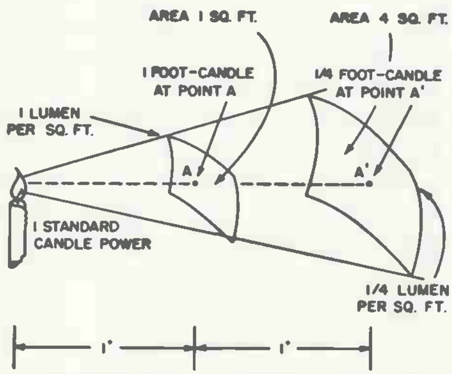


FIG. 3. Illumination standards.

an illumination of two foot-candles, or two lumens per square foot, at the photocell. There are 144 square inches in a square foot so the photocell has a surface area of 2/144 square feet. Multiply the illumination, two foot-candles, by the area, 2/144 square feet. This is 2/144 x 2. Since 2 x 2 is 4, we have 4/144 lumens. You can leave the answer like this or simplify it by dividing both top and bottom of the fraction by 4. You will then get 1/36 of a lumen on the photocell.

To summarize these three terms: Candlepower is a measure of the intensity of a light source; the foot-candle is a measure of the intensity of the light falling on a point a certain distance from the light source; the lumen is a measure of the amount of light falling on a surface, and is also used as a measure of the total amount of light radiated from a light source. The total amount of light radiated from a source is equal to 12.57 times the candlepower. For example, a one-candlepower bulb radiates 12.57 lumens; a three-candlepower bulb radiates 3 x 12.57 or 37.71 lumens.

When light was first measured, the human eye was the only measuring instrument available. For this reason, the terms candlepower, foot-candle, and lumen refer only to visible light. When it is necessary to describe ultraviolet or infra-red radiation, the intensity is given in terms of microwatts of radiant energy at each wavelength. Visible light can also be measured in microwatts of radiant energy, but this measurement is harder to apply and is almost never used when referring to visible light.

The last term concerning light which you should know is *color-temperature*. When a piece of metal is heated, there is no light from it at first. As the temperature increases, the metal glows a very dull red, becoming brighter with increased temperature. Finally, the color goes through orange and yellow to a white light of much higher intensity. The temperature at which a piece of metal will glow a certain shade is different for different types of metal and for different surfaces of the metal. Color-temperature is a means of describing the range of wavelengths emitted by a heated body. Color-temperature does not refer to the actual temperature of the material, which may be either hot or cold, but only to the character of light. It is based on the emission of an imaginary perfect radiator at different temperatures. This temperature is measured on the Kelvin or absolute

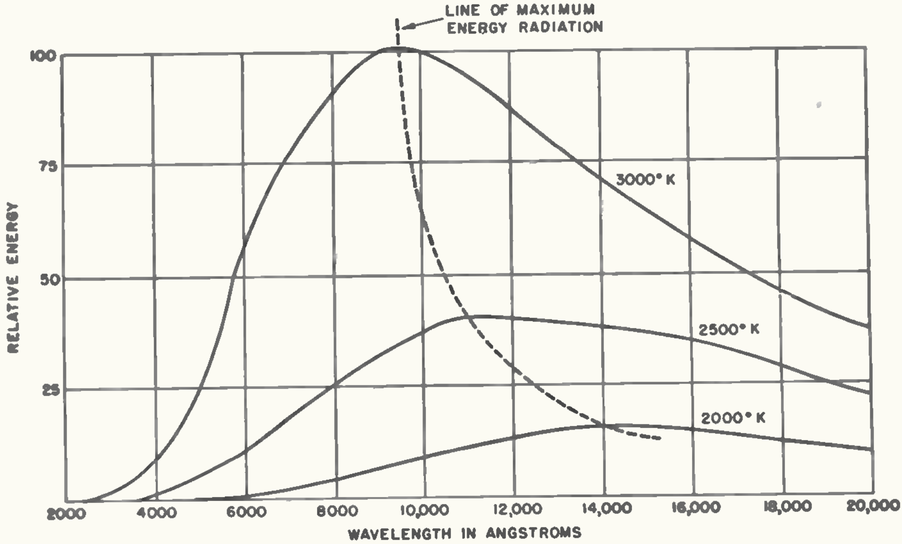


FIG. 4. Distribution of energy and shift of wavelength of maximum radiation with change in temperature.

scale. At 0°K there is no radiation; water freezes at 273°K and boils at 373°K.

If a light is said to have a color-temperature of 2870°K, it means that the light is the same as would be emitted by a perfect radiator at this temperature. As the color-temperature becomes higher, the wavelength of the light emitted becomes lower, while the total energy emitted by the body and the value of the peak emission becomes larger. This is shown by the curves of Fig. 4. Some typical examples of color-temperature are as follows: The common household light bulb has a color-temperature of about 2200°K; sunlight has a color-temperature of 6000°K; the light from a TV picture tube may be anywhere from 5000°K to 7000°K, depending upon the tube coating and the voltage used on the tube. The color-temperature of clear blue sky is 25,000°K.

It is interesting to note that blue sky, which we know is very cold, has the highest color-temperature. The face of a TV picture tube which is not warm to the touch has a color-temperature three times as high as a light bulb hot enough to raise a blister. There is no relationship between the temperature of a body and its color-temperature.

How Light Controls Electricity

Many different types of photocells are in use today. Just as tube designers developed many kinds of vacuum tubes for radio purposes, so the photocell designers have developed tubes with special characteristics for special uses. For study purposes we will divide these types into three general classes. The breakdown which we use is on the basis of the reaction of the cell to light. This reaction also affects the type of circuit in which the photocell is used. The three main types of photocells are *photoemissive, photoconductive*, and *photovoltaic,* as shown in Fig. 5.

In the photoemissive cell, light falling on a special cathode surface causes electron emission. This cell can be thought of as a vacuum tube diode with a cold cathode. In this type of cell the current flow through the circuit is directly controlled by the action of the light.

In the second type, the photoconductive cell, light changes the ohmic resistance. This cell may be thought of as a resistance which varies with changes in light.

Both of the preceding types of photocell require the application of an external voltage. The photovoltaic cell, however, develops a voltage when exposed to light. This cell may be thought of as a dc generator whose current output varies with the light intensity. This is the only type of cell which can convert light directly into electricity and does not require an external power source.

The action of each type of cell is shown in the diagrams of Fig. 5. Note that both the photoemissive and photovoltaic cells have definite polarities indicated. Electrons can pass in only one direction through the emissive cell, and the emf generated by the photovoltaic cell has a positive and a negative polarity. Only the conductive cell is independent of the polarity of the applied voltage or external circuitry.

These three major types of photocells differ in their reaction to light. Thus, each type will be studied separately.

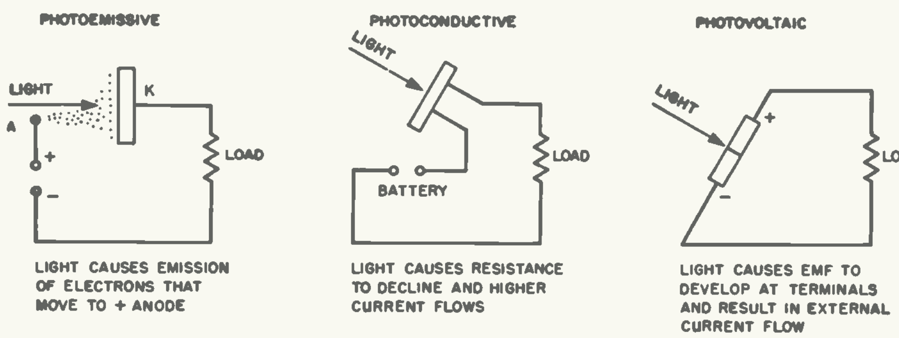


FIG. 5. Types of photocells.

PHOTOEMISSIVE CELLS

This is the only photocell which is a true electron tube. It is the easiest to use in electron tube circuits, and is the most common type in control circuits.

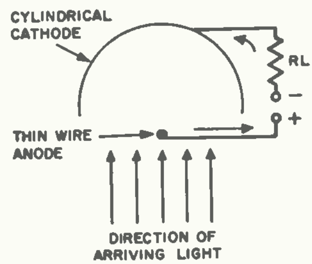
You will recall from your earlier lesson on radio tubes that electron emission can be caused in four ways. Electrons can be driven out by applying heat; they can be driven out by bombardment with very small high speed particles, such as other electrons; they can be driven out of some materials by the energy in light rays; and they can be jerked out by a very high positive potential. In our study of photocells we will be concerned with the second and third methods.

Vacuum Photocells. The simple diode phototube, shown in Fig. 6, contains a half cylinder cathode structure and a thin wire anode. The photosensitive material is deposited on the cylindrical cathode. The total emission from the cathode depends upon the area of the cathode and the amount of light striking it. Therefore, the cathode surface is made as large as possible to obtain the greatest sensitivity.

Even though the photoemissive surface is made large, the actual photoelectric current is very low. Hence, it is possible to use a very thin vertical anode as shown in the photograph. A thick anode would be a disadvantage because it would block more of the light that enters the envelope of the tube and prevent it from striking the photoemissive material.

The photoemissive material used on the cathode is made up of metals and oxides of metals. The choice of the metal used depends upon the use to which the photocell will be put. By selecting the proper materials for the cathode coating, the tube can be made to respond to light of different colors. It is possible to have the tube respond like the human eye; it is also possible to make the tube respond to ultraviolet or infrared light which the human eye cannot detect. The curves in Fig. 2 show the relative response of the human eye and three different photocell cathodes.

A second consideration in choosing cathode coatings is the emission of electrons under the pull of a potential difference. The perfect coating mate-



Courtesy RCA Tube Division

FIG. 6. Diode phototube with octal base (vacuum).

rial would emit many electrons in the presence of light, but no electrons at all in the dark. It is unfortunate, however, that most materials which have great photosensitivity also emit electrons in the presence of an electric field such as exists between the anode and the cathode. This emission, due to the electric field which is always present whether or not light falls on the cathode, is called "dark current." The presence of this dark current sets a lower limit on the amount of light which can be measured with a photocell. Very low light levels may not cause the emission of enough electrons to be measurable in the presence of the dark current.

An external current flow results when a load resistor and proper anode-to-cathode voltage are connected. Light striking the cathode causes the photoemissive surface to release electrons. These electrons are drawn to the positively charged anode. If the light is increased, more electrons will be released from the cathode surface; if the light is decreased, less electrons will be released. In this way the light on the cathode controls the flow of current through the output load resistor. The IR drop across the resistor is the output signal voltage.

The output current of a phototube is very low—around 10 to 20 microamperes. It is far too low to directly control most relays, and must be amplified before it can be used.

The output current of a vacuum photodiode is quite linear with changes in light intensity; its action is fast and its ability to follow light modulation or light pulses can be considered unlimited for our purposes.

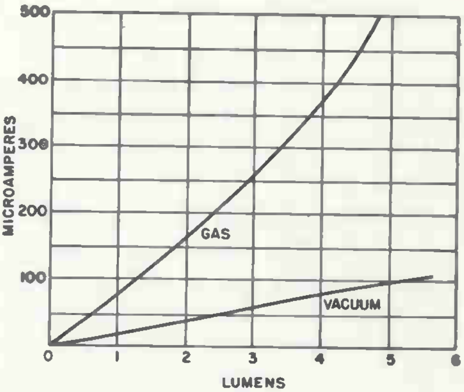


FIG. 7. Response of typical vacuum and gas photocells.

The low current output of a vacuum photocell requires considerable amplification before it can be put to use. To reduce the number of external amplifier stages necessary, two methods are used to obtain current amplification within the tube. These methods can be understood by studying the gas and the multiplier phototubes.

Gas Photocells. Earlier in the course you learned that the effective resistance of a diode can be reduced by inserting a small amount of gas into the tube. When this is done, each electron emitted from the cathode and drawn to the anode will knock additional electrons off the gas molecules. These additional electrons are drawn to the anode along with those emitted from the cathode. In this way the current through the tube may be multiplied as much as ten times. This increase in sensitivity, however, is not obtained without disadvantages. For every electron gained this way, a heavy gas ion is left behind. These heavy positive ions move much more slowly than the electrons. Because of their slow movement, the response of the tube to high frequency light pulses is greatly reduced. The tube is less linear when filled with gas, its sensitivity varies with both temperature and voltage, and its characteristics are less permanent. The gas-filled tube is used most when the presence or absence of light and ON-OFF switching is required. The vacuum tube is more suitable when the amount of light is the important item. Fig. 7 shows typical response curves for gas and vacuum photocells. These curves show the output of the tubes in microamperes for different amounts of light on the photocathode. Fig. 8 shows the comparative anode currents and anode volts for typical gas and vacuum photocells. The amount of light falling on each of the photocells was not changed in making this graph. This curve shows that beyond about 20 volts on the anode, the response of the vacuum cell is independent of the anode voltage; on the other hand, the output current of the gas cell rises rapidly with increasing voltage. This varying response of the gas cell limits its use, since any variation in supply voltage will change the output current. The dark current of a gas phototube is higher than that of a vacuum tube using the same cathode because gas amplification takes place whether or not light shines on the photocathode.

In using gas phototubes, three precautions are required. The anode voltage should be kept below 90 volts. The illumination should be no greater than necessary for proper operation. The maximum anode current given in the manufacturer's data sheets should not be exceeded. If these measures are not observed, the electrons leaving the cathode may cause the gas to glow. When this happens, the current will be limited only by the resistance in the external circuit. Even if the illumination is removed, the tube will continue to conduct. This conduction can be stopped only by removing the anode voltage. The heavy positive ions in the tube are drawn to the cathode. If too many heavy ions bombard the cathode, its surface will be destroyed. To prevent this condition, it is customary to use a current-limiting resistor of not less than 100,000 ohms in the anode circuit of a gas diode photocell.

Photo-Multipliers. Where vacuum photocells have output ratings of 5 to 10 microamperes per lumen of light, and gas tubes have ratings of 50 to 100 microamperes per lumen, electron-multiplier phototubes have rated sensitivities of around 10 amperes per lumen. This high sensitivity rating is obtained by current multiplication within the tube.

Even though the rating of the tube is given in amperes per lumen, it must be understood that this figure measures the sensitivity of the tube to light changes and does not give the current that the tube will pass. A typ-

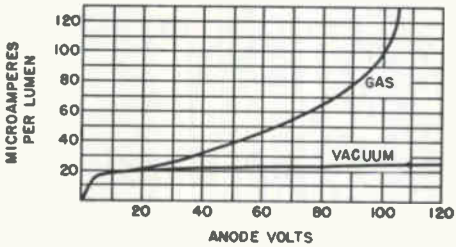


FIG. 8. Current-voltage curves for typical photocells.

ical tube with a sensitivity rating of 20 amperes per lumen is rated by the manufacturer for 750 microamperes average anode current with a peak anode current of only 7.5 milliamperes.

The high current multiplication of this tube is obtained by secondary emission; that is, the ability of a high speed electron striking an emitting surface to dislodge more electrons. The internal structure of a typical photomultiplier is shown in Fig. 9A. Note that there are eleven electrodes in this tube. One electrode is the photocathode, nine are dynodes and the eleventh is the anode. The photocathode and anode of this tube are similar to those in the photodiode. However, the dynodes of this tube are coated with material which has a high secondary emission rating. In operation, each dynode has a slightly higher voltage than the one preceding it.

Light entering the face of the tube strikes the photocathode and dislodges electrons. Each electron is drawn to dynode No. 1 where it dislodges two or more electrons. The electrons are drawn from one dynode to the next, releasing two or more additional electrons at each dynode.

As an example, consider a phototube with ten dynodes. Each of these dynodes is coated with a substance which releases two electrons for every electron which strikes it. Each electron striking the first dynode will release two additional electrons. These two electrons striking the second dynode will release four and so on until 1,024 electrons are released from the tenth dynode and collected by the anode. If three electrons were released at each dynode, 59,049 electrons would be collected by the anode. If four electrons were released, slightly over one million electrons would be collected by the anode for each electron which left the photocathode.

A second type of internal structure is shown in Fig. 9B. In this case the photocathode is deposited on the glass of the tube, and an accelerating electrode is used to attract the emitted electrons to the first dynode.

The number of electrons dislodged from a dynode by each electron which strikes it depends upon the coating of the dynode and the speed of the electron which hits it. The speed of the electron moving from one dynode to another is controlled by the voltage

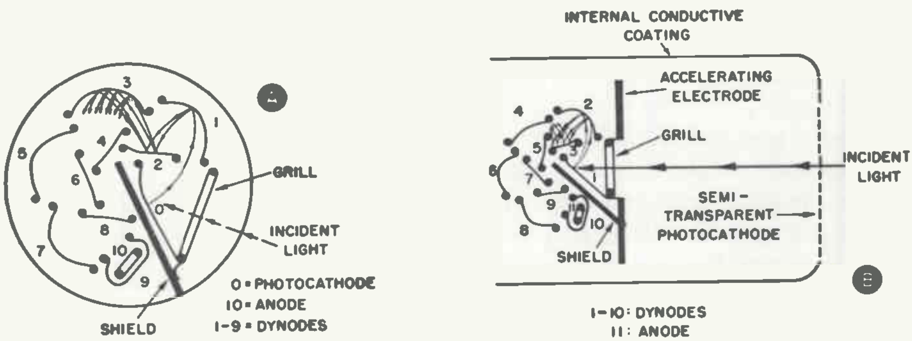
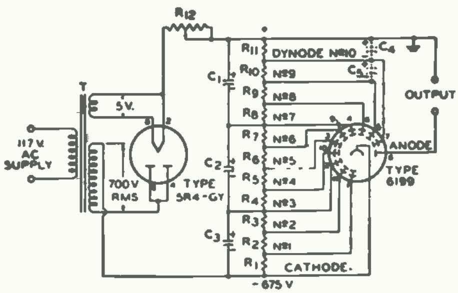


FIG. 9. Multiplier arrangements in photomultiplier tubes.



Courtesy RCA Tube Division.

FIG. 10. Power supply and connections for multiplier phototube.

difference between the dynodes. If the voltage is increased, the electron will travel faster and pick up more energy. When a fast-moving electron strikes a dynode, it can dislodge more electrons than a slower one. Since the current multiplication within a tube is dependent upon the voltage, it is customary to provide some means of controlling or changing the supply voltage for the tube to control the gain.

Fig. 10 shows a typical power supply and the connections for a multiplier phototube. In practice, dynodes are usually operated at a voltage difference of 50 to 100 volts. The voltage difference between the cathode and the first dynode is usually higher than that between the dynodes.

PHOTOCONDUCTIVE CELLS

When light falls on a thin layer of semi-conductor material, such as selenium, germanium, or cadmium sulphide, the resistance of the material varies with the light intensity. The higher the light intensity, the lower is the resistance of the semiconductor material. This variable resistance characteristic is the basic operating principle of the photoconductive cell. The cell generates no voltage. Thus, to obtain a current change in the output circuit, an external voltage must be applied to the cell terminals.

Selenium Photoconductive Cell. The earliest type of photoconductive cell was composed of a thin layer of selenium deposited between two metallic conductors. The basic construction of this type is shown in Fig. 11. Notice that interlacing the foil plates increases the total length of the gap between the plates and, hence, the amount of selenium that can be exposed to light. The longer the gap between the conductors, the more sensitive is the selenium cell. Connections to the external circuit are made at the foil plates. An external potential must be applied to this type of cell; light falling on the selenium causes its resistance to change which produces a current change in the external circuit.

Crystal Photoconductive Cell. The Clairex CL-1 crystal photocell shown in Fig. 12 is another semiconductor device that is sensitive to light. It consists of a small crystal (only a few square millimeters) of pure cadmium sulphide imbedded 1/8 inch from one end of a transparent plastic cylinder 1/4 inch in diameter

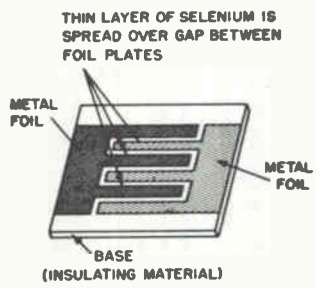
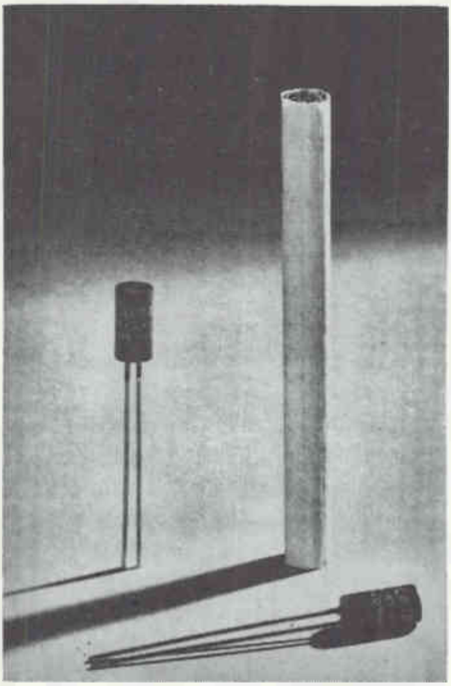


FIG. 11. Basic construction of the selenium cell.



Courtesy Clairex Corp.

FIG. 12. Clairex CL-1 crystal photocell.

and ½ inch long. This end of the cylinder is left unpainted, providing a window for the light to enter and strike the crystal.

As in the selenium photocell, the resistance of the crystal varies with the light intensity falling on it. With a supply voltage of 100 volts applied to the cell, the dark current (current flow with no illumination) is only 0.05 microampere. However, a light intensity of two foot-candles and an applied voltage of 100 volts causes the current to increase to 100 microamperes, which shows that the cell is quite sensitive.

Germanium Photoconductive Cell. A third type of photoconductive cell can be made of N-type germanium, as shown in Fig. 13. You will recall that in germanium, the number of free electrons can be increased by applying some form of external energy to increase intrinsic conduction. In the case of the germanium photocells, this energy is light.

When light falls on the germanium photocell, the output current increases because the light energy frees electrons from their valence bonds, and reduces the resistance of the germanium.

When a voltage is applied to the ends of the germanium bar, the electrons will be drawn to the positive terminal. The amplitude of the external current, of course, will depend upon the intensity of the light falling on the semiconductor material.

PHOTOVOLTAIC CELLS

Of the photocells that we have discussed in this section, the photovoltaic is the only type that generates a dc voltage when exposed to light. For many years, the selenium photovoltaic cell was the only type available. However, with the development of the transistor and crystal diode, several new types of photovoltaic cells have appeared.

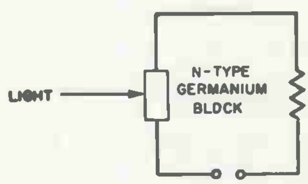


FIG. 13. Germanium photoconductive cell or photo-resistor.

Selenium Photovoltaic Cells. A typical selenium photovoltaic cell, shown in Fig. 14A, is composed of a metal base upon which are deposited several coats of selenium to serve as a light sensitive surface. A very thin film of another metal, such as gold, silver, or platinum, is then deposited over the selenium. This metal film, which is the negative electrode, is so thin that light will readily pass through it and strike the light-sensitive material. A metal ring is placed around the outer edge of the cell in contact with the metal film. The ring serves as a connection to the negative electrode; the base serves as the positive electrode.

When light energy strikes the cell, it passes through the transparent electrode and causes the selenium to release electrons. The surface between the metal film and the selenium, called the barrier layer, permits current to flow easily in one direction, but opposes current flow in the opposite direction. This barrier layer is formed by special treatment of the selenium during the manufacture of the cell. The electrons released by the light energy move easily from the selenium, through the barrier layer, to the front electrode to form the negative charge. The number of electrons that collect on the front electrode depends upon the light intensity. The higher the light intensity, the more negative will be the charge on the front electrode. The electrons cannot move back to the selenium because of the unidirectional characteristics of the barrier layer. Since the base now has a shortage of electrons, it becomes positively charged.

When an external circuit consisting of a sensitive meter, as shown in Fig. 14B, is connected to the cell electrodes, the electrons in the front, or negative, electrode move through the external circuit and return to the positive base

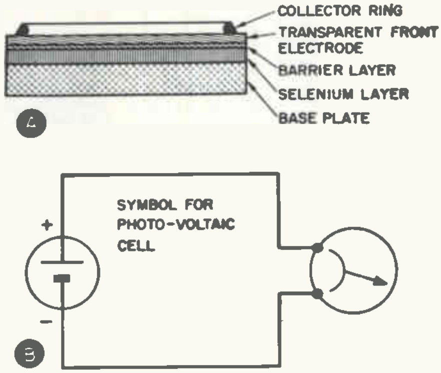


FIG. 14. A selenium photovoltaic cell.

electrode. The amount of current that flows through the circuit depends upon the intensity of the light falling on the cell, and the external load resistance. The effect of the light intensity and load resistance on the output current of two sizes of selenium cells is shown in Fig. 15.

The chart in Fig. 15A shows the output current flow for a cell with a one-quarter square inch active surface. Fig. 15B shows the output current for a larger cell which has a three-quarter square inch active surface. By comparing the curves you can see that the larger the selenium cell, the higher is its current output for a given light intensity. Also, the lower the external resistance, the more linear is the output current with changes in light intensity. Therefore, the size of the cell and the external load to use in a certain circuit depend upon the circuit application. For accurate light meters and other linear devices, a linear relationship must be established between the arriving light and the output current. However, if the photocell is to be used to operate relays, the photocell size and the output load can be chosen to obtain the maximum output power

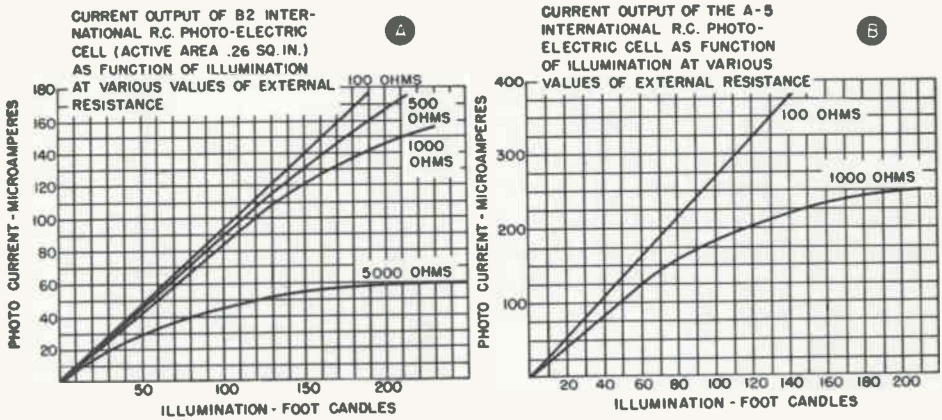


FIG. 15. Effect of light intensity and load resistance on the output current of two sizes of selenium cells.

without regard to linearity.

The output current of some selenium photovoltaic cells can be increased by connecting an external voltage source in series with the cell and the controlled device, as shown in Fig. 16. Because the resistance of the selenium goes down as the light intensity goes up, the resistance of the cell decreases with increased illumination. The total series resistance of the circuit, therefore, decreases and allows a higher current to flow from the battery source. The current produced by the battery adds to that from the cell, producing a higher current in the relay circuit. The presence of the battery in the circuit decreases the linearity of the photocell. This must be considered when the cell is used in light meters and other applications where linear response is important.

The frequency response of the selenium photovoltaic cell is limited when compared with the vacuum phototube. The capacity between the front and back electrodes is quite high and shunts high frequency currents in the output away from the load. However, the cell can record light fluctuations up to 10,000 cycles per second. Smaller cells will operate at even higher frequencies because the capacity is less than in the larger cells.

Germanium Photodiode Cell. A photovoltaic cell can be formed by using a block of germanium containing both N- and P-type sections, as shown in Fig. 17. As you learned in the transistor lesson, a P-N junction is set up at the point where the germanium types join. The action of the P-N junction is similar to the barrier layer in the selenium photovoltaic cell; electrons flow more easily in one direction than in the other. However, because the current carriers in P-type

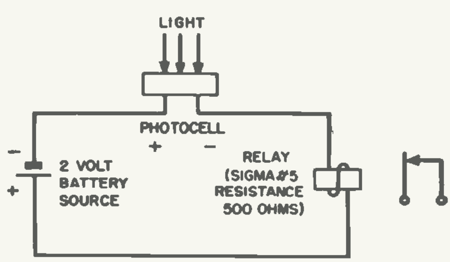


FIG. 16. Photocell amplifier circuit.

germanium are holes instead of electrons, there will also be a positive current flow in the opposite direction when an external voltage is applied. Now let us see how the germanium photodiode operates.

With no external energy, such as light or voltage, applied to the germanium sections, a depletion layer is formed at the P-N junction. In the depletion layer, holes in the P section and electrons in the N section are forced away from the junction. The depletion layer prevents the exchange of electrons and holes between the two sections. When light is focused on the

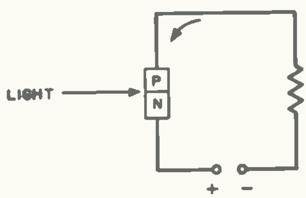


FIG. 17. Photodiode connections.

P-N junction, however, holes will move from the P-type germanium, through the junction, and into the N-type germanium. Electrons will move in the opposite direction—from the N-type to the P-type germanium sections. The resultant current flow will develop a voltage across the terminals of the photodiode. With a sensitive relay connected to the cell terminals, the current flow through the circuit is enough to operate the control unit. The cell does not require an external voltage source. However, the current output is extremely small, and to obtain a higher output voltage, an external supply is usually inserted in series with the photodiode and the load.

As you know, there are two methods of biasing a P-N junction, the forward direction or the reverse direction. When biased in the forward direction (negative voltage to the N-type section and positive voltage to the P-type section), there will be a high current flow that changes only slightly when light falls on the cell. With a reverse bias supplied to the semi-conductor sections (positive voltage to the N-type and negative voltage to the P-type), there will be a very small dark current flow because of the opposition at the P-N junction. Light falling on the cell, however, causes free electrons and holes to flow toward their attracting terminals to produce a high current flow in opposite directions through the germanium material. For this reason, the photodiode cell is usually biased in the reverse direction, as shown in Fig. 17.

Photo-transistor. The physical structure and biasing arrangement of the photo-transistor shown in Fig. 18

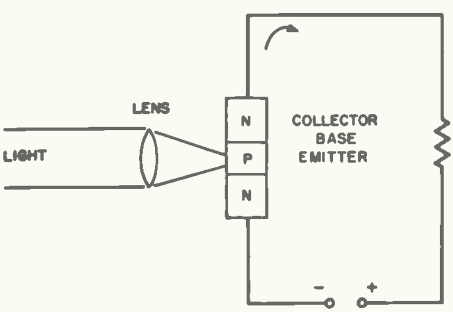


FIG. 18. Photo-transistor connections.

is similar to the conventional three-electrode transistor. It is composed of two P-N junctions, with the emitter junction biased in the forward direction and the collector junction in the reverse direction. No base lead is used on the photo-transistor.

The construction of the photo-transistor is such that either the emitter or the base is made photosensitive. When light strikes the photosensitive area, electrons are released into the collector region which produces an increase in the collector current. Again, the amplitude of the output current depends upon the light intensity.

The photo-transistor has a higher output current for a given amount of light excitation than the photodiode. However, a smaller amount of dark current is produced in the photodiode output as compared to the photo-transistor. Where the light-to-dark current ratio is important, use the photodiode. In circuits where you need a higher output current, use the photo-transistor.

Both types of germanium photo-voltaic cells are very small physically. Thus, to obtain the most efficient use of the available light, a small lens system is usually required. The lens concentrates and focuses the light on the tiny photosensitive surface.

PHOTOCELL RATINGS

In order to install photoelectric systems you must know what each item of the system can do. You should be familiar with the methods used by manufacturers to rate the different types of cells.

You will be called upon to service systems which have been in use for many years. In some cases no installation or service information will be available. When this happens you will need to work out your own adjustment procedure from your knowledge of photocell systems and the manufacturers' ratings on photocells.

In a few cases you will not be able to obtain direct replacements for the photocell. You will then have to choose a substitute. To handle these jobs, compare the characteristics of the cells available on the market with the requirements of the system. You must understand the meaning of each of the items listed in the manufacturer's rating sheet to do this.

The methods used for rating the three different kinds of cells differ slightly. For this reason each type of cell will be taken up separately, and the terms used to describe its operation will be explained.

Photoemissive Cell Ratings. When you look over the data sheet for a photoemissive tube, you will find many familiar items. In addition to the usual diode tube ratings, there will be the bulb size and shape, type of base, a diagram showing connections to the elements, mounting position, maximum anode supply voltage, peak and average cathode currents, and interelectrode capacity. These items all have the same meaning as for a diode rectifier or detector.

There will also be additional ratings applying only to phototubes. We will take up these ratings and their meanings one at a time.

Luminous Sensitivity. This information will be given for vacuum and gas phototubes in microamperes per lumen. In the case of photo-multipliers, it will be given in amperes per lumen. This sensitivity is generally measured at low light levels, about one-tenth of a lumen. The light source for these tests is a standard lamp. The color of the light given off by this

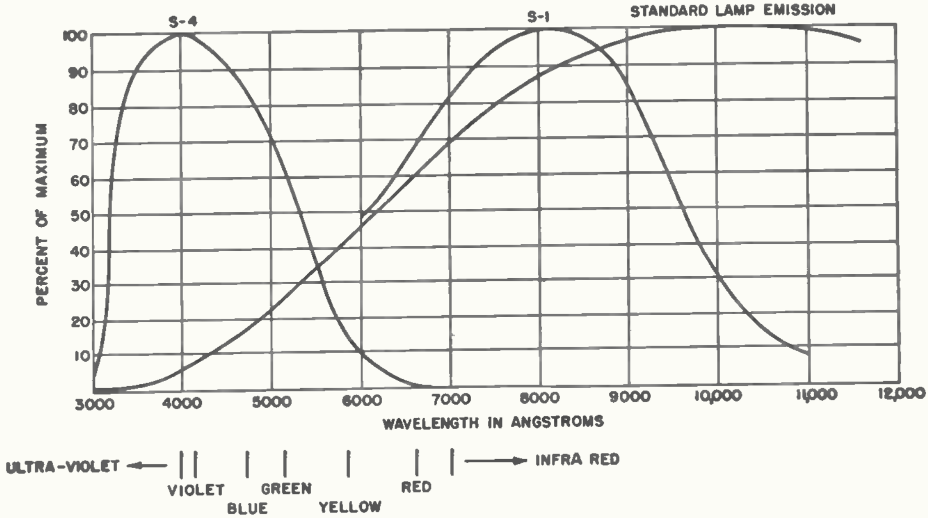


FIG. 19. Relative response of S-1 and S-4 photocells to standard lamp.

lamp is of great importance in determining the sensitivity. Luminous sensitivity ratings are accurate only for the light source with which they are made.

Fig. 19 shows the spectral response of two different cathode surfaces and the emission characteristics of a standard lamp. As you can see, the maximum response of the S-1 photocathode is much nearer the maximum emission point of the lamp. Also, a tube with an S-4 cathode would have a much greater output in blue or white light than a tube with an S-2 cathode, even if both had the same luminous sensitivity rating when used with a standard light source. Gas photoemissive tubes will also show the average sensitivity when a modulated light beam is used as the source, as would be the case if the cell were used for sound pickup from motion picture film. The output falls off as the modulation frequency increases. A rating of this type is not necessary with vacuum phototubes since their output is constant regardless of the modulation frequency.

Cathode Dimensions. The size of the cathode will be given in minimum projected length and width. These values may or may not agree with the physical dimensions of the cathode. If the cathode is a flat surface, the dimensions will be the same; but if the cathode is rounded or curved, the physical dimensions will be greater than the projected dimensions. You will recall that the definition of light flux in lumens was given in terms of the light which fell on a flat surface at right angles to the path of the light. Refer to Fig. 20A which shows a half-cylinder cathode. The radius of this cathode surface is one-half inch and its length is one and one-quarter inches. The actual area of the cathode is 1.96 square inches. However, this area does not receive equal light distribution over its entire surface. Fig. 20B shows the distribution of parallel light rays over the surface of a curved cathode. More light strikes the center than the edges. The light rays are, however, evenly distributed along line AB. This line, AB, is the projected width. The effective area is the area of the opening of the cathode. In determining the amount of light striking a cathode, it is much easier to use a projected area than to calculate the distribution over a curved surface.

Maximum Dark Current. The dark current is the electrode current which flows when there is no light shining on the photocathode. This current is always present in any installation.

Spectral Response. The spectral response will be given in terms of certain standard photocathode surfaces. Several of these responses have been shown graphically in the illustrations of this lesson. Fig. 2 shows the spectral response curves for S-1, S-3, and S-5 cathode surfaces. In addition to the spectral response curve type, the wavelength of maximum response will also be given. The reliability of many photoelectric systems can be greatly increased by matching the spectral response characteristics of the photocell with the spectral emission characteristics of the light source.

Peak Cathode Current Density. In cases where the incident light does not strike the entire photocathode, a reduced limit must be placed on the

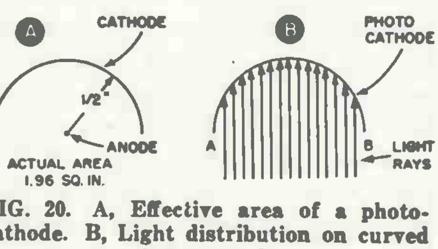


FIG. 20. A, Effective area of a photocathode. B, Light distribution on curved photo-cathode.

current through the tube. If only a small portion of the cathode is used, it may not be possible to draw the maximum peak anode current listed in the data without damage to the cathode. The peak cathode current density gives the maximum current in microamperes that can be drawn from one square inch of cathode surface. If less than one square inch of cathode is used, the peak current must be reduced in proportion.

Equivalent Noise Input. This rating is used with photo-multiplier tubes. The dynode secondary emission is not constant, but fluctuates, generating a noise signal. The amplitude of this noise signal is given as the equivalent noise input in terms of the light flux on the photocathode which would produce the same output power.

Photoconductive Cell Ratings. In selecting a cell of this type, necessary information includes the physical size, the active surface area, the operating voltage, the operating current, the spectral response, and a curve showing the response to different frequencies of light modulation. The luminous sensitivity of these cells is generally given as the ratio of light-to-dark resistance for a change in illumination of a certain number of candles at some particular operating voltage.

Maximum power output from these cells is obtained when the load has the same resistance as the cell. The resistance of the cell varies with the amount of illumination in a non-linear fashion. For this reason, curves showing the resistance of the cell for different illuminations are needed to properly match the load to the cell. Maximum current through the cell is

Cell No.	Size	Average Output (microamperes)*	Recommended External Resistance for Maximum Wattage Output (Ohms)
A15	2" diam.	750	200
A10	1-3/4" diam.	500	300
A5	1-1/8" diam.	250	800
B10	1-11/16"x7/8"	340	400
B5	1-7/16"x41/64"	220	700
B2	23/32"x7/16"	75	1000

* At 100 ft. candles illumination and 100 Ohms external resistance.

FIG. 21. Typical selenium cells.

obtained with the lowest value of load resistor, not at the value of load resistor at which the power output is greatest.

Photovoltaic Cell Ratings. These cells are sometimes rated in microamperes of output per lumen of light, but the newer small types are rated in microamperes per foot-candle. The rating in microamperes per lumen is very high, but the sensitive area is very small, so this rating is of little value. Needless arithmetic is saved by giving the rating in foot-candles.

As in the case of photoconductive cells, the manufacturer's curves must be used to obtain the maximum power output for any given illumination. If the amount of illumination is not known and cannot be measured, or if the manufacturer's curves are not available, you will have to determine the proper value of load resistance by experimentation. Fig. 21 shows the information given by one manufacturer for six of his cells. Comparing the data given in the table of Fig. 21 with the information on the curves of Fig. 15, you will see that the current output is not linear with respect to illumination at the recommended load resistance for maximum power. The greatest current output and the greatest linearity are obtained by use of the lowest possible value of resistance in the output circut. When a relay is actuated directly by a photovoltaic cell, the resistance of the relay coil should have the value recommended for maximum power output. When the cell is used for light measurement, it is better to use a very low value of load resistance so that the output current will rise linearly with the illumination.

When you want to increase the sensitivity of the photocell with an external battery, as shown in Fig. 16, you must also have data on the effect of light on the variation of the internal resistance. Typical data of this type is shown in Fig. 22. These curves show

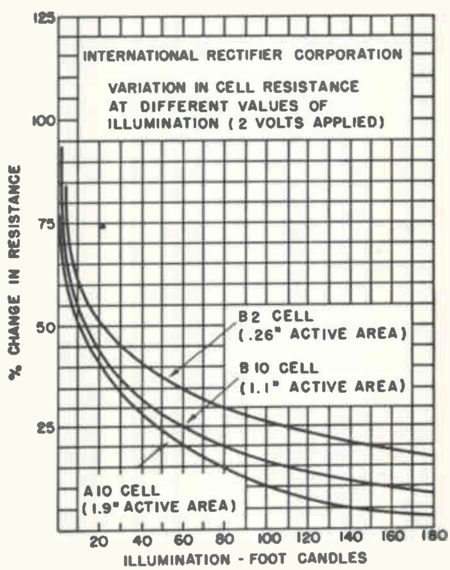


FIG. 22. Variation in cell resistance for typical selenium photovoltaic cells.

	Photo-Transistor 10A	Photo-Transistor 10B	Photo-Diode 5B	Photo-Diode 5C	Photo-Resistor 11A	Photo-Resistor 11B
Operating Temperature Range	0° to 50° C	0° to 50° C	0° to 50° C	0° to 50° C	0° to 50° C	0° to 50° C
Operating Range	1 - 10 V	1 - 10 V	1 - 10 V	1 - 10 V	1 - 10 V	1 - 10 V
Maximum Operating Voltage	15 Volts	15 Volts	50 Volts	50 Volts	15 Volts	15 Volts
Dark Current	500 micro amp. max.	50 micro amp. approx.	20 micro amp. max.	5 micro. amp.approx.	4000 ohms approx.	4000 ohms approx.
Sensitivity	Greater than 4 ma. per 300 ft. candles	50% minimum increase in current per 10 ft. candles	Greater than 1 ma. per 300 ft. candles	50% minimum increase in current per 40 ft. candles	Resistance changes from 4000 to 2000 ohms when placed in flux of 300 ft. candles	50% change in resistance per 300 ft. candles
Operating Current	10 ma.	2 ma.	5 ma.	1 ma.	10 ma.	10 ma.
Maximum Internal Power Dissipation	100 milliwatts	100 milliwatts	100 milliwatts	100 milliwatts	50 milliwatts	50 milliwatts

FIG. 23. Operating characteristics of typical germanium photocells.

only the percentage change of resistance. In addition, the dark resistance or the dark current must be known at the applied voltage. This information can be obtained from manufacturer's curves.

Tabulated characteristics comparing the operation of six different germanium photosensitive units are shown in Fig. 23. Four of these units are photovoltaic, and two are photoresistive. Since all these units are physically very small, the manufacturer has given no dimensions. Tables of this type are useful in selecting substitute photosensitive units when direct replacements are not available. You can get additional information such as variation of internal resistance and proper load for maximum power output from curves for the particular photosensitive unit selected.

Light Sources

Whenever a photocell is used for measurement or control, there must be some source of light. When daylight or the light in a room is used as the controlling light, nothing can be done to change the character or intensity of the light. In other cases, however, a special light source is required. The choice and adjustment of the light source can make the difference between success or failure of the entire system. Not only must the type of light source be chosen with care, but also you must make the best possible use of the light. In the following pages you will learn how lenses and reflectors can be used to improve a photoelectric system, by making the best possible use of the light source.

OPTICAL AIDS FOR PHOTOCELLS

To see how lenses or reflectors may make a photocell system more efficient, let us assume that we will operate a photocell six feet from its light source. The photocell has a sensitivity of 100 microamperes per lumen; the cathode surface is one square inch in projected area; and for reliable operation, 20 microamperes of current are needed at the output.

We can divide the required output by the sensitivity to obtain the light needed at the photocell cathode. This information, along with the size of the photocathode and the distance from the light to the photocell, enables us to calculate the intensity needed for the light source. This comes out to 1,037 candlepower.

Ordinary Mazda lamps run about one candlepower per watt; we need either a pretty big bulb or a much more sensitive photocell. What we want is a way to make the photocell appear bigger or the distance from the light to the photocell appear smaller. Both these things we can do, easily and cheaply.

Use of Lenses in Photocell Systems. First, we will make the distance between this source and the photocell appear smaller by means of a lens. The left-hand side of Fig. 24 shows a 32 candlepower bulb used with a 3-inch diameter lens. The lens is chosen so that the rays leaving it are parallel, forming a beam 3 inches across.

Using a 32 candlepower bulb without the lens, we have .0062 lumen on the photocell. With the lens the light on the photocathode is .124 lumen. This lens has the same effect as dividing the distance from the bulb to the photocell by 20.

We have made the distance from the light to the photocell appear smaller but this alone is not enough in this case.

We will, therefore, use the second

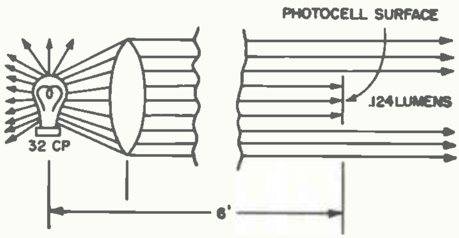


FIG. 24. Use of lens with light source to increase light intensity.

method of increasing the sensitivity of the system, making the cathode of the photocell appear larger.

At some time you have most likely used a simple magnifying glass to look at a small object. We will use the same principle here to make the photocell cathode appear larger. In this case we will use a magnifying lens the same size as that used with the light source. This lens will gather all the light of the beam and direct it at the photocathode. This is the arrangement shown in Fig. 25. When we add the second lens to our system, the light

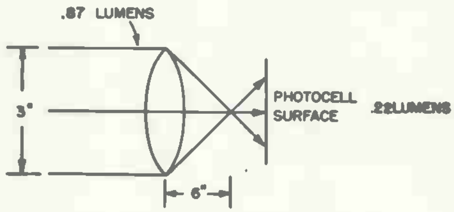


FIG. 25. Use of lens to increase total light on photo-cathode.

at the photocathode will increase to .22 lumen. This is slightly greater than the value necessary for proper operation of the phototube. Using two lenses between the light source and the photocell has enabled us to use a small 32 candlepower automobile headlamp in place of the large 1000-watt light.

Look again at Fig. 25; you will see that we have not placed the photocathode where the light rays come together. If we had done so, all the light in the beam would have fallen on a very small portion of the photocell. If only 1/10 of the photocathode received light and we had 21-microamperes output, the small portion of the cathode which was illuminated would have to emit current at a rate of 210 microamperes per square inch. This could easily be in excess of the cathode current rating of the tube. The intense light on a small area of the cathode would damage the photo surface, and greatly shorten the life of the tube.

By placing the photocathode farther from the lens than the point of convergence, the light is spread over its entire surface and more efficient use is made of the tube. The same current output is obtained, but the cathode current density is much smaller. In moving the photocathode away from the focal point, it may be moved either toward or away from the lens. In this case we have chosen to move it away from the lens; a reason for this choice will be shown in a later section when we discuss light baffles.

Another way of increasing the light on a photocathode requires only one lens. This is shown in Fig. 26. This system takes advantage of the fact that parallel rays will result only when the light source is at the focal point. In

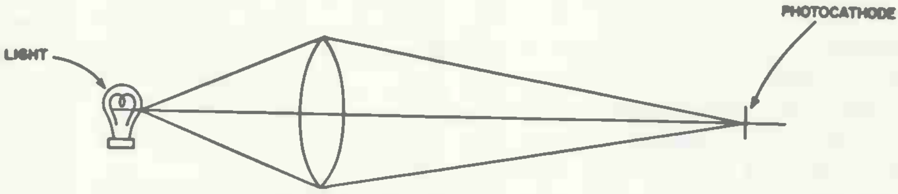


FIG. 26. Use of a single lens.

this system *one* lens performs the light gathering function of the lens in Fig. 24 as well as the lens in Fig. 25. The position of this lens is quite critical. In most cases the light bulb socket will be mounted so that it can be moved to obtain a maximum amount of light at the photocathode. This is a very common system when the distance from the light to the photocell is from 3 to 6 feet.

When the lens cannot be placed at the light source, it may be placed at the photocell. When used in this manner the phototube receives all the light falling on the lens. In this way the photocell appears to have an area equal to that of the lens. The light gain is not as great as when the lens is at the light source, but light gains up to ten may be had.

Whenever you use small photosensitive elements such as the photodiode, photo-transistor, or cadmium sulfide cell, a light-gathering lens is necessary. These new photosensitive units have very high sensitivities in microamperes per lumen, but the sensitive surface is very small. The photosensitive surface of these devices is only a fraction of an inch across. However, due to their high sensitivity, the use of even a small lens to intercept

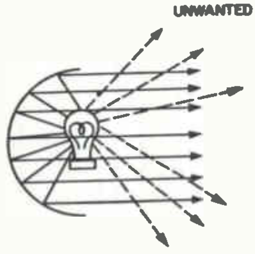


FIG. 27. Use of reflector to concentrate light.

and concentrate the beam of light can give a relatively large output. When an efficient lens system is used, the current output of these devices at low levels of light is very close to that of the vacuum photocell.

Use of Reflectors in Photocell Systems. A second and even better method of concentrating the light from the lamp into a beam is by using a curved reflector. A parabolic reflector is familiar to all of us since it is the principle of the automobile headlamp. The physical arrangement of the bulb and reflector is shown in Fig. 27. The total light flux radiating from a lamp

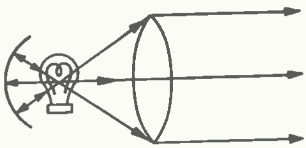


FIG. 28. Use of reflector and lens to obtain high intensity beam.

is equal to 12.57 times the candlepower. If one-half of this light can be gathered by the reflector and formed into a small beam, the intensity of the beam from a 32-candlepower lamp would be equal to the light from a 200-candlepower lamp. By using a reflector similar to an automobile headlamp and a small filament bulb, we can obtain light gains of nearly 1,000 by this means.

Fig. 28 shows a way of combining a small spherical reflector with a lens to obtain a high intensity beam. Light radiated by the bulb toward the back will be reflected from the mirror and return along its original path, passing through the bulb to the lens. This doubles the total amount of light striking the lens. The light gain in a

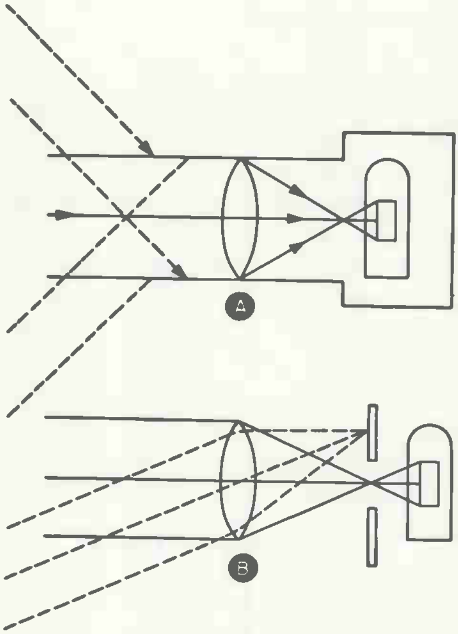


FIG. 29. A, Use of tube as light baffle. B, Use of baffle plate at focal point.

practical system would be around 40 to 60.

Light Baffles and Filters. Whenever a photocell is used with a special light source, there is always a chance that unwanted light will strike the cell and cause false responses. Where a photocell is used to turn on street lights or advertising displays after dark, an automobile headlight might strike the cell and cause the street lights to go off.

Light baffles around the lens and a light tight enclosure around the photocell can prevent most of the stray light from actuating the system. Fig. 29A shows how a simple housing with a tube can be used to exclude stray light. In this case the solid lines show the rays of desired light and the dotted lines show stray light from outside sources. This diagram shows how most of the outside light is prevented from striking the phototube. This is a very simple method of keeping unwanted light from striking a photocell. You should remember it. If you do much work with photocells, you will probably have occasion to add a baffle tube to increase the reliability of a system.

Another common method takes advantage of the fact that the photocell is not placed at the point of convergence of the rays from the desired light beam. A sheet of opaque material, with a very small hole in the center, is placed between the lens and the phototube as shown in Fig. 29B. The desired light beam, shown by the solid lines, converges after passing through the lens and goes through the small hole in the baffle to strike the photocell behind it. Light which does not enter the lens head-on converges and either strikes the baffle itself or, not being in focus at the baffle, is largely cut off and little of it passes through the small hole. In this way it has little or no effect on the photosensitive surface of the cell.

Photocell Applications

Photocell equipment can be divided into two basic classes. The first of these are ON-OFF applications in which variations of light intensity control a relay to start or stop some action. This change in light may be merely a small difference in intensity, or it may be a complete on-off cycle of the light.

The second type of equipment is that in which an output signal varies with changes of light intensity so as to indicate the light level at the photocell.

Most of the applications of photocells in industry are of the "On-Off" type. Familiar examples are street light control systems, photoelectric burglar alarms, automatic door openers, fire and smoke alarms, and photoelectric counters.

The second type of equipment in which the output varies with the light intensity includes light and exposure meters, photoelectric temperature recorders, and reproduction of the sound track on motion picture film.

No matter what the use of the photocell system may be, the photocell must be electrically coupled to some metering or control device. Since the output of the cell is very low, the coupling or load circuit must be carefully planned to obtain maximum sensitivity and reliability. The type of load circuit used will depend on the use made of the circuit, on the output current of the photocell, and on the internal impedance of the cell.

PHOTOCELL OUTPUT CIRCUITS

When the light intensity is high and the output current relatively large, a sensitive meter or relay can be used as the load. In most cases, however, the output current must be amplified before it can be applied to the control device or meter.

The amplifier stages used in radios are of two types, voltage amplifiers and power amplifiers. Now we will discuss a variation of the voltage amplifier which gives current amplification.

Current Amplifiers. When you studied how tubes were used in circuits, you learned that the mutual conductance of a tube is equal to the ac plate current divided by the ac grid voltage when there is no load in the circuit. This definition means that for a given change in grid voltage, a high mutual conductance tube will show the greatest change in plate current. So for best current gain, we want a tube with high mutual conductance.

The maximum current can be drawn from any source when the load resistance is zero; so you can see that the load resistance must be kept as low as possible.

Our definition gave output current in terms of grid voltage, while we are concerned here with signal current in the grid circuit. If the signal current is passed through a resistor connected between the grid and the cathode of the tube, there will be a voltage drop across the resistor. This voltage drop will be the signal voltage at the grid. For a fixed current, the larger the resistor, the larger will be the signal voltage.

There are three key points that the designer checked in designing any photocell amplifier: (1) use of a tube with a high mutual conductance; (2) the plate load resistance is made as small as possible; (3) use of a very large value of grid resistor. These three things have the greatest effect on the operation of an amplifier. They are the main points to check in service work.

When more than one stage of amplification is used, the first stage has the large grid resistor, and the last stage has the high transconductance and low plate load resistance. All stages but the last act as voltage amplifiers and should use high mu tubes.

There is a limit to the size of the resistor that can be used in the grid circuit of a current amplifier. Leakage resistance between the grid and cathode of a tube has a very high value, but it will vary under different operating conditions. There will also be leakage resistance between the terminals of the photocell and between the leads connecting the photocell to the amplifier tube. Suppose the leakage path resistance is 200 megohms on a dry day, but drops to 50 megohms in humid weather. If a photocell load resistance of 5 megohms is used, the combined dry resistance is 4.88 megohms, and on a humid day, 4.54 megohms. This would result in a 7% change in plate current. However, if a 20-megohm grid resistor were used, the resultant dry resistance would be 18.2 megohms and when damp, 14.3 megohms. Thus, a change in humidity would result in a 21% change in plate current. This large change would make it hard to adjust the circuit for reliable operation.

Some photocell amplifiers will use grid resistors even larger than 20 megohms. When servicing these systems, you should keep in mind the effect of dust and moisture. All dust should be removed, and moisture kept out. Check the leads for brittle or cracked insulation. Look for rosin running from a joint to ground.

Even when a tube grid is biased negatively, there will be small currents flowing in the grid circuit. If the grid resistor is too high, these currents flowing through the grid resistor may cause voltage drops as great as the signal from the photocell.

Grid currents may originate in three ways: (1) electrons from the cathode may strike the grid directly; (2) electrons may be emitted from the grid; and (3) positive ions formed from residual gas molecules may be attracted to the grid. Grid emission and positive ions cause current to flow from the external circuit to the grid. Electrons striking the grid directly give rise to current flow from the grid to the external circuit. Since grid currents are formed which flow in both directions, opposing each other, the resultant current may be either to or from the grid, and may either add to or oppose the signal current.

It is possible to reduce the net grid current to zero by applying the proper bias. The proper amount of bias for any tube can be found by connecting the operating plate voltage to the tube, disconnecting all leads from the grid and measuring the voltage from grid to ground with a very high resistance voltmeter.

This bias will vary for different tubes of the same type. If provision was made for adjusting the bias, this method can sometimes be used to set the correct bias after changing tubes or even as a tube ages. This is a refinement in operation that is generally used only in measuring very low levels of light, or very small light changes.

The effects of grid current can be reduced by operating the tube at low plate voltages. When the tube current controls a relay, the bias should be adjusted so that when no signal voltage is present, the plate current is very low, and with signal voltage, the plate current is high. This is practically class B operation. Nonlinearity of this type of operation does not matter when using relays.

It is easy to see that current amplifiers are impractical for use with photovoltaic cells. A high grid resistor would make the output current from the cell too small to be of any value. Also, the big advantage of the photovoltaic cell is that no external power source is needed for its operation. If a power supply must be furnished for the vacuum tube, this advantage is lost.

Current amplification following the output of a photovoltaic cell can be obtained by the use of transistor amplifiers. The transistor amplifies both voltage and power. In the grounded-emitter connection, power gains up to 1000 are possible. The input resistance of a transistor connected in this way is low and provides a good match to the photocell. The transistor has a high output impedance and matches high resistance relay coils.

When transistor amplifiers are used with semiconductor photocells, the power requirements are low, the sensitivity is high, and the system is physically very small. For these reasons you can expect to see many such units in use.

Photovoltaic Cell Circuits. This type of cell has a very low internal impedance. Since it is a source of current, it can be used with a meter or a sensitive relay directly in its output circuit. The power output of these cells is very low, and power is needed to move a relay armature or a meter pointer. To obtain good sensitivity and maximum power output, the load resistance must be matched to the internal resistance of the cell.

These cells can be connected either in series or in parallel combinations to increase the output power; however, connection in multiple changes the internal resistance. We will take an example using the International Rectifier Corporation B2 cell.

Fig. 15 shows that with an illumination of 150 foot-candles and a 1000-ohm load, the output current of this unit is 120 microamperes. If two such cells are connected in parallel, the output current would be 240 microamperes. However, the internal resistance is halved, so the load resistance must also be cut in half. By using a 500-ohm load with two cells in parallel, the power output is twice that from a single cell working into a 1000-ohm load. If two cells are connected in series, the current will remain the

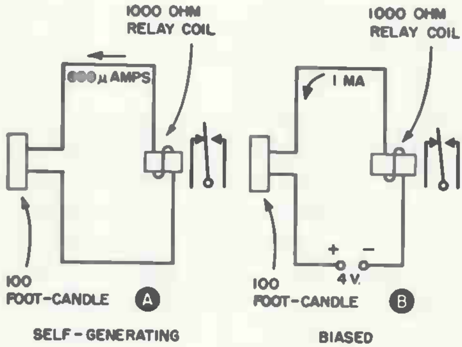


FIG. 30. Selenium cell output circuits.

same, the internal resistance will be twice that of a single cell, and the load resistance should be doubled. In the series connection, the power output is also doubled and is the same as when two cells are used in parallel.

If it is ever necessary to substitute different types of photocells in this circuit, you should keep these resistance relations in mind.

Earlier in this lesson, you learned that the sensitivity and the output current of this type of cell can be increased by using an external source of voltage in series with the cell. This is done in many commercial systems.

A word of caution about the use of an external voltage. Some cells will be destroyed by use of any external power. Any cell will be damaged by too much voltage. Do not try to increase the sensitivity by increasing the voltage.

Typical circuits using large selenium cells are shown in Fig. 30. The circuit of Fig. 30A shows the cell connected in a self-generating circuit. With a 100-ohm load and 100 foot-candles of illumination, the output current is 600 microamperes. This results in a power to the load of 36 microwatts, which is enough to operate many types of light meters and sensitive relays.

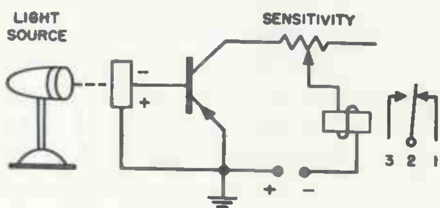


FIG. 32. Simple photoelectric unit.

To increase the current change, an external voltage source can be applied as shown in Fig. 30B. As discussed earlier, this type of circuit takes advantage of the change in resistance of the photocell circuit under light excitation. The change in resistance causes a change in the current supplied by the external battery. Thus, a larger current change results in the output and a less sensitive relay can be used.

In the example shown, using a 1000-ohm relay, a light change from dark to 100 foot-candles causes a current increase of about 1 milliampere. This results in 1000 microwatts of signal power at the relay. This is nearly thirty times the power output of the self-generating circuit.

The photo-transistor is especially

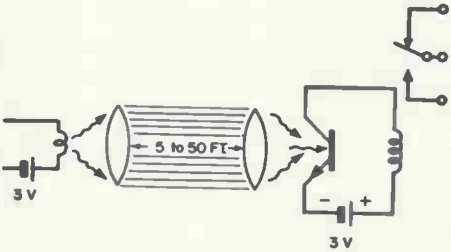


FIG. 31. Photo-transistor output circuit.

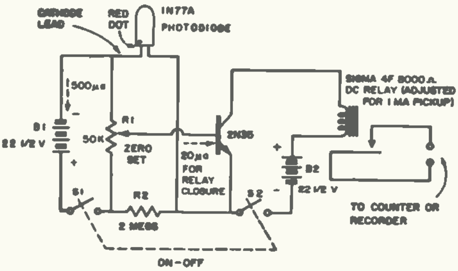


FIG. 33. A photodiode and amplifier circuit.

adaptable to direct drive in a relay circuit because of its high sensitivity and high current output. It has a low enough output impedance to be easily matched to a relay coil. With light excitation the output current of a photo-transistor is several milliamperes, more than enough to operate a sensitive relay. As shown in Fig. 31, only a very low voltage supply source is required. When using photo-transistors, a lens for collecting the light is necessary because of the very small photosensitive surface.

The use of a transistor to increase the output of a photovoltaic cell is shown in Fig. 32. In this circuit the output of the photocell supplies the base-emitter current to the transistor. As a result, an increased collector current flows when light strikes the cell. This collector current is high enough to actuate the relay in the collector circuit. The sensitivity of the photoelectric operation can be controlled by the adjustable resistor in series with the relay.

A germanium junction photodiode and transistor amplifier circuit is shown in Fig. 33. The circuit uses a bridge with the photodiode, the two sides of potentiometer R1, and resistor R2 as the bridge arms. The photodiode shown is used with an external voltage supplied by battery B1. With the photodiode darkened or with a normal light level on the photodiode, the bridge is balanced by adjusting resistor R1. At this setting, the input current to the transistor is zero. An increase in light causes the photodiode current to increase. Thus, the bridge becomes unbalanced and current flows in the base-emitter circuit of the transistor. This current causes an increased current in the collector circuit which closes the relay.

A similar circuit using a phototransistor, but requiring only one voltage source, is shown in Fig. 34. In this circuit, two of the arms of the bridges are adjustable and a sensitivity as well as a balance control is provided.

The use of self-generating photocells or semiconductor germanium cells with transistor amplifiers greatly reduces the size and weight of photoelectric units. The power supply requirements are very much reduced compared with the elaborate systems needed by vacuum phototubes. Sensitivity and stability of this type of photoelectric unit can be made as

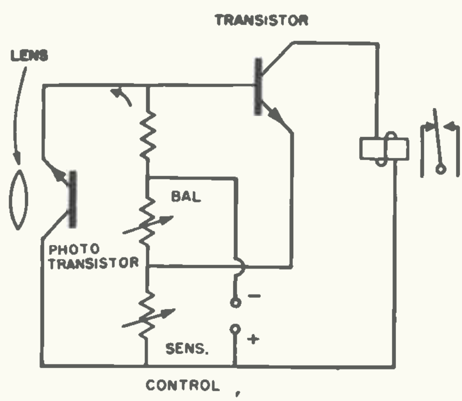


FIG. 34. A photodiode-transistor circuit.

good as, or better than, the vacuum tube type. The response of the semi-conductor germanium cells to modulated light throughout the audio range is superior to the larger selenium cells.

Photoemissive Cell Circuits. The two basic circuits using a photoemissive tube with an amplifier tube are shown in Fig. 35. In Fig. 35A, the light beam is applied continuously to the photocell. The direction of the output current of the photocell through resistor R1 biases the tube to cut-off. When the light beam is interrupted, this bias is removed, the tube will pass current and the relay contacts will be closed. In Fig. 35B, the output current of the photocell opposes the bias on the tube. Without light, the tube is held at cut-off and the relay contacts are opened. When light strikes the phototube, current flows through resistor R1, opposing the battery bias and allowing current to flow in the plate circuit of the tube. The current energizes the relay coil and causes the contacts to close.

A more practical circuit is shown in Fig. 36A. The circuit arrangement and adjustment shown here are the same as in Fig. 33. The circuit is adjusted at the normal light conditions by resistor R1 so that the relay is open. An increase in light striking the photocell will increase the current flowing through resistor R2 and raise point B to a higher voltage above ground. This reduces the bias on the grid of the amplifier tube, allowing it to pass more current and close the relay. If resistor R1 is adjusted so that the relay closes at a given amount of light, a reduction in the light will lower the voltage at point B, increasing the bias at the grid of the tube and reducing plate current to allow the relay to open.

In the circuit shown in Fig. 36A, light falling on the photocell will always increase the current through the amplifier tube. If it is desired to have light cut off the relay by reducing the

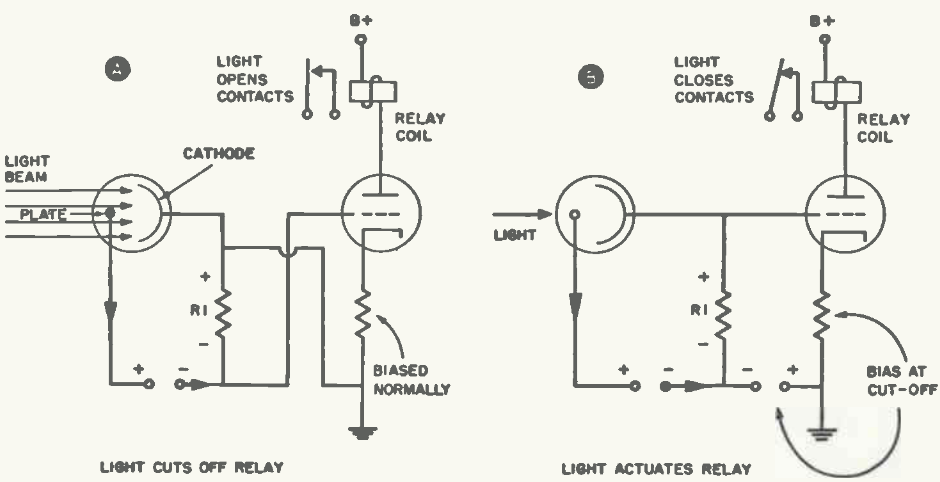


FIG. 35 Relay control either by light or by interruption of light.

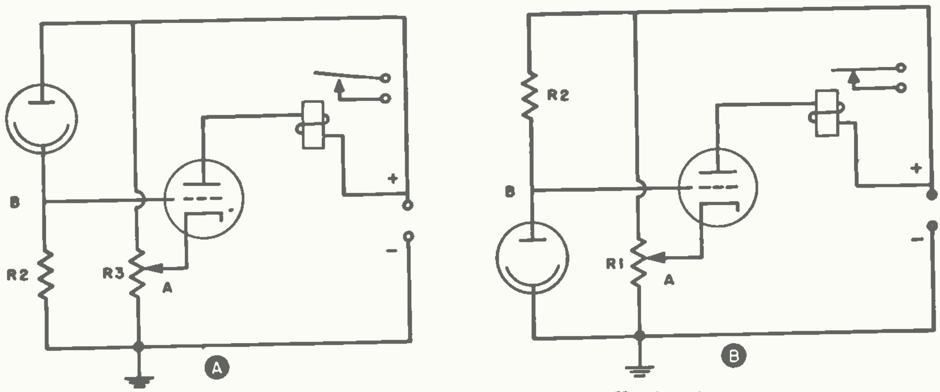


FIG. 36. Practical photoemissive cell circuits.

current through the tube, the photocell and resistor R2 must be interchanged as shown in Fig. 36B.

The circuit diagram in Fig. 36 shows a direct current source of power. However, this circuit will operate equally well when ac is applied to the power input terminals. The circuit connections are such that both anodes will be positive at the same time. Both the photocell and the amplifier tube will conduct only when their anodes are positive. Therefore, the circuit works only during the positive half cycles of the supply voltage. When the circuit is operated on alternating current, a fairly large capacitor must be connected across the relay coil. This is to prevent the relay from chattering due to loss of current during the negative half cycles of the supply. A capacitor of about 2 microfarads would be satisfactory across a relay with a 5000-ohm coil.

The circuits shown in Fig. 36 have direct connections between the photocell and the tube grid. Because of this direct connection, gradual changes in the light will affect the current in the relay circuit. These slow changes in current may be large enough to open or close the relay, giving false indications of light level. To avoid this condition, the circuit shown in Fig. 37 may be used. This is known as an impulse type photoelectric circuit.

The circuit is changed only by adding capacitor C1 between the bridge and the grid and providing resistor R3 as a dc grid return for the amplifier tube. Capacitors do not transmit direct current nor very low frequencies such as would result from gradual changes in light intensity. However, if there is an abrupt change in light, the sharp voltage pulse result-

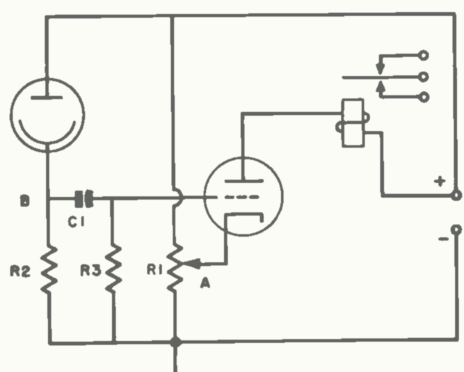
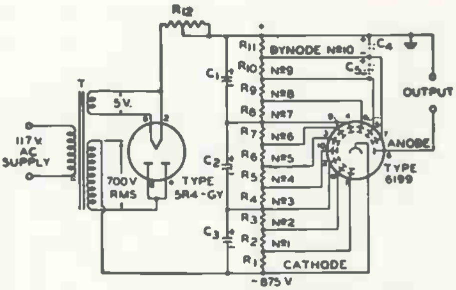


FIG. 37. Impulse type photoelectric circuit.

ing at point B, whether it is positive or negative, will be transmitted to the tube. There will be enough momentary change in plate current to cause the relay to open or close as the case may be. This circuit is not effective when a meter is used as the plate load of the tube but is very effective when a mechanical counter is actuated by the relay or when a latching type of relay is used.

This circuit may also be used with a modulated light beam. The variations in intensity of the light beam should be rapid enough to be transmitted by capacitor C1 and will cause a similar variation in the plate current of the tube.

A neon bulb powered from the ac lines will flash 120 times a second. If this light source is used with an impulse type of photocell circuit, each flash of light will cause a pulse of voltage to be transmitted through the capacitor to the tube. The plate current of the tube will consist of pulses of current at 120 cycles. A capacitor across the relay coil will prevent chattering as it did when using ac power in the circuit of Fig. 36. If two stages of amplification are used, they should be ac-coupled. In this way, the photocell system becomes reliable in the presence of high unwanted light, even if this light level changes. Also, the reliability of the system with changes in light intensity is greatly increased. The individual pulses of light may vary greatly, but so long as they are of sufficient amplitude to provide a voltage pulse at the grid of the tube, their variation will not change the operating conditions in the plate circuit of the tube.



Courtesy RCA Tube Division.

FIG. 38. Power supply and connections for multiplier phototube.

The impulse type of circuit is also adaptable for use with photovoltaic cells. When the cell is to drive a relay without an amplifier, a transformer is placed between the photocell and the relay coil. This will isolate the steady dc variations from the relay and can also be used to provide a better impedance match to the cell. A capacitor would be used as in Fig. 37, if a transistor amplifier follows a photovoltaic cell. No dc connection is necessary to the base in this circuit, so there would be no counterpart of R3 used with the transistor.

Vacuum and gas phototubes are used in exactly the same way and in the same circuits. The gas tubes have greater sensitivity but poor linearity, and their response falls off when the light beam is modulated.

Because of their higher sensitivity, gas type photocells are used for sound pickup from motion picture film. To make up for the reduced output at the higher audio frequencies, an equalizer circuit is used to reduce the gain of the amplifier at the lower audio frequencies.

When operation at very low light levels is required, multiplier type phototubes are used. Fig. 38 shows a typical power supply and voltage divider arrangement for this type of tube. In this circuit, R12 acts as a sensitivity control. By varying the voltage across the tube, the electron multiplication within the tube can be changed. A voltage regulator should be used with multiplier phototubes whenever good stability is required.

The circuits of Fig. 35 are the type used to couple a photo-multiplier to a current amplifier. Because of the high anode-to-cathode voltage across these tubes, they are not suitable for use in the bridge type circuit. The amplifier and the control or metering circuits used with a multiplier phototube are the same as would be used with any other photoemissive cell. The only precaution necessary is to hold the grid noise and gas current of the first amplifier tube as low as possible.

Photoconductive Cell Circuits. These cells are merely variable resistances, and they can be used in any control circuit in which a variable resistance is required as the controlling element. Unlike the other types of light sensitive devices, photoconductive cells have no polarity requirements. Either terminal may be positive or negative with equal results; the polarizing voltage may also be ac.

Earlier types of cells were generally made of selenium, but cadmium sulphide and germanium semiconductor cells of very small size and high sensitivity are coming into use. Selenium photoconductive cells may be used in the same bridge and current amplifier circuits as photoemissive cells. They have poorer response to modulated light than any of the other types of photosensitive devices. This poor high frequency response is due partly to slow response and partly to high shunt capacitance within the cell.

The high sensitivity of the modern semiconductor photocell is shown in Fig. 39. In this circuit a Clairex CL-1 crystal photocell can actuate a sensitive relay with only a 5-candlepower light source. Light from the source is formed into a parallel beam by the collimating lens and projected to the collecting lens. The collecting lens concentrates the light on the surface of the crystal photocell.

The crystal itself is very small and is imbedded in a transparent plastic cylinder. Nevertheless, just two footcandles of illumination result in a 100-

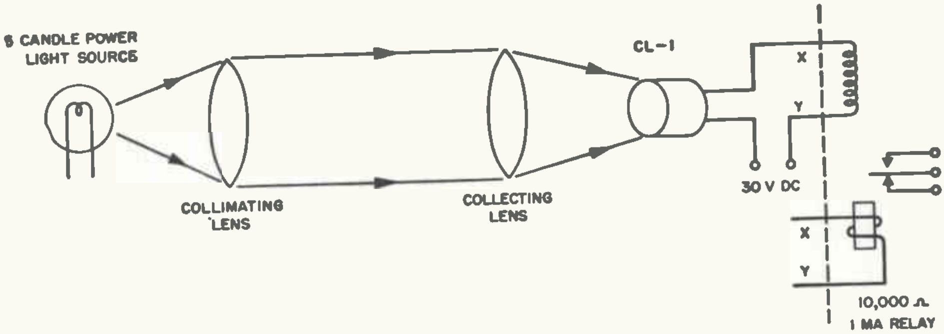


FIG. 39. Clairex CL-1 cadmium sulphide photocell system.

microampere current when using an external voltage source of 100 volts. With this lens system, the photocell can generate a 1-milliampere current for relay operation despite the low intensity of the light source.

One of the circuits we studied was the impulse type circuit which is not affected by slow changes in light. Now we will study an example of a circuit in which momentary flashes of light do not affect the system. Only sustained light changes on the photocell will change the relay position.

This slow response circuit is shown in Fig. 40. It employs the Clairex CL-1 semiconductor crystal photocell. Instead of a high vacuum current amplifier, this circuit uses a cold cathode gas discharge triode. This type of tube can pass a high current without heating the cathode. When a sufficiently high voltage appears on the igniter electrode connected to pin 4, the gas is ionized and current passes between the cathode connected to pin 7 and the anode connected to pin 1. This current flow can be used to actuate a relay directly or, as in the example shown, it may be used to operate a thermal delay relay. It is this relay which gives the unit its slow response.

Instead of a magnet coil, this relay

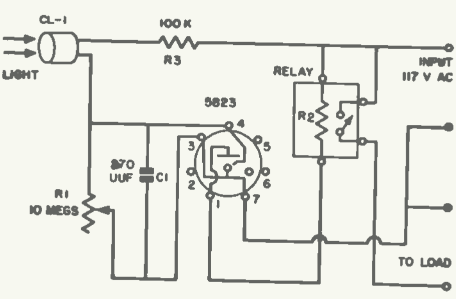


FIG. 40. Clairex darkness switch.

uses a resistive heater indicated on the diagram as R2. Current passing through this resistor heats the thermostatic switch causing, in this case, the contact to open. This switch, in turn, controls the power to the external load. The delay time is adjusted by changing the position of the heater coil in relation to the thermostatic switch. The farther the switch is from the heater, the longer it will take before the switch will operate after current has started to pass through the heater element.

When light strikes the photocell, it passes a current which flows through resistor R1. The voltage drop across this resistor charges capacitor C1. When capacitor C1 is charged to the ionization potential of the gas, it discharges through the igniter electrode of the tube. This causes the gas to be ionized and the entire tube will then conduct between pins 1 and 7. The voltage across the photocell CL-1 is adjusted by varying resistor R1. The variation of voltage across the crystal determines the charging time for capacitor C1, and hence, the sensitivity of the circuit. Resistor R3 is a current limiting resistor to protect the crystal when the igniter passes current.

This type of circuit is used to switch on signs, lights, etc., at dusk and turn them off at dawn. At dusk, the photo current is reduced and the gas triode ceases to conduct. Heat from the resistor decreases, causing the contacts to close and turn on night lights. At dawn, reverse action occurs and the lights are turned off. The thermal delay relay is used in this circuit so that headlights of passing automobiles or lightning flashes will not open the load circuit and turn off the street lights or signs. In the instantaneous types of circuits, headlights of passing cars would cause the lights controlled by the photocell to flash on and off throughout the night.

A vacuum triode could be used in this circuit as effectively as the gas triode. The gas type tube is used here because it does not have a filament; there is no need for a filament transformer nor is there worry of filament burnout. The gas tube with its discharge capacitor could have been used with any of the types of photoemissive cells which we have studied in this lesson.

ADJUSTMENT AND SERVICE OF PHOTOELECTRIC DEVICES

The installation and service of small photoelectric units is not difficult. One of the most important points is to have enough light to obtain reliable operation. Care should always be taken to avoid undesired light reaching the phototube. Stray light can cause very erratic results. The optical system should be adjusted with a meter in the photocell output circuit. Adjust all lenses and reflectors for maximum output current.

Due to the extremely small circuits and high impedances in the photoelectric circuits, great care should be taken to assure good insulation and low capacity between various parts of the circuit, particularly between leads from the phototube. Short leads should be used wherever possible. Also, the circuit must be shielded from stray electric fields. In extreme cases, the power supply may even have to be shielded, too.

After the photoelectric units are mounted and the optical system adjusted, the sensitivity of the system must be adjusted. In a case where the relay is operated by light striking the photocell, adjust the sensitivity of the cell circuit so that stray light does not operate the relay. Turn on the light and, if the relay operates properly, decrease the sensitivity slightly to guard against an increase in stray lighting. If the relay does not operate, several things can be done. You can increase the sensitivity of the relay. Most sensitive relays have adjustments which control the pull-in and drop-out points. If an amplifier is used, adjustment of the bias and plate voltage to give lowest mutual conductance under stray light conditions and highest gain at the desired light level may be effective. If both of these adjustments are made, they may interact on each other making it necessary to repeat them several times. In any case, the greater the intensity of the desired light and the better the shielding against stray light, the easier it will be to adjust the system.

In circuits in which the relay is operated by an interruption of the light beam, the sensitivity control should be adjusted, with the light on, to the point where the relay just operates. It should then be backed off slightly from this point to guard against a reduction in light from the source. The operation should be checked by interrupting the light beam, in which case the relay should operate. If the relay does not operate when the light beam is interrupted, the same steps should be taken as in the preceding case. An installation of this type is generally simpler to adjust than one which operates when light strikes the photocell.

CARE OF PHOTOCELLS

Photocells are rugged and have long life, but they should never be subjected to excessive light or voltage. Some of the photoconductive cells, such as selenium and germanium, will last almost indefinitely. They must, of course, be protected against intense heat, moisture, or corrosive fumes. Gas, germanium, and cadmium-sulphide cells must have a resistor in series with them to prevent excess current when strong light strikes them. Photovoltaic cells, which are not rated for use with external voltage, should be protected from stray electric fields and from pickup by induction on the leads to the photocell.

Photocells can be tested by measuring the output current at known values of light level, as shown in Fig. 41. A lightmeter calibrated in foot-candles is needed for such measurements. A sensitive current meter can be used to measure photoelectric current. The tube is rated in terms of current output for a specific amount of illumination, or in terms of current change for a specified change in light level.

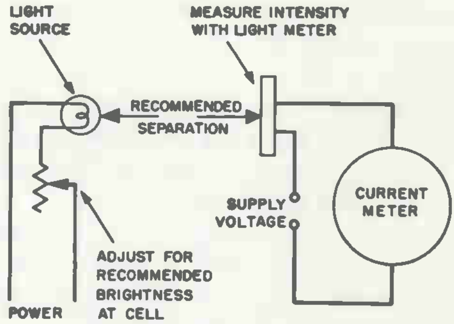


FIG. 41. Photocell test arrangement.

In this lesson you have learned how the basic types of photocells operate. You have learned the characteristics of the different types and their advantages and disadvantages as compared with each other. You have studied light sources and the manner of using them to best advantage in many photocell systems. You have learned how these systems are installed and adjusted, and how photocells themselves may be tested.

In your study of circuits for use with photocells, you have learned to make the greatest use of the power output of photocells when coupled directly to meters or relays. You have seen typical circuits for amplification of the current output of these photocells. In this lesson we have carried the circuits no farther than the relay coil. In a following lesson, we will discuss in more detail the physical make-up and contact variations that are possible in relays. You will learn how photocells and other types of detectors and control elements are put to use in electrical control circuits. Photocells are only one part, even though an important part, of any complete control system in which they are used.

Lesson Questions

Be sure to number your Answer Sheet 26B.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What is the light flux in lumens falling on a one square inch photocell from a 48-candlepower source which is two feet from the photocell?

2. Which of the three basic types of photocell does not require an external power source?

3. Should a gas-filled phototube glow when light strikes the cathode?

4. Why is it customary to use a controlled voltage supply with photomultiplier tubes?

5. What is dark current?

6. Why is it necessary to know the resistance of a photoconductive cell?

7. Why are lenses and reflectors used in photocell systems?

8. What three points should be kept in mind when checking a current amplifier?

9. (a) When two photovoltaic cells are connected in parallel, what happens to the output current? Does it increase, decrease or stay the same? (b) When two photovoltaic cells are connected in parallel, is the internal resistance of the pair greater than, less than, or the same as the internal resistance of a single cell?

10. Which type of photocell has no polarity requirements?

AT THE END OF THE RAINBOW

The only pot of gold you'll find at the end of the rainbow is the one which you put there yourself.

Now, when your best earning years are still ahead, is the time for you to fill that pot of gold. You're an NRI student—you're carrying the ball down the field right now for a touchdown—and everything favors you to make the goal you have in mind.

Will you falter now and be thrown for a loss, or will you keep right on going? Will you complete your training Course just as steadily as you started it, with no losses, no set-backs, preparing yourself for that rainbow trail to success—or will you let minor successes now lure you from your planned path to a sound future?

There is no royal road to anything. Steady progress step by step will get you anywhere and bring you a success which endures. The only failure you need to fear now is failure to stick to the goal you know is best.

J. E. Smith

ELECTRONIC CONTROL SYSTEMS

27B

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE NO. 27

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ **1. Control Relays. . . . . Pages 2-13**

In this section you study electro-magnetic relays and the various arrangements of relay contacts; latching and holding relays and time delay relays and relay circuits are also discussed. You learn how to choose a relay for a specific application.

☐ **2. Gaseous Control Tubes. . . . . Pages 14-19**

Here is a discussion of the thyratron tubes and cold cathode gas tubes. Photocell control of Thyratrons is explained.

☐ **3. Light-Operated Control Systems. Pages 20-25**

You learn about some commercial photo-electric systems. Automatic Headlight Control and Outdoor Lighting Control installations are covered.

☐ **4. RF-Operated Control Systems. . . . . Pages 26-36**

The operation of carrier current controls, capacity-operated relays and simple radio control systems are explained in this section. You learn how garage door openers operate.

☐ **5. Answer the Lesson Questions.**

☐ **6. Start Studying the Next Lesson.**

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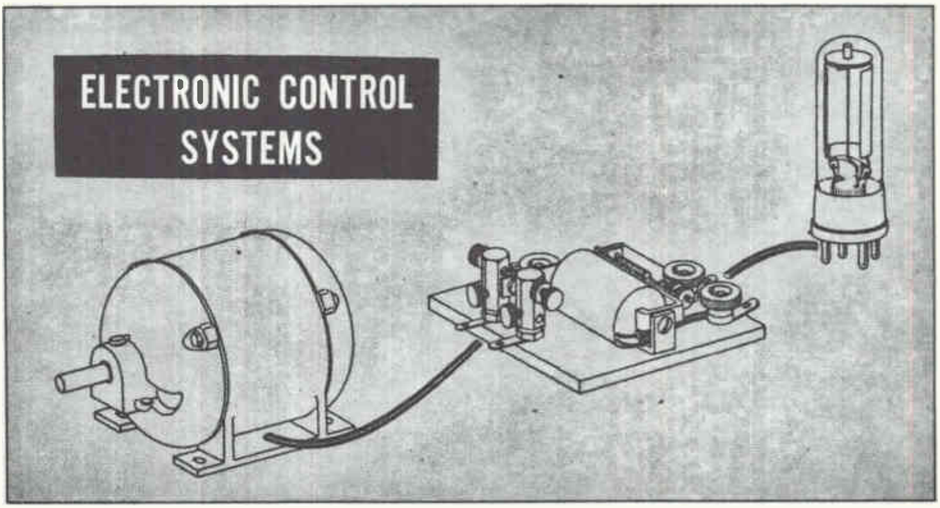


ELECTRONIC control systems are becoming very common in the home and in business. These systems range from a simple photocell circuit which turns on street lights at night to controlling the operation of an oil refinery.

In this lesson we will study only the smaller systems. We will further limit ourselves to "on-off" operations. For example, a photocell system might be used to turn street lights on at night and off in the daytime without holding the brightness of the light at a definite level. Another example would be starting and stopping a motor without trying to control its running speed.

The systems we will study can be divided into two broad classes: control from a distance, and automatic control. In a system which starts or stops an operation from a distance, a manually operated switch either produces or starts a control signal which is transmitted to the equipment under control. This is simply a remote control device. This type of system requires an operator to decide when to start and stop the operation.

An automatic control system generates a control signal whenever some previously decided upon event occurs, and transmits the signal to the equipment to be controlled.

A control system is made up of three parts: a manual or automatic signal generator, a means of transmitting the control signal, and a controlled device which is actuated by the control signal. Most of the systems which we will study use either a switch or a photocell to produce the control signal and a relay as the control device. There are many other ways to produce control signals, but these are the most common examples.

Many control units are made by companies specializing in power equipment, not in electronics. The service manuals and schematic diagrams for these units use different symbols for parts from those used in radio diagrams. Fig. 1 shows these symbols beside those you know. When you first see diagrams using these symbols, they may be confusing; but once you know the symbols, the diagrams will be simple and easy to read.

Control Relays

Most control systems you will work with will use a relay as the control device. A magnetic relay is a simple piece of equipment. Once it is properly set up, it rarely needs adjustment and lasts a long time. By means of a relay, a small signal can control large amounts of power; an ac signal can control dc power; low voltage ac can control high voltage ac; or one circuit can control another without any electrical or magnetic coupling between them.

The electro-mechanical relay is so important and so common in control systems that it must be given special attention. Therefore, in this section we will describe the types you will find most often in electronic control circuits.

ELECTROMAGNETIC RELAYS

In an electromagnetic relay a current flows through a coil and produces a magnetic field which moves the relay armature. The movement of this

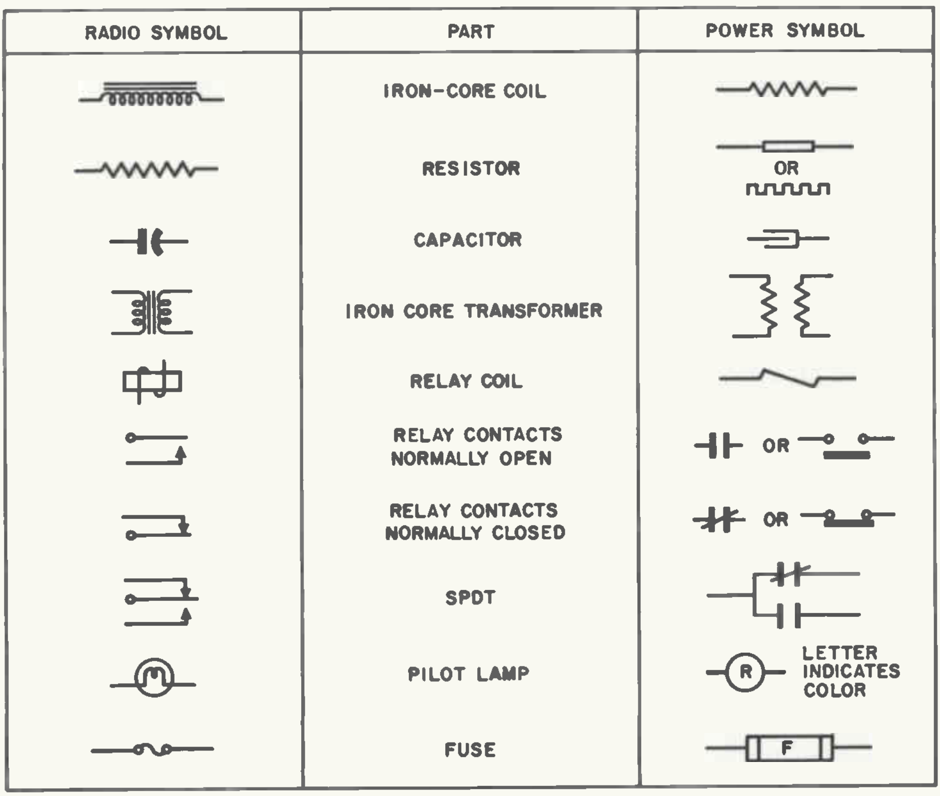
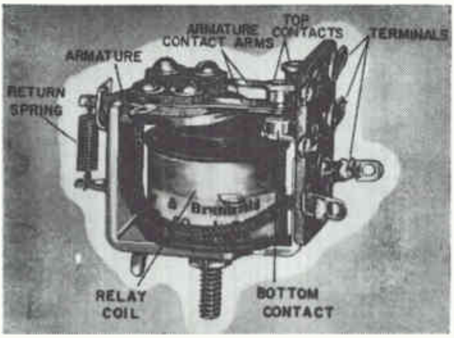


FIG. 1. Comparison of Radio and Power symbols.



Courtesy Potter and Brumfield

FIG. 2. Mechanical assembly of a typical relay.

armature opens and closes the relay contacts. The mechanical assembly of a typical relay is shown in Fig. 2.

The coil is connected to the control current source. When enough current flows through the coil to overcome the tension in the spring (shown at the left in Fig. 2), the magnetic field pulls the armature down. The contact arms are fastened to the armature but insulated from it. When no current flows through the coil, the contact arms touch the two top fixed contacts on the relay terminal board at the right.

As soon as current flows through the coil, the armature and contact arms move downward. The arms break contact with the top terminals, and make contact with the two lower fixed contacts of the terminal board. The switching action is the same as the usual double-pole, double-throw switch. In this case, the armature contact arms are the poles that change over between the two pairs of fixed contacts.

When the current in the coil stops, the return spring pulls the armature up, and the contact arms again touch the top terminals. Connections to the various terminals and contact arms are made to the terminal lugs on the terminal board on the right hand side. The four top lugs are the connections for the top and bottom relay contacts. The bottom pair of lugs are the connections for the armature pole contacts.

A typical inexpensive plate circuit relay is shown in Fig. 3. It has single-pole, double-throw contacts. Notice that the contact arm of this relay is not insulated from the armature and relay frame. When no current flows through the relay coil, the armature contact remains in the "up" position and connects to the top fixed contact. When the armature is pulled down, this connection is broken and the connection is made to the lower fixed contact.

Relay Contact Arrangements. The contact variations on relays are almost endless. However, various types of relay contact arrangements are available for special needs. Fig. 4 shows some of these combinations, along with the names describing them. They are shown with the armatures unenergized (no current flow through the coil).

The first arrangement is called a "make" contact or single-pole, single-throw, normally-open contact. When the armature is pulled by the relay coil, connection is made between an

Courtesy Potter and Brumfield

FIG. 3. Plate circuit relay.

arm and a fixed terminal. (In the illustration it is assumed that the relay pulls the armature down).

The second arrangement is also a single-pole, single-throw switch. However, this is called a "break" contact because the connection is broken between the fixed terminal and arm when the armature is pulled downward. It is also referred to as a single-pole, single-throw, normally-closed contact arrangement.

The third group is a single-pole, double-throw. This is often called a "break-make" arrangement, because the armature movement first causes the armature to break contact with the upper fixed terminal, and then to close or make contact with the bottom fixed terminal. Fig. 3 shows this type.

The fourth contact arrangement is a variation of the third type and is called a "make-before-break" arrangement. The armature movement causes the connection to be made between terminals 1 and 3 before it is opened between terminals 2 and 3.

The fifth combination is a four-terminal arrangement. The armature movement causes the following sequential switching: "break" between terminals 1 and 2, "make" between terminals 2 and 4, and finally "break" between terminals 3 and 4.

A double-pole, double-throw arrangement of contacts is shown in the sixth illustration. Two poles switch circuits between two pairs of fixed contacts. The contacts of the relay in Fig. 2 would be shown this way in a schematic diagram.

The final arrangement is a three-pole, single-throw combination with "break" contacts. In other words, when no current flows through the relay coil, contact is made between 1 and 2, between 3 and 4, and between 5 and 6. When the relay is actuated,

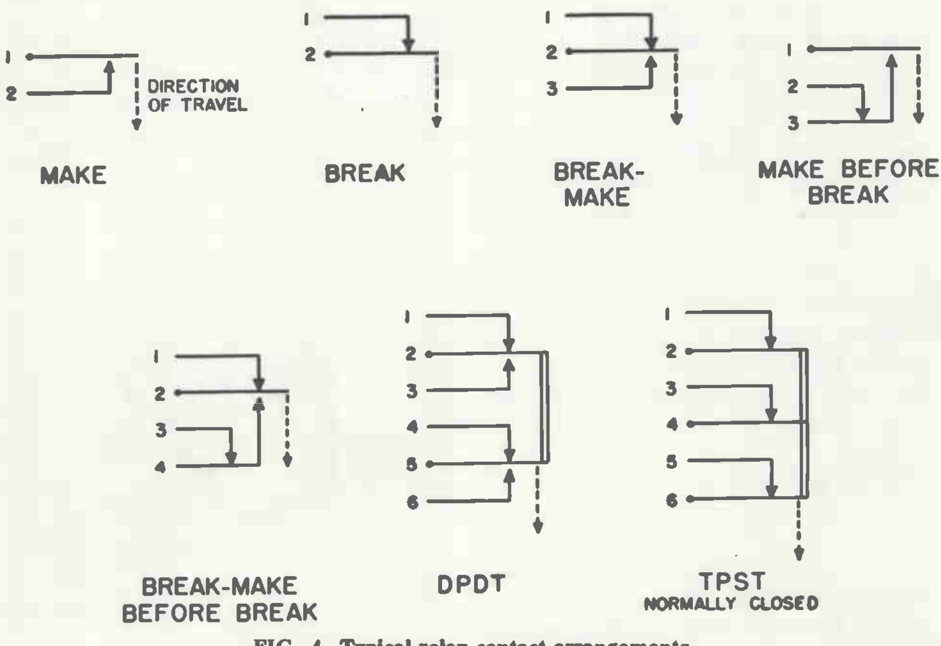


FIG. 4. Typical relay contact arrangements.

connection is broken in **each** of the three pairs of contacts.

Contact Protection and Care. The contacts cause most of the failure in relays. The connecting surfaces of the contacts are faced with silver or some other low resistance material. This contact face is gradually worn away by friction, arcing and burning. The life of a relay is determined by the life of the contact faces.

It is a good plan to install relays so that the contacts can be checked and serviced. Whenever possible the relay should be mounted so that the contact faces are not horizontal. Where there is a great deal of dust, the relay and its contacts should be enclosed. The contacts should be checked often, and any dirt on their surfaces brushed off. Contacts discolor as they are used; but, unless there is sulphur in the air, this discoloration does no harm and should not be removed.

If the contacts become pitted or burned due to arcing or excess current, clean them lightly with crocus cloth or fine sandpaper. In cases of pitting, you can file the high spots lightly, but you should not try to file a contact smooth. If you remove too much of the contact face, you will greatly shorten the life of the relay. When a contact is pitted so deeply that the pit extends through the face material to the base, discard the relay.

Remember that excessive contact cleaning can shorten the life of a relay just as much as no care.

Protective circuits may be used across the relay contacts to minimize arcing. If a capacitor is connected across the relay points, the current that flows through the contacts when they are closed will flow into the capacitor when they are open. By the time the capacitor is charged, the contacts will be far enough apart to keep an arc from forming. However, when the contacts close again, the charge on the capacitor will flow through the points producing a very high current which may exceed the contact rating. For this reason a low value resistor is connected in series with the capacitor across the relay points to limit the current when the contacts close. The resistor should be large enough so that the current through it at full line voltage does not exceed the contact rating.

When this type of protective circuit is used with an ac power source, the value of the capacitor should be small enough so that the current through it will not operate the device being controlled by the contacts. In any case, it is best to use the lowest value capacitor that will prevent arcing when the circuit is open.

RELAY CHARACTERISTICS

A number of factors must be considered in choosing a relay for a specific purpose. You must know the operation to be performed, the control current and voltage available, and the characteristics of the device to be controlled with the relay. The major points are as follows:

Contacts. The contact arrangement must be chosen according to the switching operations needed in the circuit. Some types of switching arrangements for relay contacts are shown in Fig. 4.

The starting current for many electrical appliances such as motors, heaters and light bulbs is much higher than the average current drawn by such a unit. Relay contacts must be able to handle the high starting current so they will not be burned and pitted. The relay manufacturer lists

Coil Resistance Ohms	Standard Adjustment		Minimum Adjustment	
	Ma.	Volts	Ma.	Volts
2500	9	22.5	6	15
5000	6.3	31.6	4.3	21.3
10000	4.5	44.7	3	30

FIG. 5. Typical sensitive relay coil ratings.

the current-carrying ability of the contacts. Therefore, compare the contact rating with the current required by the device to make sure that current will not flow through the terminals. The type of load placed on the contact is also important. For example, a highly inductive load causes a high "kick-back" current which can damage the relay contacts if they do not have enough spacing and current-carrying ability. When switching high voltages, the contacts must break quickly to prevent arcing, and the spacing between the open contacts must be large enough to prevent high voltage breakdown in the air space between the terminals.

Coil Ratings. The choice of relay coil depends on the source of control current and the voltage. The coil ratings for most of the low power and appliance relays are given in terms of voltage—6, 12, 110 volts ac or dc. The average current required by the relay coil is also indicated. Often the coil resistance is listed.

Many of the standard relays available permit a choice of coils. When ordering a relay you must state its coil voltage and whether it is to be an ac or a dc coil.

The power needed to operate a relay is determined primarily by the strength of the armature return spring. Since the spring is not changed when the coil is changed, the same amount of power must be supplied to overcome the spring tension, no matter what coil is used.

The second factor which determines the operating power required is the force needed to hold the contacts together when the armature is pulled down. This force is the total pull of the magnet, less the pull required to overcome the spring.

Data for sensitive plate current relays are often shown as in the chart of Fig. 5. The table indicates the performance characteristics of the relay type in Fig. 2 and lists the voltage and current required for three coils having different resistances. The recommended values for the most reliable relay operation are given in the "Standard Adjustment" column. The "Minimum Adjustment" column lists the minimum voltage and current values that can be applied to the coils.

This type of relay with standard adjustments uses approximately 200 milliwatts for any of the three coils. With the minimum adjustment, this relay requires 90 milliwatts. There is much less force holding the contacts together at this power than with the standard adjustment. If the contact pressure is too low, vibration will cause the contacts to bounce and chatter.

Plate current relays are designed to work in the plate circuit of a vacuum tube amplifier. Therefore, the relay coil you choose for a particular circuit should operate at current equal to or less than the plate current of the amplifier at the grid bias and plate voltages used. For example, to use a relay having characteristics like those listed in Fig. 5 for standard adjustment, the tube must be capable of delivering at least 200 milliwatts to a load at the currents shown.

Large relays drawing higher coil currents are used for the more complex switching set-ups and in high current circuits. Many times large currents or complicated circuits must be controlled by low output devices like photocells. In this case, the sensitivity of the circuits can be increased by connecting a small, sensitive relay, called a pilot relay, between the photocell circuit and a heavy duty relay. Pilot relays usually have contacts with low current ratings and simple switching arrangements. A circuit of this type is shown in Fig. 6. Where involved switching arrangements are required, the pilot relay can control several power relays.

Relay Sensitivity Adjustment. On most sensitive relays there is provision for adjusting the pull-in and drop-out currents. The relay shown in Fig. 7 has three points of adjustment: The spring tension adjustment and the front and back contact adjustments.

Changing the tension on the spring changes the restraining force on the armature. If the spring tension is reduced, less power will be required to close the relay and there will also be less pressure at the back contact when the relay is not pulled in.

This relay is shown in the energized position. Notice that the armature does not touch the coil core. There should be a slight air gap when the relay is closed. If the armature touches the core, there may be enough residual magnetism in the core to hold the relay closed when the current is interrupted in the core.

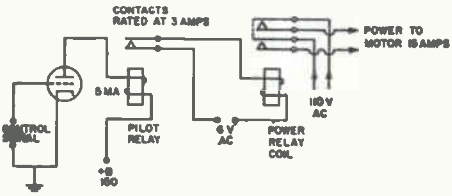


FIG. 6. Use of pilot relay to control power relay.

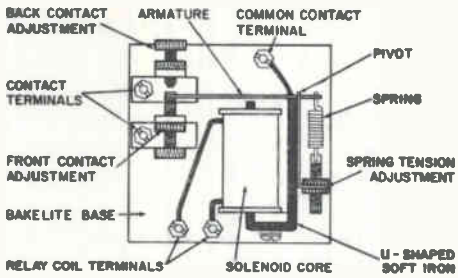


FIG. 7. Adjustments on a sensitive relay.

The pull-in and drop-out currents can be adjusted by varying the air gap, using the front and back contact adjustments to position the armature. You know from your earlier lessons that magnetic flux is greater in magnetic materials than in the air. The magnetic flux provides the pull which moves the armature. The shorter the air gap between the core and armature, the greater will be the pull on the armature for a given current through the coil. The least current is required to close the relay when the back contact holds the armature near the core. In a circuit in which the coil current does not drop to zero, the pressure of the armature on the back contact will be lower when the armature is held close to the coil.

When the armature is pulled in, the gap is less and the current through the coil may then be reduced below the pull-in point without releasing the armature. The closer the armature comes to the core, the greater must be the reduction of the current through the coil before the relay drops out. The front contact adjustment limits the travel of the armature toward the magnet, and thus sets the drop-out current and the contact pressure. The farther the armature is from the coil, the less will be the pressure.

Let's summarize the possible adjustments on this relay. The coil current required to pull-in the armature can be reduced by reducing the spring tension and screwing in the back contact adjustment. The drop-out current is increased by increasing the spring tension and screwing in the front contact adjustment. Front contact pressure is increased by decreasing the spring tension, and backing out the front contact adjustment. Back contact pressure is increased by increasing the spring tension and backing out the back contact adjustment.

You can see from the above paragraph that the adjustments in a sensitive relay interact with each other. For this reason, adjustments must be made for best all-around operation in the circuit in which the relay is used. When a relay is used in a vacuum tube plate circuit, you will rarely be able to adjust it for either lowest pull-in current or highest drop-out current. The adjustment must be a compromise between the two.

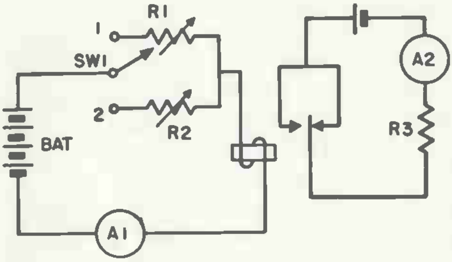


FIG. 8. Test circuit for adjusting relay sensitivity.

The circuit shown in Fig. 8 can be used to measure the current through the relay coil and to adjust the relay for the desired operating currents. To use this circuit, throw the switch SW1 into position 1 and adjust the variable resistor R1 until the meter A1 shows the desired pull-in current. Then throw the switch to position 2 and adjust R2 for the proper drop-out current. When you have the proper current through the coil, adjust the front and back contacts and the spring tension while throwing the switch back and forth from position 1 to position 2. Make the adjustments until you get pull-in and drop-out at the proper currents with good contact pressure.

The battery and meter circuit across the contacts of the relay will serve for checking contact pressure. In this circuit, R3 is a current limiting resistor. After you have set the proper coil current ranges, jar the relay and watch the meter A2 for flicker. If the relay is adjusted with good contact pressure, meter A2 will not move when the relay is jarred.

Sensitivity adjustments are usually provided only for low coil current relays. Current flows through the coil of a power relay only when it is closed. The current is interrupted to open the relay; so no drop-out current adjustment is necessary.

SPECIAL RELAYS

Relays are available for specific mechanical design requirements. For example, some relay types have special contact arrangements for the more detailed electrical switching sequences, and special low capacity and low loss contact arrangements for switching radio frequency circuits. Photoflash relays can be obtained with contacts of proper spacing and switching speed to prevent discharge arcing and permit accurate timing of photographic exposures.

Extremely sensitive relays are also available. Some operate with coil powers of just a few milliwatts or current flows measured in microamperes.

Latching and Holding Relays. There is one type of relay, called the latching relay, that does not need a continuous current through the coil.

A short pulse of current, just long enough to cause the relay to close, is the only requirement. The basic arrangement is shown in Fig. 9.

In this relay, coil 1 and armature 1 control the contacts. When coil 1 is energized, armature 1 moves down toward the coil and pushes back armature 2. The ratchet end of armature 2

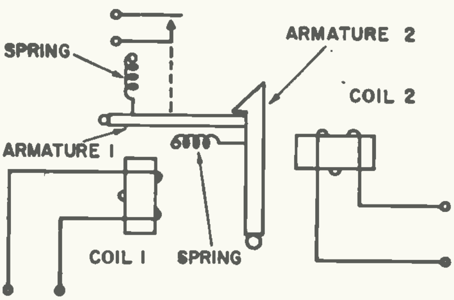


FIG. 9. Basic latching relay.

engages armature 1 and prevents it from returning to its initial position when the current through coil 1 is interrupted. A second coil, coil 2, releases the armature of coil 1. In some cases a second coil is not used; the armature must be released mechanically. As shown in Fig. 9, two sets of control lines are necessary for a complete cycle of the relay.

This type of relay is often used in overload circuits. Excessive current in a circuit causes armature 1 to be pulled down. The contacts controlled by this armature break the power fed to the load. Breaking this power feed removes the current from the relay coil, but armature 2 holds the circuit open.

In some circuits, an extra pair of contacts are closed by armature 1. These contacts control a time delay relay which in turn controls coil 2. In this way, armature 1 can be reset automatically after a given length of time. Automatic reset circuits are used where momentary overloads are common.

It is possible to use a double-pole double-throw relay and an extra power source to provide a holding action. The circuit for this arrangement is shown in Fig. 10. This system does not require a magnetically controlled mechanical latch, yet produces the same results.

When the control signal energizes the relay, contact arm 2 moves from arm 3 to arm 1. This action switches the relay coil from the line which carries the control signal to a separate battery. The battery holds the relay in the energized position. At the same time contact arm 5 is drawn over and makes contact with arm 4 to complete the circuit to the controlled device.

The switch contacts 1 and 2 are called "holding contacts." The switch SW1 in the battery circuit is the reset switch. This is a spring loaded switch normally closed. To reset the relay, the switch is momentarily depressed

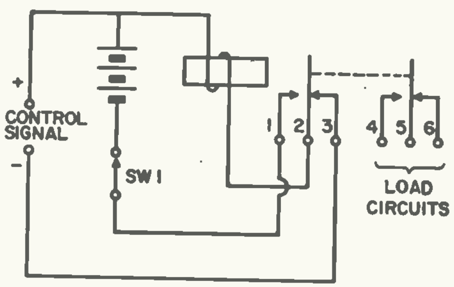


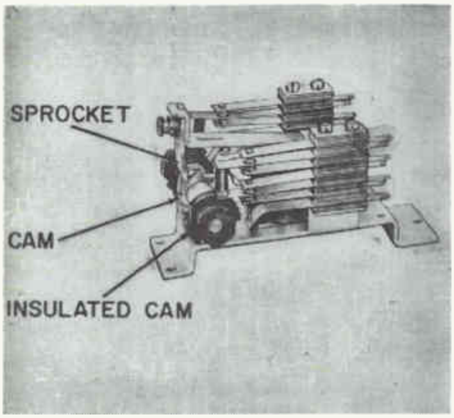
FIG. 10. Single coil electrical latching relay using holding contacts.

and breaks the current feed to the relay. The switch SW1 can be replaced by a normally closed SPST relay or an automatic reset circuit.

You will note in this circuit that once the control signal has energized the magnet, the control circuit is broken and no current is drawn on that path. At the same time, after the relay has been reset, the battery circuit is broken and no current is drawn there. The only requirement for this relay is that it must make fast and positive contact between arms 1 and 2 before the armature can fly back.

The impulse relay shown in Fig. 11 is a more elaborate version of a latching relay. In this type of relay each impulse of current through the coil causes a sprocket and cam assembly to move one position. The insulated cams are made of bakelite, and their raised spots and notches can be set up to follow a pre-determined switching sequence. By using different cam and leaf combinations for each bank of contacts, various switch combinations can be set up.

Time Delay Relays. Time delay relays are also available, and special circuits can be constructed to operate a conventional relay in a time delay sequence. The purpose of a time delay system is to turn a device on or off a certain period of time after the control signal is received. For example, a time delay relay system controlled by the filament circuit of a high powered vacuum tube could prevent the plate voltage from being applied



Courtesy Potter and Brumfield

FIG. 11. Ratchet type impulse relay.

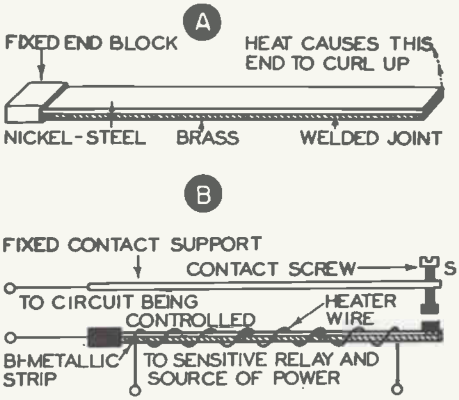


FIG. 12. Bi-metallic strip time delay relay. A, Action of two metals with different expansion rates. B, Heater wire wrapped around the strip.

until the filament reaches correct operating temperature. Also some television receivers use time delay relay circuits to prevent plate voltage from being applied to the sweep tubes before their cathodes reach proper operating temperature.

Probably the most common type of time delay relay is operated by heat. You have already studied one relay of this type in your lesson on photocell circuits. The basic principles and mechanical arrangement of this type of relay is shown in Fig. 12.

Metals expand when heated, but different metals expand different amounts with the same increase in temperature. If two metals with different expansion rates are welded or riveted together and then heated, one will still expand more than the other (see Fig. 12A). This difference in expansion causes the metal strip to bend in the direction of the metal that expands the least. By using a heater wire near a bi-metallic strip, contacts may be closed or opened by the distortion of the strip when a current is passed through the heater. The drawing of Fig. 12B shows the heater wire wrapped around the strip. However, this is not always the case. The heater may be a short distance from the strip where more time delay is needed.

The delay obtained by this type of relay is not constant. If the relay is operating when the temperature is low, there will be a longer time delay before the strip heats and bends enough to make contact. This feature is used to good advantage with mercury vapor rectifier tubes. Since these tubes must not have plate voltage applied to them until the gas has reached its operating temperature, different time delays are required depending upon the temperature of the gas in the tube. The colder the tube, the longer the time required. If a thermal relay of this type is placed near the tubes, it will have the same temperature and can be made to have the required time delay regardless of whether the region around the rectifiers is at a high or low temperature.

A time delay can be made electrically using the charging characteristic of a capacitor, current flow delay in a small vacuum tube or a thermistor. (In a thermistor, the resistance changes with heating.)

A large value capacitor located in the grid circuit of the control vacuum tube, as shown in Fig. 13A, can be used to delay relay operation. The tube is normally biased to cut off until the charge on the capacitor builds up to a high enough value to permit the tube to draw plate current. The delay time can be controlled by the choice of capacitor and series resistor values. Thus, the operation of the relay can be delayed a definite length of time after the control signal has been applied to the control tube grid.

It is also possible to delay the release of a relay by connecting a large value capacitor across the relay itself as shown in Fig. 13B. In this arrangement, the charge on the capacitor will cause current to flow through the relay after the tube itself has been driven to cut off. The relay will continue to hold until the voltage charge on the capacitor has been drained off. Of course, the delayed release time can be made longer by increasing the capacitor value.

A circuit frequently used in the power supplies for electronic equipment is shown in Fig. 14. Due to the resistor in the filament circuit of the 6J5, the tube heats slowly and 30 to 60 seconds are required before the relay closes. By this time all other tubes are well heated.

When more precise time delays are required than can be obtained by a thermal relay or by the charge char-

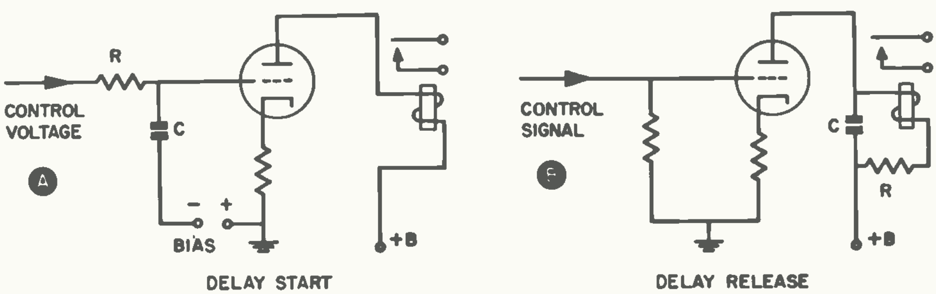


FIG. 13. Delay methods in relay circuits. A, Capacitor in the grid circuit of control vacuum tube. B, Capacitor across relay itself.

acteristics of a capacitor, it is customary to use small synchronous motors as clocks. Clocks of this type have delays ranging from 10 seconds to hours. Most of these units are adjustable and have calibrated dials so that almost any desired time delay can be selected. They have rotating arms which close small switches after a fixed time has passed. The clocks usually have a friction clutch which disengages and prevents damage to the motor after the switch has been closed and the arm stopped. In some cases, an extra set of contacts on the switch disconnects the motor from the electric circuit and a latch holds the switch in position.

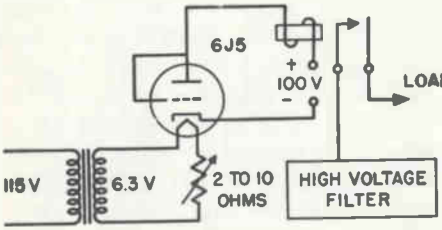


FIG. 14. Circuit for using the heating time of a vacuum tube to give a time delay.

RELAY CIRCUITS

Semi-conductor diodes or vacuum tube diodes are used with relays, either as protective devices or to perform specialized circuit functions. For example, a crystal diode, connected as shown in Fig. 15A, can be used to cause the relay to operate when the applied control voltage has a definite polarity. When a positive potential is applied to terminal 1, a high current flows through the series crystal and relay coil circuit. (The crystal biased in the forward direction.) If the input control voltage is negative at terminal 1, however, the crystal diode is reverse-biased, and only a very small current can flow—not enough to operate the relay.

When the connections to the crystal diode are reversed, the relay operates with a negative potential applied to terminal 1. It is possible then to use two such circuits on a single control voltage line. With the crystals connected with opposite polarities, either relay can be operated by changing the polarity of the control voltage, as shown in Fig. 15B.

Fig. 16 shows how a dc relay system can be made to function with an applied ac signal by adding a rectifier circuit. In this arrangement either power line, audio, or radio frequency voltages of the proper amplitude can be used to operate the relay.

On positive half-cycles of the applied signal voltage, diode D1 conducts and causes a high series current to flow through the crystal and relay coil. As a result, the relay closes. When the input signal swings negative, diode D2 conducts and shunts a low resistance path across D1 and the relay. Capacitor C is used to block dc components so that relay operation is

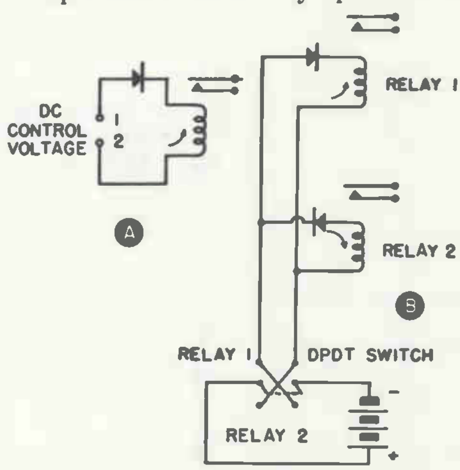


FIG. 15. Polarity-sensitive relay connections. A, crystal diode connected with definite polarity. B, crystals connected with opposite polarities.

strictly controlled by the ac signal.

Fig. 17 shows how a crystal diode can also be used to protect the relay contacts when supplying voltage to an inductive load. In the circuit the crystal is inverse-connected across the inductive load. Consequently, when the load device is operating normally, there is very little crystal current be-

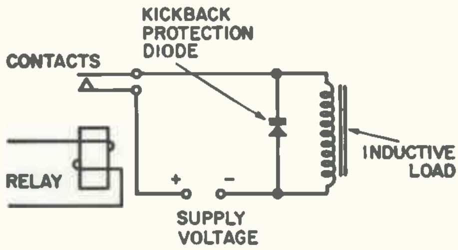


FIG. 17. Inductive load contact protection.

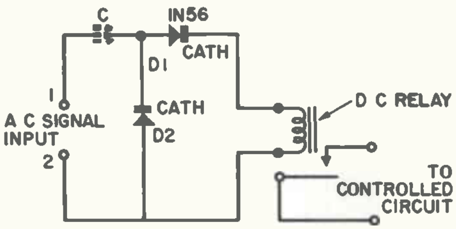


FIG. 16. Operation of dc relay with an ac control signal.

cause of its inverse connection. When the relay opens, however, the collapsing magnetic field induces a voltage of opposite polarity; this can produce contact arcing because of its very high amplitude. With the crystal in the circuit, the energy of the collapsing field will be dissipated in its low forward resistance, instead of arcing across the relay contacts.

Gaseous Control Tubes

Many control circuits use a special gas-filled electron tube called the thyratron or grid-glow tube. These tubes look very much like ordinary receiver tubes, but instead of a vacuum, the envelope contains a small amount of gas. The gases used are mercury vapor, argon, neon and hydrogen. An example of one such tube is shown in Fig. 18.

These tubes have a cathode which emits electrons, a control electrode or grid, and a plate or anode which attracts the electrons emitted by the cathode. These three electrodes have the same purpose as the electrodes in a vacuum tube. However, the presence of gas in the tube completely changes the operating characteristics.

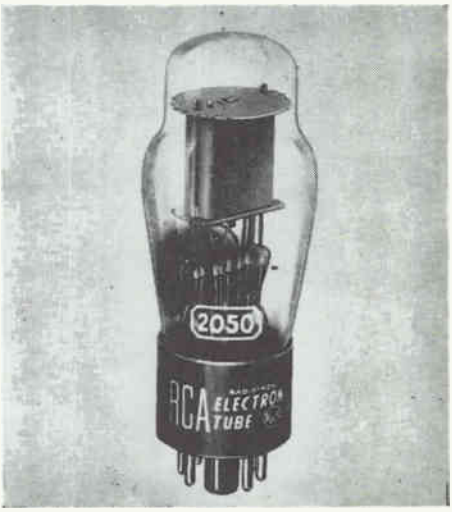
The vacuum tubes which you have studied up to this time are used as power or voltage amplifiers. Gas-filled tubes cannot be used in amplifier circuits, but instead act as electronic relays.

A vacuum tube can act as an amplifier because its grid controls the plate current. When an alternating voltage is applied to the grid, the plate current varies in exactly the same way as the grid voltage. In a gas-filled triode, the grid can only prevent the plate current from flowing; it cannot change the value of the plate current nor stop it once it has started. Because of the gas in the tube, the grid cannot change or limit the plate current.

That last paragraph is extremely important. It sums up the difference between a gas-filled triode and a vacuum triode. When plate current flows in a gas-filled tube, the grid loses all control. This one simple fact explains the difference in circuits using the two types of tubes. Now let's see why this is so and how it affects the circuit.

The flow of plate current in a gas triode can be prevented by applying a negative bias to the grid of the tube. This bias stops electrons from leaving the cathode and traveling to the plate. When this bias is removed, electrons are attracted to the plate at high speeds. These electrons bump into gas molecules and knock one or more electrons off each molecule. The electrons which leave the gas molecules are attracted to the plate and electron multiplication takes place just as in the gas photocell.

Each gas molecule becomes a positively charged ion when it loses an electron. These positive ions are repelled by the positive anode and attracted by the negative cathode. This follows from our most basic rule in electricity. Like charges repel; and unlike charges attract.



Courtesy RCA Tube Division

FIG. 18. Thyratron tube.

When you first studied vacuum tubes you learned that a cloud of electrons, called a space charge, forms around the cathode. This negative space charge acts against electrons leaving the cathode and keeps the emission fairly low. In a gas-filled tube, the positive ions are attracted to the space charge. Each ion that reaches the space charge takes on an electron and becomes neutral. The positive ions greatly reduce or completely eliminate the space charge. Removing the space charge reduces the voltage drop across the tube and allows a very high current to flow.

If the grid is again biased negative, positive gas ions will be attracted to it. The grid does not emit electrons and there is no space charge around it. Therefore, the ions are drawn right to the grid surface. There they obtain electrons and are neutralized. The grid becomes completely surrounded by positive ions and can exert no repelling force against electrons from the cathode. The grid no longer has any control over plate current. It can neither reduce nor stop the flow of electrons from the cathode to the plate.

The presence of positive ions has neutralized the space charge around the cathode and neutralized the negative field around the grid. This has three very important effects on the tube circuit. First, the grid is unable to control the plate current. Second, the ions take electrons from the grid which causes a current to flow in the grid circuit. Third, neither the grid nor the space charge can hold down the plate current. The plate current raises to very high values and the voltage drop across the tube becomes very low.

A resistance must be placed on the grid circuit to limit the grid current.

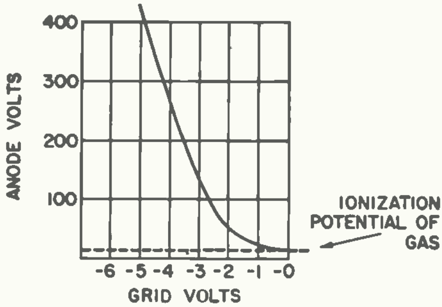


FIG. 19. Typical grid-voltage plate-voltage conduction curve for thyratron.

Otherwise, the tube would destroy itself. The resistance of the plate circuit is the only thing that controls the plate current. There must be a high enough resistance in the plate circuit to limit the current to safe values.

When a gas-filled tube is conducting, the voltage drop across it does not change. This voltage drop will depend on the gas used and the pressure of the gas. The voltage drop is always the lowest that will give the electrons emitted by the cathode enough speed to ionize the gas. This voltage is called the ionization potential of the gas.

The grid voltage at which conduction within the tube starts will depend upon the anode (plate) voltage. The graph in Fig. 19 shows how the conduction point varies with changing grid and plate voltages. The tube will not conduct with any combination of voltages below the curve. Any combination of voltages above the curve will cause conduction. Once conduction has started, no change in grid voltage can stop it. It can be stopped only by reducing the plate voltage below the ionization potential. The thyratron tube acts in a dc circuit in the same way as a latching electromechanical relay.

The need to cut off the anode voltage to stop conduction would appear to limit the use of these tubes. This is true when direct current is used in the anode circuit. However, the tube may cut off periodically by using an ac plate source. The rectifying action of the tube will stop conduction on each negative half cycle of the supply source. For this reason, thyratron tubes are generally used with ac power supplies.

THYRATRON CIRCUITS

A basic thyratron circuit is shown schematically in Fig. 20A. The large dot within the tube envelope means that it is a gas-filled tube. In this circuit a positive dc voltage is applied to the anode. The grid gets its bias from a negative dc source. When the arm of the potentiometer R2 is moved as far above ground as possible, the negative voltage applied to the control grid prevents conduction. As the arm is moved down toward ground, the negative voltage applied to the grid is reduced. Finally, the grid bias is reduced to the conduction level, and the thyratron begins to conduct. As soon as the current flow starts, the relay closes. Once the tube is conducting, the arm of the potentiometer can be moved away from ground toward a high bias without changing the thyratron current. The relay remains closed regardless of the setting of the grid bias.

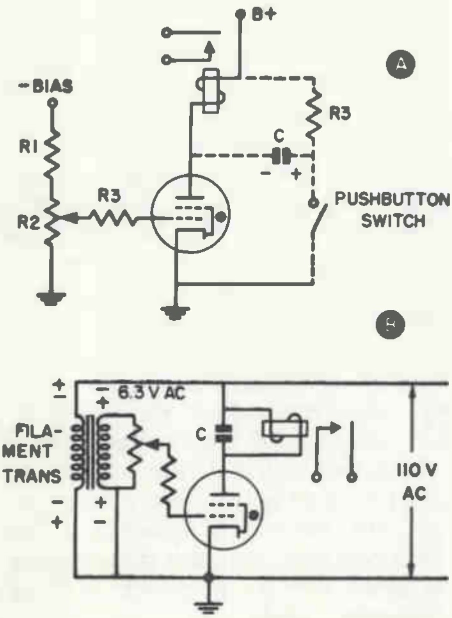


FIG. 20. Basic thyratron circuits. A, using a dc supply source and B, using an ac supply source.

Thyratron current flow can be stopped only by interrupting the anode voltage. One method of doing this is shown in the dashed line portion of the schematic in Fig. 20A. Capacitor C charges during the conduction period with polarities indicated on the diagram. When the pushbutton is depressed momentarily, it connects the positive side of the capacitor to the cathode of the thyratron. Thus, the difference in potential between plate and cathode is reduced sharply and the thyratron ceases to conduct current. To restore current flow in the thyratron, it is again necessary to reduce the negative voltage on the grid.

Fig. 20B shows the basic thyratron circuit using an ac supply source. An advantage of using an ac power source for the thyratron is that the tube conduction can be controlled by varying an ac supply in the grid circuit.

In the circuit in Fig. 20B, 110 volts ac is applied to the anode-cathode circuit, while a 6.3 volt ac source is used for supplying control grid-to-cathode bias. On the positive alternation of the applied supply voltage, the plate of the thyratron is positive with respect to the cathode, and the tube will conduct. At the same time, when the arm of the potentiometer is above ground, the phase of the 6.3 volt ac

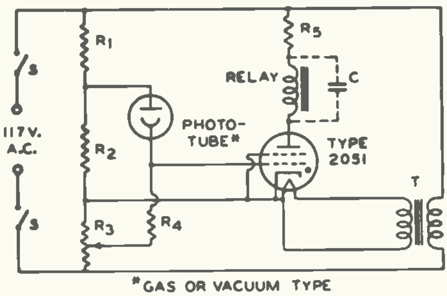


FIG. 21. Schematic showing how thyratron closes relay with light increase.

is such that the grid is negative with respect to the cathode.

The arm on the potentiometer can be adjusted to set the average grid-to-cathode bias either at a high value which holds the thyratron cut off or, when the arm of the potentiometer is moved toward ground, at an average bias which permits the thyratron to conduct. Since the tube conducts on each positive alternation of the power signal applied to its plate, the thyratron plate current flowing through the relay causes it to close when the grid bias is set correctly. However, in this circuit the thyratron tube can be cut off again by increasing the grid bias. In this way, the control grid bias can control the plate circuit relay.

Since the thyratron current flow is interrupted for each cycle of the power source, precautions must be taken to prevent the relay from chattering (attempting to close and open) at the power line rate. The chatter can be stopped by connecting a capacitor across the relay coil. This capacitor acts as a storage unit and will supply current to the relay coil during the negative alternations of the power source.

Photocell Control of Thyratrons. Two practical thyratron circuits (as used with phototubes) are shown in Figs. 21 and 22. In Fig. 21, the relay will close when the light intensity on the photocell increases. The relay in Fig. 22 will close when the light source is decreased or is interrupted. The thyratrons and phototubes are powered by the 117 volt ac line. The phototubes are so connected that their plates are supplied with the positive half-cycle of the power signal at the same time as the plate of the thyratron. Thus both the phototubes and the thyratrons conduct at the same time.

In Fig. 21, the control grid-to-cathode bias is obtained from a voltage divider consisting of resistors R1, R2, and R3. The control grid is biased negatively with respect to the cathode on the positive alternation by tapping off the control grid voltage at a point lower on the divider than the cathode. The average bias on the control grid can be made less negative by moving the arm of the potentiometer toward the junction of resistors R2 and R3.

With no light exciting the phototube, or with the phototube excited by stray light, the potentiometer R3 is adjusted to the point at which the thyratron just ceases to function. When the control light is applied to the phototube, the thyratron will be

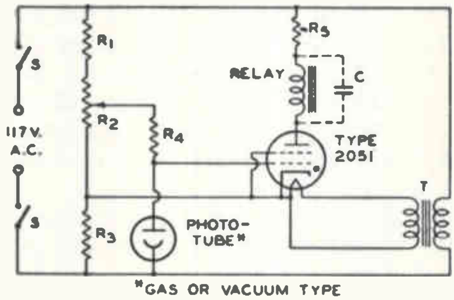


FIG. 22. Schematic showing how thyratron closes relay with light decrease.

brought into the conducting range. The phototube current flows up through resistor R4 and develops a positive voltage at the grid of the thyratron. Thus, excitation by the control light causes the phototube current to increase and develop a less negative voltage at the control grid. As a result the thyratron is triggered into operation. Thyratron conduction, of course, causes the relay to close.

When the light excitation is removed, the phototube current decreases. As it decreases, the control grid is made more negative with respect to the cathode and stops the thyratron current flow. Remember that with an ac power source, the thyratron can be cut off by regulating the control grid bias because the plate of the thyratron is made negative with respect to its cathode during the negative alternation of the power cycle.

The capacitor across the relay prevents chattering at the power supply frequency. Resistor R5 is a safety precaution. Its value is chosen to prevent too high a thyratron current and possible damage to the relay coil and tube. Its value is adjusted until the thyratron current is no greater than the rated safe current for the relay coil.

Fig. 22 shows a slightly different circuit arrangement because the relay closes when the light falling on the phototube decreases. In this circuit the relay remains open when the phototube is excited by light. However, when the light source is interrupted, the thyratron tube conducts and causes the relay to close.

The circuit arrangement is the same as Fig. 21 except for the phototube and thyratron control grid circuits. The control grid bias is removed from the positive side of the cathode tap on the voltage divider instead of the negative side, as in the previous circuit. Thus, when no current flows in the phototube, there is a positive bias between the control grid and cathode of the thyratron. However, the phototube current flow is in such a direction as to develop a negative voltage on the control grid side of resistor R4. Thus, the combination of the negative voltage across resistor R4 and the positive voltage at the arm of the potentiometer develops the correct amount of negative bias between the control grid and the cathode.

When light is directed on the phototube, there is enough negative voltage developed across resistor R4 and applied to the control grid to prevent the thyratron from conducting current. However, when the light source is interrupted, the phototube current suddenly falls. The bias on the grid of the thyratron becomes less negative (less current flow through resistor R4) and the thyratron tube begins to conduct and the thyratron current flow through the coil causes the relay to close. When the light source is again turned on, the phototube current increases and the thyratron bias becomes more negative to cut off the thyratron conduction.

The thyratron is an excellent control tube for a number of reasons. It can jump from no current flow to a high current flow to provide positive operation of relays. Power relays with their heavier contacts can be used because the thyratron can supply the higher current required by the power relay coil. The thyratron is adaptable to 117 volt ac operation. Thus, a rectifying power supply and filter circuit is not required.

The thyratron tube is not as stable as a vacuum tube. Changes in the temperature of the tube will cause changes in the cut-off bias for any plate voltage. At the higher plate voltages, a large change in bias is required to maintain cut-off with small changes in plate voltage; so the tube should have a well regulated plate supply.

There are large differences between tubes of the same type. The action of the tube is dependent on the gas pressure within the tube. Very small changes in the gas pressure will cause large changes in cut-off bias. If you replace a thyratron, you will have to adjust the bias for best operation.

COLD CATHODE GAS TUBES

All of the thyratron tubes we have discussed so far in this lesson have used filaments to heat the cathodes. There is, however, a group of gas-filled tubes used for relay control work that do not require filaments.

In most of these tubes the cathodes are coated with a material which gives up electrons readily when struck by heavy ions When a large potential difference exists between the anode and cathode, some of the gas molecules between them are ionized. These positive ions are attracted to the cathode. When they strike the cathode they heat it and cause more electrons to be emitted. These electrons are attracted to the anode and a large current results.

A third electrode called the starter anode is placed near the cathode. Since this electrode is close to the cathode, the gas molecules between it and the cathode are subject to a very strong force. Because of this strong force, gas ionization will take place between the starter anode and the cathode at a low voltage. Once ionization has been started in this region, current will begin flowing between the anode and cathode.

This starter anode differs in operation from the grid in a hot cathode thyratron. The grid of most tubes prevents the flow of electrons between the cathode and the anode. In this tube, the starter anode does not prevent the flow of electrons, but is used only to start ionization. Simply changing the voltage between the starter and the cathode is not enough to cause tube ionization. A cathode-to-starter current flow of about 100 microamperes is needed for the gas to be ionized. Another difference is that the tube cannot be biased off by the starter anode. The starter is always at a positive potential with respect to the cathode.

These tubes are very economical to use in ON-OFF applications because no current is drawn when the tube is not conducting. There is, however, a disadvantage because an appreciable current is required at the starter to cause ionization. At some anode to cathode voltages, current will flow between the main anode and the starter anode. Also the voltage drop across these tubes is much higher than for hot cathode thyratrons.

This type of tube is used in the night light control circuit that was discussed in the lesson on photocells. In this circuit remember that the photocell was not required to pass the full current drawn by the starter anode. A small capacitor was connected between the starter anode and cathode. The starter current was obtained by the discharge of the capacitor through the starter anode circuit.

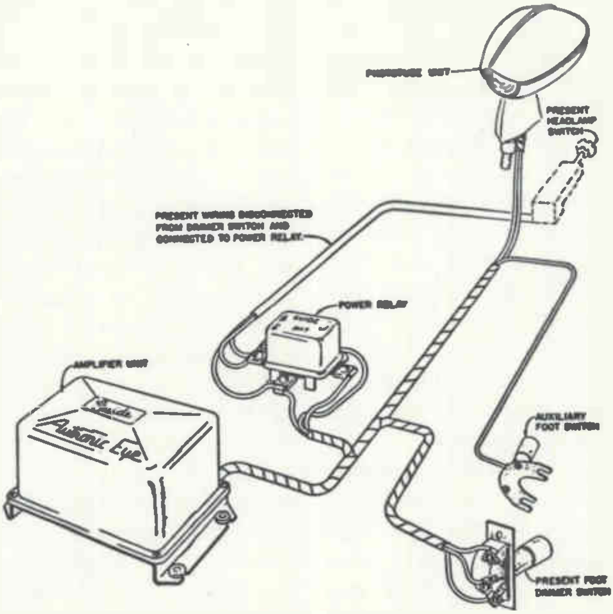
Light-Operated Control Systems

A photo-electric installation generally converts a light level change into a mechanical operation. In most cases, the light change results in the opening or closing of relay contacts. The relay contacts, in turn, switch on electrical circuits that operate electrical appliances, lights, motors, bells, or heaters.

A few commercial photo-electric systems will be discussed in this section of the lesson. The previous lesson on photo-electric cells and equipment covered the fundamentals of photocell operation.

AUTOMATIC HEADLIGHT CONTROL

A very common commercial type of photo-electric installation is the Autronic Eye used on General Motors cars. This is an automatic headlight control that switches the headlights between high and low beam in response to the light from the headlamps of an oncoming car. The major units of such an installation and the general interconnection plan are shown in Fig. 23. The phototube unit consists of phototube, lens, filter, and mask as shown in Fig. 24. The lens system makes the phototube directional so that it will respond to the oncoming headlights rather than overhead and reflected stray light. The phototube unit is mounted on top of the instrument panel so that light from the oncoming car passes through the windshield and strikes the photosensitive surface in the phototube.



Courtesy Guide Lamp Division, General Motors Corp.

FIG. 23. Interconnection plan for automatic headlight control.

The amplifier unit is mounted under the hood of the car and receives the photoelectric current from the phototube. It increases the phototube current to a level high enough to operate the relays. When the sensitive relay contacts in the amplifier unit are closed, it causes the power relay to close. The power relay is a separate unit also mounted beneath the hood. It has special heavy duty contacts for switching the headlight circuits between upper and lower beams.

An auxiliary foot switch is often included with this type of installation. It is mounted near the standard foot dimmer switch. When it is pressed down, it holds the headlights on bright beam position regardless of the amount of light striking the phototube. In this system the headlights are controlled automatically when the regular foot dimmer switch is in the high position. The other position of the standard foot dimmer holds the headlamps on low beam. The car operator, therefore, has a choice of manual or automatic headlight control.

A schematic diagram of the photoelectric headlight dimmer is shown in Fig. 25. First, examine the power relay circuit at the bottom of the schematic. When the power relay is not actuated, the relay contacts are closed as shown. In this position the battery voltage is supplied to the high beam position of the headlight. When the relay is actuated, the arm closes with the bottom contact of the power relay. In this position the battery voltage is applied to the low beam.

The standard foot dimmer switch is shown to the right of the power relay. It is in the automatic position. Following the line going to the right of the foot dimmer switch, you see that it connects to one contact of the plate circuit relay in the amplifier unit. This contact controls the current through the coil of the power relay. Thus, the contact switching is under control of the sensitive or pilot relay in the plate circuit of the amplifier tube.

The current from the vacuum phototube develops a negative voltage on grid 1 of the amplifier tube. When the phototube is dark, there is very little bias on the grid of the first section of the tube, composed of grid G1, cathode K1, and plate P1. The tube passes current and the pilot relay is held closed. This is the condition shown in the diagram. The power relay coil is connected to the back contact, contact 3, of the pilot relay. Therefore, when the phototube is dark, the amplifier tube passes current, the pilot relay closes, the power relay opens, and the headlights are on high beam.

When the phototube conducts, the amplifier tube is cut off, the pilot re-

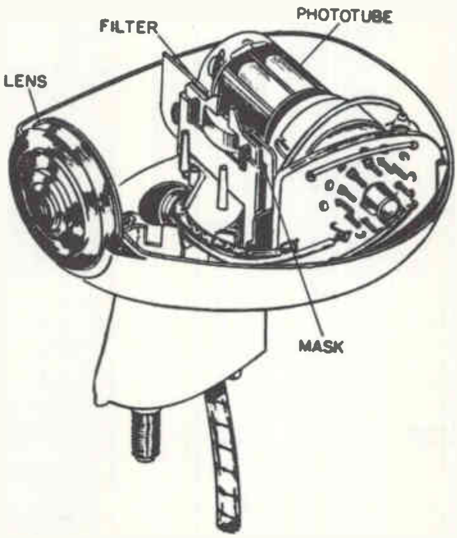


FIG. 24. Phototube unit.

lay opens, the power relay closes, and the headlights are on low beam.

Notice that when the sensitive plate circuit relay is energized, contacts 1 and 2 are closed, placing resistor R1 in parallel with grid resistor R2. This reduces the value of the grid resistor on the amplifier tube, and also the current gain of the tube circuit.

The system is most sensitive when the pilot relay is open and the lights are on low beam. If this were not the case, there would not be enough light from a car approaching on low beam to hold the amplifier tube at cut off until the car passed. The phototube amplifier, however, cannot be operated at maximum sensitivity at all times; otherwise, reflection from snow or wet pavements would cause the car's own lights to trip the circuit.

When the oncoming car passes and the phototube is again in darkness, the photo-current decreases. The negative voltage drop across resistor R2 falls to a point where plate current flows in the amplifier tube and the pilot relay again closes. This pulls the armature so that it makes contact between terminals 1 and 2 and breaks contact between terminals 2 and 3. Resistor R3 absorbs the voltage inducted by the collapsing magnetic field around the power relay when the circuit is broken. This protects the contacts of the pilot relay from damage due to arcing.

The second triode section of the amplifier tube, which includes grid G2, cathode K2 and plate P2, operates with the auxiliary foot switch. Notice that the grid and cathode of this tube section connect to the foot switch. Thus, when the foot switch is depressed, the grid and cathode of the second section are grounded. Therefore, a high plate current flows through the plate circuit relay and holds contacts 1 and 2 closed regardless of the amount of light striking the photo-

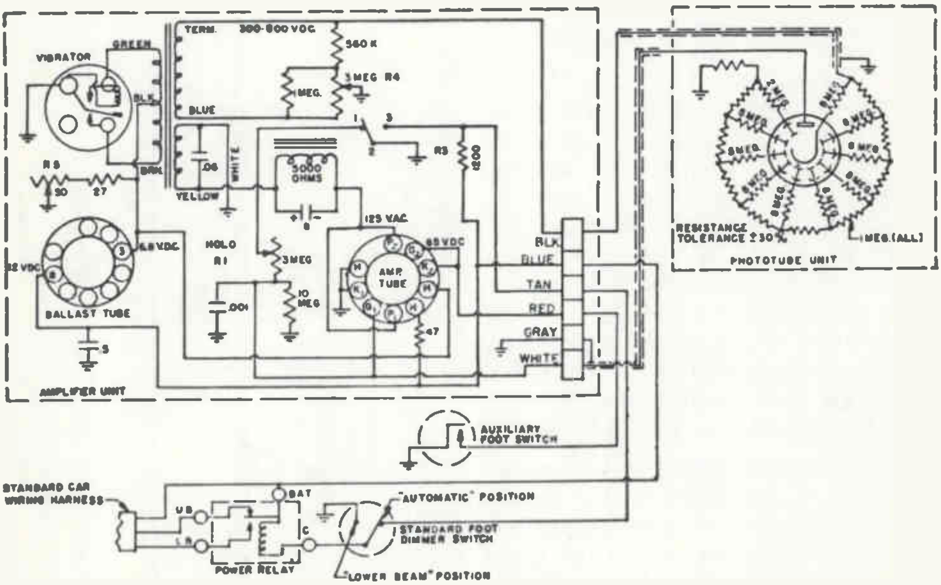


FIG. 25. Photo-Electric headlight control.

tube. The car operator, therefore, can use the auxiliary foot switch to keep the headlights on high beam without regard to the amount of light striking the phototube.

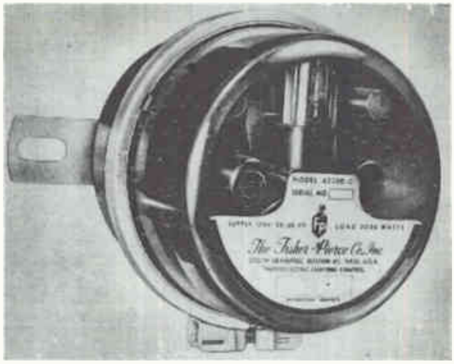
Note that if tube or power supply fails, the pilot relay opens, the power relay closes and the lights are held on low beam.

A vibrator power supply is operated from the car battery to obtain the necessary phototube and amplifier tube voltages. A ballast tube is used to get good regulation and surge protection. Since the photocell is operated on ac from the vibrator supply, a .001 mfd. capacitor is placed from grid to ground in the amplifier for filtering. The 8 mfd. capacitor across the pilot relay prevents it from chattering at the vibrator frequency.

There are a number of adjustments in the amplifier unit. The rheostat, R5, is adjusted to obtain the proper voltages at the transformer center tap for the ballast tube and the amplifier tube filament.

Resistor R4 is used to adjust the high voltage applied to the phototube. The hold control, resistor R1, determines the shunting effect of resistor R1 across R2. Actually, it regulates the amount of negative voltage applied to grid 1 for a given amount of photo-current.

A number of mechanical adjustments also must be made when a headlight control system is installed or serviced. The phototube unit itself must be aimed correctly both horizontally and vertically. Special test devices and levels are available for making these adjustments. Horizontal adjustment of the phototube unit is important because the light from the oncoming car is to the left of dead center. The horizontal sensitivity range must be controlled so as not to respond to stray light rays that could arrive from the far left or right. Likewise, the vertical range of operation must be controlled so that the dimmer does not respond to overhead lighting or to reflections off the highway from the car's own headlamps or from stray lighting sources.



Courtesy Fisher-Pierce Co., Inc

FIG. 26. Automatic street light control.

Special testers are also available for adjusting the hold and high voltage controls, R1 and R4. These controls determine the amount of light needed to open the sensitive plate circuit relay. In effect, they determine from how many hundred yards away the photo-electric unit will be triggered by the light from an oncoming car. They are adjusted to hold the headlight on low beam position with limited intensity fluctuations in the arriving light beam from the moving car. Also proper adjustment prevents rapid switching of the headlights with rapid changes in light intensity when a group of cars are passing.

OUTDOOR LIGHTING CONTROL

The unit shown in Fig. 26 is used mainly for street lighting control and for highway billboards. A similar unit can be used to control lighting for parking lots, factory yards and shipping areas, public buildings, storage areas, apartment buildings, etc.

The photo-electric control usually faces the northern sky and is designed to evaluate changes in the blue light range and to be insensitive in the red range. The blue light of the northern sky is most typical of the gradual change in brightness as the sun sets or rises. Red sky lighting is more of a variable and is too dependent on atmospheric conditions, dust content, etc.

In practice, street lighting is turned on by the photo-electric unit approximately 20 to 25 minutes after sunset and turned off about the same length of time before sunrise. A "turn off" delay of some 5-7 seconds is provided to prevent street lights from being turned off at night by passing lights which might focus on the control. Lights can be made to come on when the north sky illumination falls to any pre-set value between ½ and 5 foot-candles. Lighting will be turned off whenever the illumination increases one foot-candle above this pre-set value.

The power contactor shown in the diagram in Fig. 27 is able to switch powers of 3000 watts, while the photo-electric control itself draws only ten watts. The 110 volt ac power to operate the control unit is obtained from terminals 1 and 2 on the base plate assembly. The lights to be controlled are connected between terminals 2 and 3.

The automatic light control shown in Fig. 27 uses two vacuum tubes in addition to the vacuum phototube. A two-stage amplifier with feedback provides positive operation of the relays and the correct operating point between turn on and turn off. The 1P39 phototube is blue-sensitive and is well suited for outdoor lighting control.

When light falls on the phototube the current flow in the tube develops a negative voltage across resistor R-21-1 and on the grid of the 6SQ7 amplifier tube. This first amplifier stage is direct-coupled through a delay network to the control grid of the second stage.

The delay network (resistor R-21-2 and capacitor C53) prevents any plate

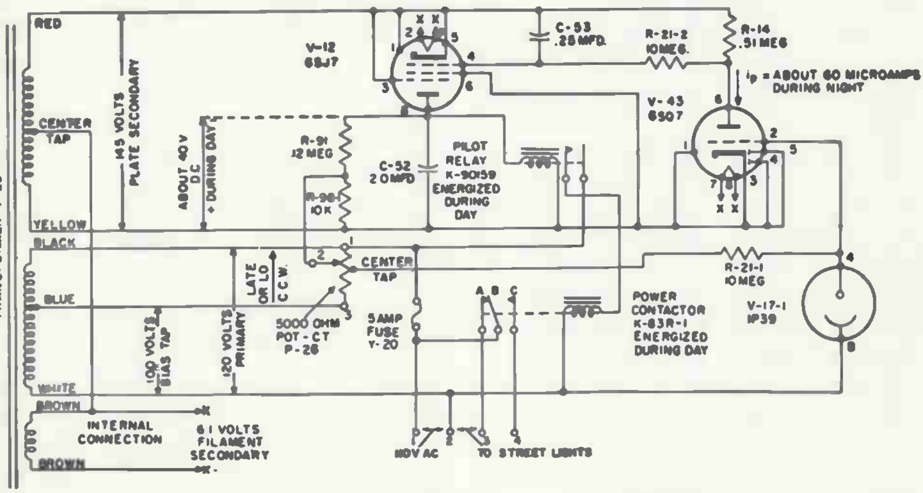


FIG. 27. Circuit for typical lighting control unit.

voltage rise at the first stage from being applied immediately to the control grid of the second stage. Instead, the voltage on the grid of the second tube rises slowly as capacitor C53 charges through the 10 megohm resistor. Thus, 5 to 7 seconds pass before a light change can cause the grid voltage to rise on the second stage.

When the light falling on the phototube causes the control grid voltage of the 6SQ7 tube to increase, the plate current of the 6SJ7 tube flowing through the pilot relay increases, which causes the relay contacts to cease. When the pilot relay contacts close, a high current also flows in the coil of the power relay. Thus, contacts B and C are closed and power is not applied to the lighting line.

At dusk the illumination falls at the phototube and the grid of the first amplifier becomes less negative. Therefore, the plate current increases and the plate voltage decreases. The decreased plate voltage drives the grid of the second stage more negative. The second stage plate current decreases and the pilot relay contacts open.

The opening of the pilot relay contacts removes power from the power relay coil and its contacts are broken between B and C and established between A and B, in the position shown in the diagram. Now power is switched into the lighting line between terminals 2 and 3 of the base plate.

Feedback voltage is tapped off at the junction of resistors R91 and R98-1. It reaches the grid of the 6SQ7 tube through potentiometer P-28 and resistor R-21-1. A feedback link provides a fast, positive switch-over and permits the turn-off point to be a fixed number of foot-candles above the turn-on light level. Consequently, on and off levels are separated, and switching does not become erratic at dusk and dawn.

The purpose of this unit is to turn on lights at night. It is constructed so that, if the fuse blows or a tube fails, the lights will come on automatically and remain on until the unit is repaired. This type of operation is called "fail-safe"; that is, if the unit fails, the desired operation is obtained anyway.

Whenever controlled systems are used as alarms or safety devices, either some form of "fail-safe" arrangement should be used or a controller failure alarm should be installed.

RF-Operated Control Systems

There is no limit to the ways control circuits can be used. The control signal may be generated by any device which can produce a change of voltage, current, phase, or frequency in an electrical circuit. The control signal may be transmitted by wire or radio.

The control signal may be in the form of ON-OFF pulses such as the dc switching system which controls the current to a relay coil. A system of this type can handle only one signal at a time. If more than one signal must be transmitted at once, ac pulses of different frequencies can be transmitted together and separated at the receiving end by tuned circuits.

When the distance from the control signal generator to the controlled devices is short, it is best to use separate wire circuits for each control signal. When the signal must be sent over long distances or when radio control is used, separate frequencies for each control signal provide the best means of control.

It is impossible to discuss all the possible uses for electronic control systems in one lesson. There are hundreds of clever units for producing control signals from changes in temperature, pressure, humidity, etc. Most of these units operate on very simple principles, and you will not have any trouble understanding them.

The operation of some of the more common rf-operated control systems will be explained in this section. We will cover carrier current controls, capacity-operated relays, and simple radio control systems.

CAPACITY-OPERATED DEVICES

Capacity-operated electronic devices are excellent for presence indicators or intruder-warning units. In this type of installation, a small antenna or plate is connected to the grid of a self-excited oscillator. Any person, animal or large moving object which comes close to this antenna will absorb power from the antenna and reduce the feedback voltage at the grid. The body of the person or animal acts as one plate of a capacitor, while the antenna acts as the other plate. This capacitor bypasses part of the rf current at the grid to ground. The change in feedback of the oscillator reduces the self-rectified grid bias of the tube and causes an increase in plate current. This increase in plate current can be used to operate a relay.

A typical capacity-control system is shown in Fig. 28A. It consists of a pentode oscillator using a Hartley circuit. A metal plate or feeler connection is on the control-grid side of the grid resistor. The feeler can be compared to an antenna on a radio set. Any object coming near the feeler causes a change of capacity from grid to ground, and causes an increase in the tube plate current.

To understand the operation of this circuit, think of the feeler capacity as the capacitor C3 shown dotted in the circuit of Fig. 28A. In any oscillator, the amplitude of oscillation is dependent upon the feedback. In this circuit the feedback is dependent upon the point where the coil is tapped and the ratio between capacitors C2 and C3. The smaller the value of C3 compared with C2, the greater will be the amplitude of oscillations.

In this circuit, the tap is fixed on the coil. When any object comes near the feeler, it increases the value of capacitor C3. This reduces the feedback, which in turn reduces the amplitude of oscillation. The tube is grid leak biased by the 10 meg. resistor in the grid circuit. As the amplitude of oscillations is reduced, the bias generated by rectification between grid and cathode in the drop across the 10 meg. resistor becomes less and the plate current increases. This increase in current closes a relay in the plate circuit.

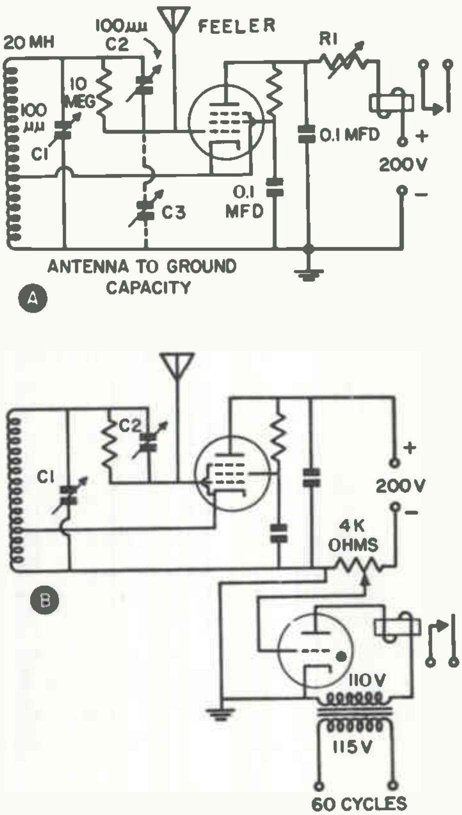


FIG. 28. Capacity-operated relay circuits. A, pentode oscillator using a Hartley circuit. B, use of thyratron tube to operate relay.

This oscillator is designed to operate at about 100 kc so any receiving type pentode tube can be used in this circuit. The screen dropping resistor is selected to apply the proper value of screen voltage to the tube.

When the unit is put into operation and connected to its feeler, the adjustment is done in the following way. Resistor R1 is set at its minimum value, then backed off until the relay just opens. The value of C2 is reduced until the relay closes. Then R1 is backed off until the relay opens and C2 is reduced until it opens again.

These adjustments are repeated alternately until it is no longer possible to cause the relay to close by reducing the value of C2. The unit should then be checked by coming near the feeler to assure that the relay will close. When this unit is adjusted, greatest sensitivity is obtained by using the smallest possible value of C2.

If the lead to the feeler or the antenna wire is very long, it may be impossible to find any position in which this circuit will operate properly. If this is the case, fixed capacitors will have to be added in parallel with C2 or in series with the feeler lead.

The sensitivity of this unit can be increased by using a thyratron tube to operate the relay. The proper circuit for doing this is shown in Fig. 28B. This circuit is adjusted by setting the 4K ohm potentiometer for minimum bias on the thyratron, then adjusting capacitor C2 and the 4K ohm potentiometer alternately until the desired sensitivity is obtained.

Such a capacitive device is especially effective as an intruder-warning unit. The feeler can be wrapped around a window or door frame. When anyone climbs in the window or enters the door, the capacitive change sets off the control device and sounds a buzzer, turns on a light, or gives some other warning.

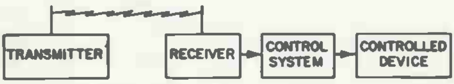


FIG. 29. Block plan of radio-control system.

Another effective use for the capacitive device is in window displays. The feeler can be placed on the glass pane. When a pedestrian passes close to the feeler or puts his finger near a marked location, the capacitive-controlled unit can turn on some type of moving window display. The feeler can also be attached near the entrance of a store to turn on attractive displays in the salesroom as people enter.

RADIO CONTROL SYSTEMS

Electronic control systems can also be triggered by a radio-control signal. As shown in Fig. 29, a small transmitter can be located at a point some distance from the device to be operated. When the transmitter is turned on, it sends out a signal that is picked up by a receiver at the device to be controlled. After the signal is picked up and detected, it provides the current or voltage change necessary to trigger the electronic control system.

Before you try to do any work with radio control systems, you should obtain a copy of Part 19 of the Federal Communications Commission's Rules and Regulations Governing the Citizen's Radio Service. It is available from the Superintendent of Documents, Washington 25, D. C., for five cents in coin. You can get all future amendments to this part of the rules and regulations by returning the form they will send you with the pamphlet to the Federal Communications Commission.

It is impractical to give complete information on frequency stability, power limitations and licensing requirements for this type of service in a textbook. The regulations are changed from time to time, and only by reading the amendments as published by the Federal Communications Commission can you be sure that you are operating within the law.

A transmitter used for radio control must be designed so that its power output is low, and so that it is impossible to tune it to the wrong frequency.

There are three classes of stations used for radio remote-control, depending on the type of equipment used, and the frequency at which they operate. The frequencies assigned to this service are called "Citizen's Radio." Class A and Class B stations operate between 460 and 470 mc, and Class C stations operate at 27.255 mc.

You can operate any of these without an operator's license if you have FCC approved equipment. However, even though you do not need an operator's license, you must have a transmitter license. You can get one by applying to the FCC.

The permissible frequency variations for these stations are: 0.02% for Class A, 0.5% for Class B, and 0.04% for Class C. The maximum permissible bandwidth is 200 kc for Class A, 4.65 mc for Class B, and 10 kc for Class C. The maximum permissible input power is 50 watts for Class A, 10 or 50 watts, depending upon frequency, for Class B, and 5 watts for Class C.

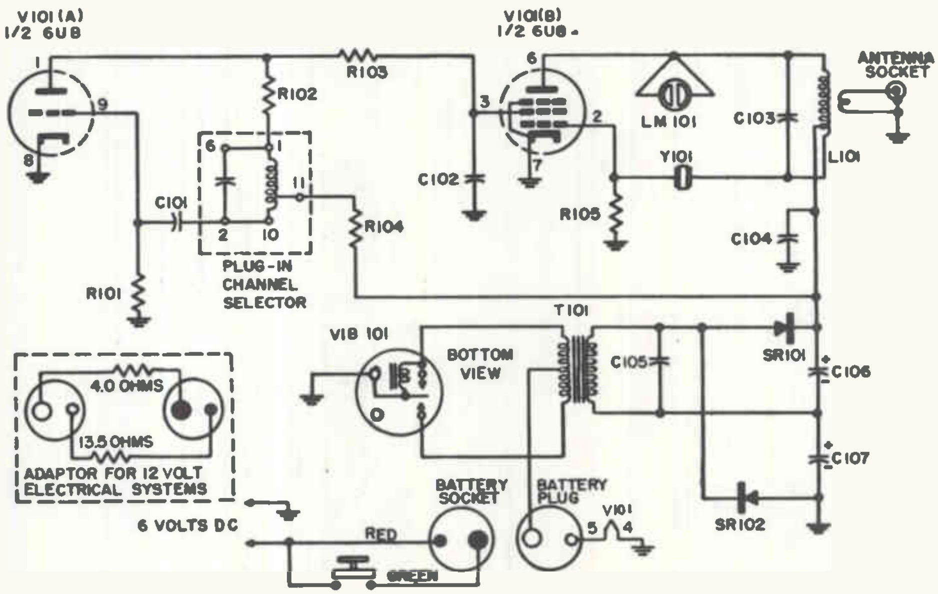
Garage Door Openers. A typical transmitter and a receiver used by the Perma-Power Company for their automatic garage door opener are shown in Figs. 30 and 31. The transmitter is a single tube unit using a 6U8 triod-pentode. The pentode works as a crystal-controlled oscillator, screen-modulated by the triode section.

The modulator is really an audio tone oscillator using a modified Hartley circuit. The output of the audio generator is applied to the screen grid of the oscillator. Tone modulation is used to prevent interference between similar type installations in a given neighborhood. Approximately 10 modulating frequencies are available between 600 cycles and 4700 cycles.

The pentode section functions as a modulated crystal-controlled oscillator with the output tank circuit tuned near the frequency of the crystal. The output tuned circuit is link-coupled to the coaxial line that feeds the signal to the antenna. A neon lamp tuning indicator and peaker is a part of the output circuit. Maximum glow indicates maximum output and radio frequency voltage in the tuned circuit. However, best stability and easy starting of the oscillator occurs when the tank circuit is tuned slightly above resonance. This, unfortunately, is not the setting for maximum output.

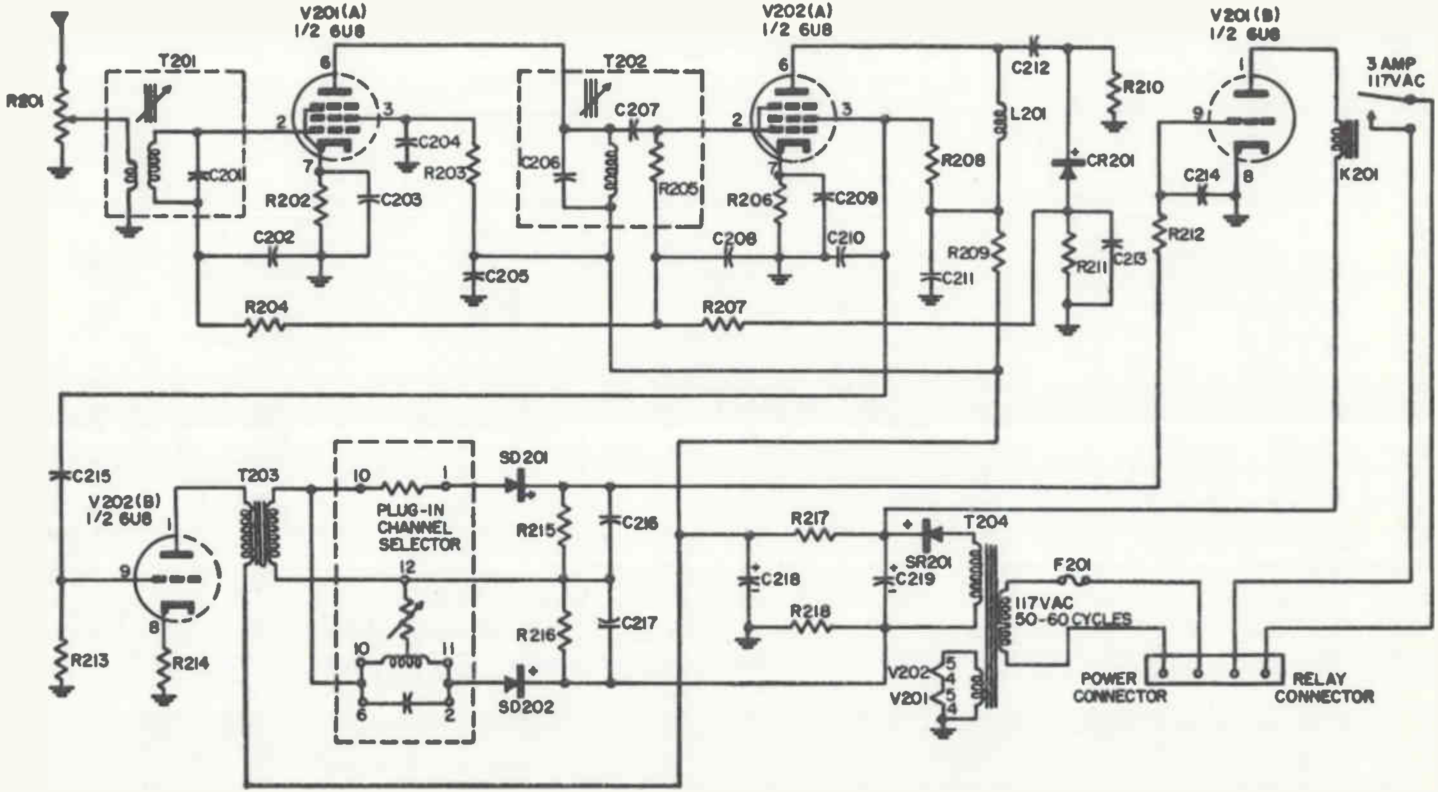
When the neon bulb is not lit, the tuned circuit operates on a frequency slightly above resonance. Thus, the oscillator starts easily. Once the oscillations build up, the neon lamp glows and shunts an additional small capacity across the tuned circuit, bringing it to exact resonance and maximum output. This produces easy and reliable starting as well as maximum output, and it occurs automatically when the plate tank is tuned for maximum brilliance of the neon bulb.

The transmitter is powered from the car storage battery using a vibrator and selenium rectifier power supply. A special adapter is available for operation on a 12-volt battery. The transmitter turn-on button is located in the hot lead to the car battery.



Courtesy Perma-Power

FIG. 30. Radio-control transmitter.



Courtesy Perma-Power

FIG. 31. Radio-control receiver.

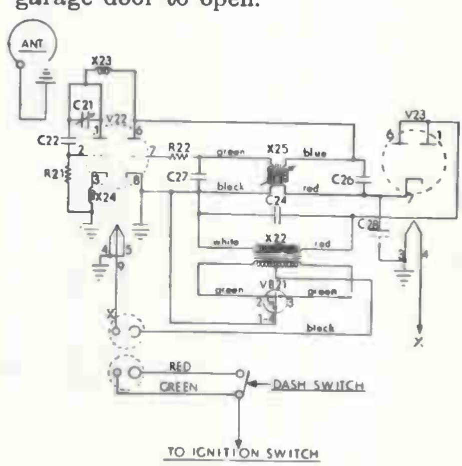
The radio-control receiver shown in Fig. 31 uses two 6U8 tubes and a germanium crystal diode, CR201 and two selenium diodes, SD201 and SD202. The receiver is powered from a 110-volt, 60 cycle ac source, and also uses a selenium rectifier power supply. The pentode sections of the 6U8 tubes function as a two-stage radio frequency amplifier, supplying an rf signal to the crystal diode detector.

The audio signal developed across the diode load resistor R211 is coupled back to the grid of the second pentode rf stage through resistor R207. This stage is now used a second time as an audio amplifier with the amplified audio signal being taken off at the screen grid and coupled through capacitor C215 to the control grid of the triode, V202(B). The resistor-capacitor combination, R204 and C202, have high enough values to function as an audio filter. Therefore, the audio variations are filtered and develop a dc component of avc voltage across the capacitor and on the grid of the first pentode.

The audio signal at the grid of the triode is amplified and applied through transformer T203 to the channel selector. This is a filter that is tuned to the audio frequency used for tone modulation of the transmitter. Thus, at this point any audio signal of improper frequency is rejected and does not operate the garage door mechanism. Only the tone modulation frequency from the transmitter in the car is accepted and permits the doors to open.

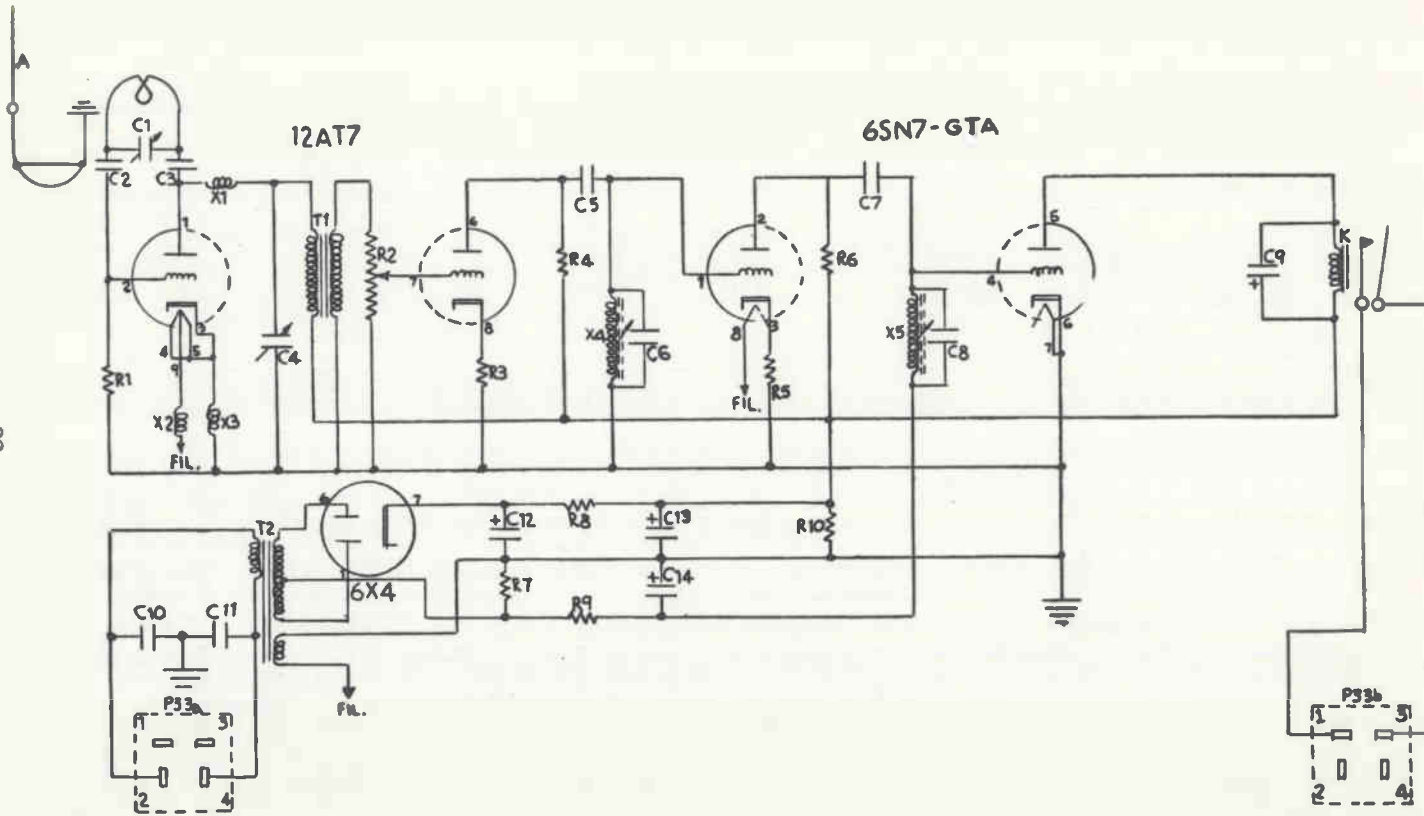
The audio selection circuit consists of the special filter and the two selenium diodes. Current flow develops nearly equal voltages of opposite polarity across resistors R215 and R216. When no signal is received or an off channel tone signal is received, the negative voltage across resistor R216 is somewhat higher than the positive voltage across resistor R215 (selenium current flow is down through resistor R215 and up through resistor R216). This produces a negative bias for the grid of the triode section, V201B. Additional steady bias is developed across resistor R218 in the selenium rectifier and filter circuit. Thus, the negative voltage on the grid of the triode holds the plate current low enough to prevent the relay from closing.

When the audio signal is of the correct control channel frequency, it sees a high impedance at the filter ahead of the lower diode. Hence, the audio signal does not reach the diode, and the voltage across resistor R216 drops sharply. The positive voltage developed across resistor R215 is now higher than that across R216, and produces a less negative voltage on the grid of triode V201B. The increase in the triode plate current through the relay coil causes the contacts to close. The closed contacts in turn supply power to a motor, which causes the garage door to open.



Courtesy The Alliance Mfg. Co.

FIG. 32. Lift-A-Door remote-control transmitter.



Courtesy The Alliance Mfg. Co.

FIG. 33. Lift-A-Door remote-control receiver.

Resistor R201 in the antenna input circuit regulates the sensitivity of the radio control installation. When the control is adjusted properly, the receiver will operate only when the car is a certain distance from the garage door. For example, it can be set to permit operation when the car pulls into the driveway, and at the same time to prevent operation by cars passing in front of the house.

The transmitter and the receiver used in the Alliance Lift-A-Door garage door opener are shown in Figs. 32 and 33. This radio-control circuit operates in the 250-mc range using tone modulation frequencies of 8, 10, 12 or 15 kc. Operating carrier frequencies are available every 10 mc between 245 mc and 285 mc. Consequently, there are 20 different combinations of carrier frequency and modulation.

The transmitter in Fig. 32 consists of a dual triode, with one section used as an ultra-audion high frequency oscillator and the other section as an audio modulator. A tuned line serves as a resonant tank circuit with a pickup loop for transferring the signal to the antenna. The modulator section of the tube also functions as an audio oscillator that generates the tone frequency required by the specified channel. The audio transformer X25 can be tuned to obtain the exact adjustment of the audio frequency.

This transmitter also operates from the car battery and contains the usual vibrator and vibrator transformer. A vacuum tube half-wave rectifier and filter circuit provide the dc plate voltages for the transmitter.

The receiver shown in Fig. 33 is a three-tube unit consisting of two dual triodes and a rectifier tube. A 12AT7 dual triode is used as a super-regenerative detector and first audio amplifier, and the 6SN7 dual triode functions as a second audio amplifier and relay control tube.

Capacitor C1 and the VHF (very high frequency) tuned loop represent the signal input circuit of the super-regenerative detector. The quenching frequency used for this type of detection is obtained by using the proper value of control grid resistor and capacitor, as well as the regeneration signal fed back from the plate circuit. Capacitor C4 serves as the regeneration control. The detected audio component is supplied through transformer T1 to the two-stage audio amplifier.

In the grid circuit of each audio stage is a tuned resonant circuit (X4-C6 and X5-C8). These two tuned circuits resonate at the tone frequency of the channel employed. A high-amplitude audio-tone signal is applied to the grid of the final triode. This tube is normally held near cutoff by the negative voltage developed across resistor R7 in the power supply circuit. The high-amplitude audio frequency signal component drives the

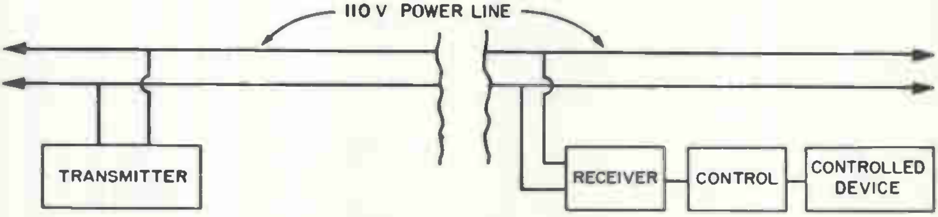


FIG. 34. Carrier control system.

final tube into conduction. The positive alternations of the audio signal excite the tube high into the conduction region. As a result, the average plate current increases when a signal is received. The resultant plate current through the relay coil closes the relay contacts and supplies power to the motor-driven garage door opening mechanism. A large capacitor shunts the relay coil, and acts as a filter and transient suppressor.

Carrier Control Systems. There are a number of other methods of electronic control. In industry, in particular, there are many electronic devices that respond to temperature or humidity changes and, through circuits that respond to these changes, form control signals.

Control operations to control lights, motors, automatic doors and locks, bells, etc., can be obtained by sending radio frequency control signals over the power line. In this carrier control system, as shown in Fig. 34, a radio frequency transmitter forms a signal that is fed into the power line instead of being radiated by an antenna system. The frequency of operation is generally somewhere between 25 kc and 200 kc. Recently, the lower frequency has been used for this system of carrier-control because many electrical appliances now contain filters which are used to shunt rf interference signals to ground. These filters have a greater shunting effect on the high frequency carrier signals than on lower frequency signals.

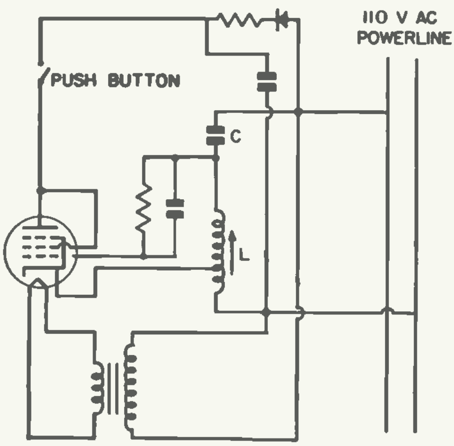


FIG. 35. Carrier-current transmitter.

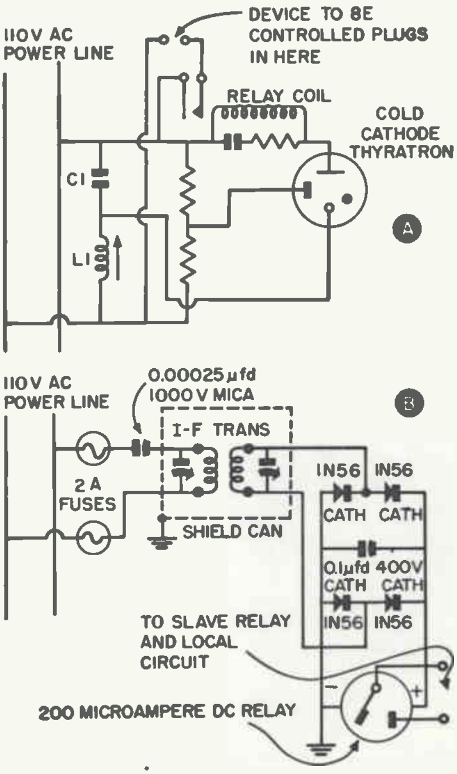


FIG. 36. Carrier-control receivers. A, using a cold-cathode gas discharge tube. B, using a sensitive relay and crystal detector.

No license is required for this type of control system. However, the FCC requires that the system must be constructed and operated so that no appreciable signal radiates from the power line. If the system causes interference with any radio service, the FCC can stop its operation.

In a typical carrier-control system, the sending or transmitting end, as shown in Fig. 35, is an oscillator circuit. In some installations a buffer or power amplifier follows the oscillator to increase power output. For most small carrier-control systems, enough power is generated by a small oscillator. Series resonant tank circuits are preferable because they can cause a high circulating current flow through the low impedance of the power line (a few ohms at the highest).

Two types of receivers can be used in the carrier-control system. Either a cold-cathode gas discharge tube, as shown in Fig. 36A or, for added sensitivity, a sensitive relay and crystal detector (Fig. 36B) can be used. The receiver can also be a sensitive detector which will trigger a succeeding thyratron tube.

In operation, the signal reaching the receiver (see Fig. 36A) appears as a high amplitude voltage across inductor L1 and, therefore, across the control elements of the gas tube. As a result, the gas tube is triggered, and draws a high current through the relay coil. The relay contacts close and the 110 volt ac power line voltage is applied to the output terminals. Any external device can then be connected to these terminals and remotely controlled by the carrier signal. A resistor and capacitor are shunted across the relay coil to prevent chatter and high surge currents.

The second receiver circuit in Fig. 36B uses four crystal diodes connected in a full-wave bridge circuit. The output from the bridge operates a sensitive 200 microampere relay. This relay, in turn, operates a higher powered relay for control of an external device that draws a substantial power. It is also possible to trigger directly a vacuum tube or thyratron circuit from the output of this type detector.

Tone Control Systems. It is sometimes necessary to control several relays at a remote point independently of each other. This requires extra control wires or separate transmitters and receivers, if any of the systems we have shown so far in the lesson are used. The circuit of Fig. 37 shows one way to operate three control relays individually, using only one transmitter-receiver pair on a single radio carrier. Three tone generators are used to feed the modulator of the transmitter. At the receiver, filters tuned to each of the tone generators separate the incoming audio fre-

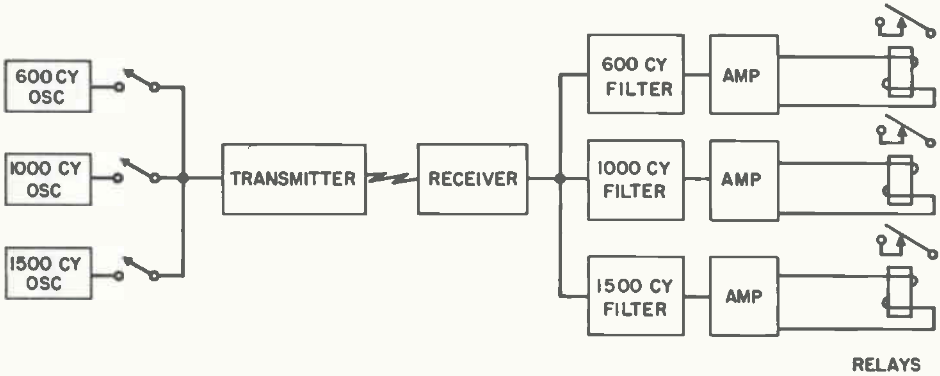


FIG. 37. A tone modulation system.

quencies. After amplification, each tone operates a separate relay.

Fig. 38 shows a modification of the receiver end of this circuit that makes it possible to use only one amplifier for all three tones. In this circuit, each of the three relay coils is tuned to one of the tone frequencies by series capacitors. Some small current passes through each relay for every

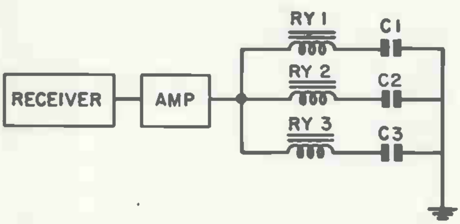


FIG. 38. A tuned relay tone modulation system.

tone that is transmitted, but only the relay tuned to the particular tone being transmitted passes enough current to operate.

LOOKING AHEAD

There are many more possible control circuits than have been covered in this lesson. Most of the control devices you will encounter will be simple circuits similar to those discussed here. These circuits have been chosen to show as many control methods as possible.

Larger and more complicated control systems can be made up by adding to and combining these circuits you have studied. When you come across a large control circuit, you will find that it can readily be broken down into groups of simple circuits.

When analyzing a complex control circuit, the first thing to do is to find out exactly what operations are controlled and what controls them. Then, determine whether each operation is controlled independently of the others. If this is the case, the large circuit is simply a group of smaller circuits working parallel to each other.

If the operations are not independent, check to see whether they operate in a fixed order. When you have sequential operation, the complex circuit breaks down into a control or programming unit which determines the order of the individual operations, and simple control circuits for each operation.

When operations are not independent and not controlled in order, the circuit may be arranged so that the actuation of one operating circuit prevents some of the other operations from starting. On the other hand, the circuit may be arranged so that the completion of one operation starts another without the use of a programming section.

In summary, whenever you are called upon to service a control circuit, first determine exactly what is controlled, and second what starts each control circuit operating. Then trace out the wiring between the actuating device and the control device.

Lesson Questions

Be sure to number your Answer Sheet 27B.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What part of a relay is most likely to fail and also requires the most maintenance?

2. Why should a resistor be used in series with the arc-preventing capacitor that is connected across the relay contacts?

3. What is the purpose of the pilot relay used to control a heavy-duty relay?

4. What operating advantage does a latching relay have over ordinary electromagnetic relays?

5. What is the main difference in the operation of a Thyratron as compared to a vacuum tube triode?

6. What limits the plate current in a Thyratron circuit?

7. What is the purpose of a capacitor across the relay coil in an ac-operated Thyratron control circuit?

8. What kind of license is required when a radio transmitter is operated on 27.255 mc?

9. What are the FCC requirements regarding transmission of radio frequency carriers on the power lines?

10. How can multiple controlled channels be provided using a single radio frequency carrier?

DELIVER THE GOODS

"There are 57 rules for success. The first is to deliver the goods. Never mind the rest."

Like many striking assertions, the quotation above is not altogether true, because there are other rules which cannot be ignored. But there is a lot of truth in this statement.

If you want to be a success in life, deliver the goods. Employers want men who *earn* their salary each and every day — men who have the training required for their particular jobs and actually do apply this training to their work.

You can always excuse yourself if you fail — but nobody else will ever excuse you. Customers may be polite to you and may feel sorry for you, but they will go elsewhere the next time they need service work. Employers are equally indifferent to excuses, for they must have good men if they themselves are to deliver the goods.

Make it your business to be where you are needed, when you are needed, with the service or help that is needed. Have all the knowledge which may be required. Be the man who delivers the goods and gets the money.

J. E. Smith

INTRODUCTION TO HIGH-FIDELITY SYSTEMS

29 B-2

RADIO-TELEVISION SERVICING

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

ESTABLISHED 1914

STUDY SCHEDULE NO. 29

☐ 1. **Introduction** .... **Pages 1-6**

Here we take up some characteristics of high-fidelity systems, discuss their importance to the radio-TV serviceman, and compare package and component-type systems.

☐ 2. **Characteristics of Sound** .... **Pages 6-11**

We take up characteristics of sound in relation to high-fidelity reproduction, such as amplitude and frequency, and discuss types of distortion.

☐ 3. **Sources of Sound for High-Fidelity Systems** .... **Pages 11-19**

There are three main sources for high-fidelity systems: tape, records, and broadcasting. We discuss records and broadcasting here. In a later lesson you will learn about tape recorders.

☐ 4. **Pickup Cartridges** .... **Pages 19-28**

You learn about various cartridges used for both monophonic and stereophonic systems.

☐ 5. **Tone Arms** .... **Pages 29-36**

You study various characteristics of tone arms in relation to both monophonic and stereophonic systems.

☐ 6. **Answer Lesson Questions.**

☐ 7. **Start Studying the Next Lesson.**

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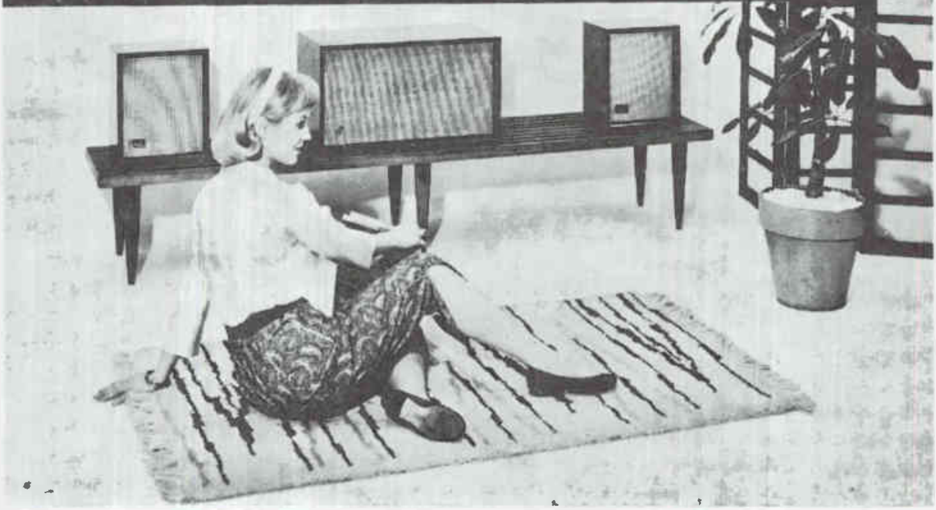
Printed in U.S.A.

INTRODUCTION TO HIGH-FIDELITY SYSTEMS



AN EXACT definition of the term "high fidelity" is not possible. It is a much used and abused phrase—as anyone who listens to radio, watches TV, or reads newspapers well knows.

According to the dictionary, "high" can be defined as "advanced to" and fidelity as "exactness." We could therefore define a high-fidelity music system as one "advanced to exactness" or "close to perfection."

Decades ago, some music reproduction systems were called high-fidelity simply because it was possible to recognize an individual's voice! How close we are to perfection in the present state of the art is probably best demonstrated in the many "live vs recorded" concerts held every year in major cities. At these concerts, the audience is treated to live music from an orchestra, and recorded music from equipment and speakers on the stage. The program is switched from live music to recorded and the musicians pretend to play during the recorded sections. Few people in the audience are able to tell the difference. The equipment used in such demonstrations is not custom-built, but is the same type that is designed, built, and sold for home music systems.

It is possible to assemble a high-fidelity system in the home capable of almost perfect reproduction. Just why a system is not quite capable of perfect reproduction in the home (as it sometimes is in concert halls) will be thoroughly investigated in this and later lessons.

CHARACTERISTICS OF HIGH-FIDELITY SYSTEMS

High-fidelity systems are often erroneously judged on the merits of their frequency response. We might assume that a certain system with a response from 20 cps to 20 kc would be better than another system with a response of only 40 cps to 15 kc. This is a false assumption. The frequency response of a system is only one characteristic of the system and is not the most important one. It is possible for a system with a narrower frequency range to sound better than one with a wider frequency range. Such characteristics as distortion, stability, transient response (the reproduction of steep wave fronts), and others can affect the way a system sounds more than the frequency response.

HIGH-FIDELITY AND THE SERVICEMAN

The field of high-fidelity service and installation is becoming more and more important to the serviceman. In fact, a recent survey has shown that more money is spent on concerts, records, and record-playing equipment than on all spectator sports (baseball, football, etc.) combined.

It is only natural for the radio-TV serviceman to be called upon to install and maintain these many audio systems. This is a field that you should know, since it can be very easy for you to increase your income by installing and servicing these systems. In fact, it is almost impossible for a service shop to avoid doing some of this work without driving customers to competitors.

As in any other new field, it is important for the serviceman to have a good knowledge of the fundamental practices, and be familiar with the terms used to describe the equipment and results that are obtained. As you become more familiar with the equipment, you will find that there are actually very few new ideas to contend with. The success and high quality of equipment is primarily due to better engineering design, circuit refinement, and high-quality components. Probably the greatest difference between the radio-TV and high-fidelity fields is in customer relations.

This is because of two important facts. First, high-fidelity equipment is unique among consumer products in that detailed specifications are furnished by the manufacturer. The owner is usually better informed about his high-fidelity system than about his TV set, for instance. Second, even the best high-fidelity systems "sound" different from each other. But then, so do orchestras and even musical instruments of different manufacturers!

The difference in sound texture in hi-fi systems is primarily due to the differences in speakers and cartridges, but is also greatly affected by such characteristics as amplifier transient response, damping, and room acoustics. No matter what the reason, this difference in sound texture leads to loyalty or prejudice on the part of the customer for and against certain manufacturers and certain products. This might, at first, seem surprising, but it is probably not much greater than the strong feelings that most people attain for other products, such as automobiles. This texture-difference has little to do with actual quality. It is similar to seating preference at a concert. Some people would like to sit on the conductor's podium, while others wouldn't be happy unless they were half-way down the auditorium. Some like to be to the right or left where they would be "blasted" by the brass or woodwinds.

In almost all discussions of high-fidelity systems, both written and oral, the expression "matter of opinion" or something similar will be brought up. Although the choice of the system is to a certain extent a matter of opinion, quality is not as much a matter of taste as one would be led to believe. Although no one can dictate to the consumer just how much cream (if any) to put in his coffee, the consumer can, no doubt, tell the difference between a carefully brewed cup of coffee and a pot of boiled grounds.

Similarly, there is a world of difference between a poor system and a good system. It is the choice among the good high-fidelity systems that parallels the "amount of cream in coffee."

STEREO SYSTEMS

You will notice in this introduction that no mention has yet been made of stereophonic sound. Stereophonic sound or "stereo" as it is better known is a part of high fidelity. It is not a new and radical method of achieving high-quality reproduction. It is simply an improvement--another step toward "perfection." It is, however, a "giant" step. The difference between a high-quality monophonic system and a high-quality stereophonic system is very often as substantial as the difference between an ordinary phonograph and monophonic high fidelity.

Stereophonic sound works somewhat like stereoptic slides. The stereoptic slide contains two photographs taken from slightly different angles that duplicate the different angles from which the eyes—because they are a little way apart—actually see real things. When the slide is seen in a viewer, the eyes combine both photographs into a single picture, creating a third-dimensional effect. Similarly, a stereophonic record contains two slightly different recordings of the same performance made from slightly different locations in the studio. These slightly different locations duplicate the different angles from which the ears actually hear real sounds. When played back, each slightly different recording, called a channel, is fed to its own amplifying system and speaker. The listener's ears combine the sounds from both speakers to create the two stereo dimensions, depth and direction.

A carefully chosen and properly operating stereo system is an improvement over the ordinary, or monophonic system, since it more closely resembles live sound. Unfortunately, a poor stereo system can sound worse, or shall we say, less natural, than a poor monophonic (single-channel) system.

PACKAGE VS COMPONENT HIGH-FIDELITY

A high-fidelity music system is not a complete unit in itself, but is composed of individual units connected together.

Fig. 1 illustrates in block form, a typical monophonic high-fidelity music system. The simplest type of system is shown in Fig. 1A. A record changer using a high-fidelity cartridge is plugged into a high-fidelity combination preamplifier-amplifier. To complete the system, a high-fidelity speaker mounted in an acoustically designed enclosure is connected to the output of the amplifier. The simplest type of stereo system is shown in Fig. 1B. Again a record changer is used, but the cartridge used is a stereo cartridge. Two preamp-amplifiers are required, as are two speakers in suitable enclosures.

Of course, these are not the only ways that stereo or monophonic systems can be assembled. Fig. 2, for example, shows a typical high-quality installation. In this system, a professional type turntable and tone arm

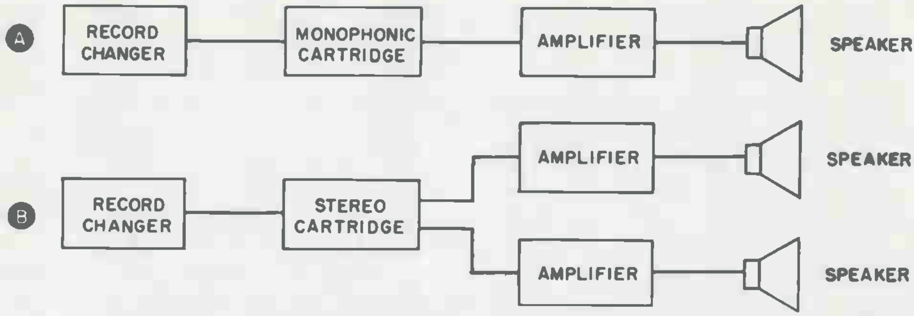


FIG. 1. Block diagrams of (A) a monophonic system, and (B) a stereophonic system.

are used instead of a record changer. The stereo cartridge used would, no doubt, be one of the finer magnetic types. The stereo preamplifier is self-contained on a single chassis and includes the volume, tone, and other such necessary controls. Separate power amplifiers are coupled to separate high-quality speaker systems.

Of course, there are other "source" components of a high-fidelity music system that are not considered in these illustrations. Many systems also utilize AM tuners, FM tuners, and tape recorders.

No matter how the system is compiled, there are actually two major types of high-fidelity available to the consumer today. One type offered by radio and TV manufacturers such as RCA, Zenith, Magnavox, etc., is generally contained in a single package (with possibly an extension speaker for stereo) and is popularly known as "package" high-fi. A typical example is shown in Fig. 3. The other major type of high-fidelity system is assembled from separate components made by different manufacturers such as Shure, Garrard, Lansing, Eico, etc., and is known as "component" type hi-fi. An example is shown in Fig. 4. Each type of high-fidelity system has advantages and disadvantages.

Package high fidelity, as the name implies, is pre-packaged and assembled. All the owner needs to do is plug it in and turn it on. In addition, the "package" generally consists of a high-quality furniture-type cabinet that can be chosen to fit with any decor.

The typical package system consists of a record changer with a crystal cartridge and a preamp-amplifier on one chassis. The speaker system, mounted in the cabinet with the other equipment, generally consists of from one speaker in the most inexpensive package, to six or seven or more speakers in the more expensive versions. Extension speakers available for stereo package systems also consist of from one to many units. These speakers are usually of the replace-

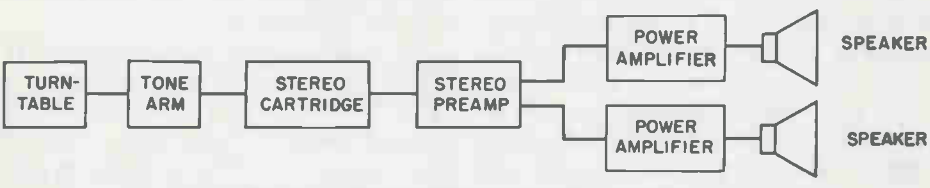
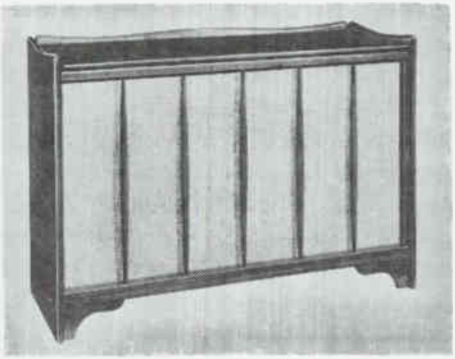


FIG. 2. A typical high-quality stereo system.



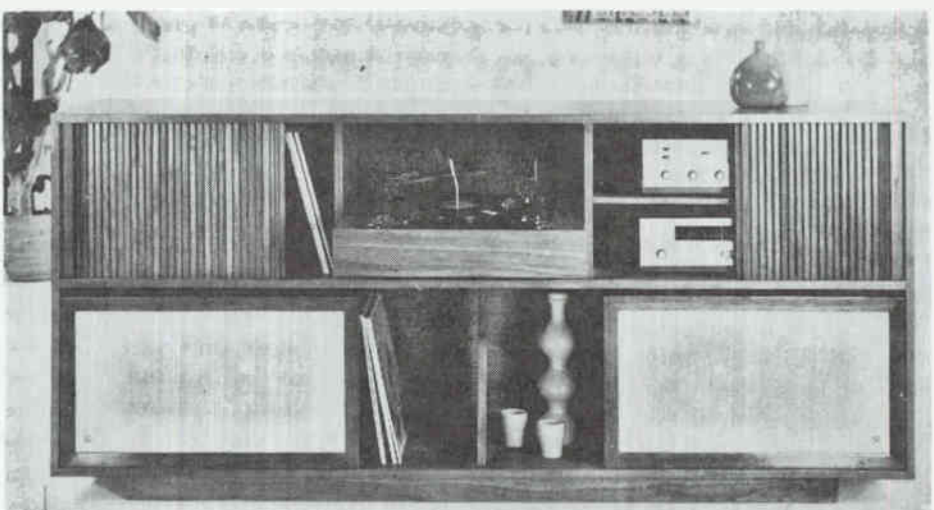
Courtesy V. M. Corp.

FIG. 3. A typical "package" type of high-fidelity system.

ment or P-A type. Since the record changer and amplifier are in the same cabinet, an acoustically designed speaker enclosure is not usually possible. Most cabinets are open on the bottom and in the back.

As explained above, a component system consists of individual components assembled and connected together. Since a furniture-type cabinet is not furnished, the systems are not set up and ready to play. Instead, the individual components, made by different manufacturers, must be chosen and connected together. By choosing wisely, either through knowledge and experience, or with the help of reputable salesmen, a higher quality high-fidelity system can be assembled. The individual components are generally of higher quality, since they must stand by themselves and "furniture" is not involved.

Most package high-fidelity systems are simply high-quality phonograph systems with some new features. For example, since separate bass and treble tone controls have always been an integral part of component high fidelity, customers expect to find them in any high-fidelity system. Therefore, the package systems often have separate bass and treble controls rather than the familiar "radio" tone control. Another example is in the speaker system. High-quality component systems almost always have multi-speaker systems. That is, woofers for the bass and tweeters for the treble. Package systems, therefore,



Courtesy Acoustic Research, Inc.

FIG. 4. A typical component-type high-fidelity system.

also utilize a number of speakers, although they are of different types and quality.

The major difference, then, between package and component high fidelity is appearance and quality. Because of its fine furniture, the package system is more pleasing to the eye; because of higher quality components, the component system is more pleasing to the ear.

Incidentally, it is, of course, possible to install the individual components, except the speakers, of a component-type system in a custom-built cabinet. The system is then still a component-type system and the cabinet designed to house the components is simply another component. The difference between such systems and the typical package system is considerable.

Characteristics of Sound

In order to understand the reproduction of sound better, we will first look at a few characteristics of sound itself.

As you learned in a previous lesson, sound is energy in the form of air pressure variations traveling away from the sound-producing source. When the vibrations occur at a rate that can be heard by the human ear, we say that sound is produced.

Various characteristics of this sound are important in reproducing it faithfully. Among these are the amplitude and the frequency of the sound. We will take up these characteristics in relation to human hearing, and in relation to the system that must reproduce sound. Then we will look at some types of distortion that might be introduced.

AMPLITUDE

One of the important characteristics of sound is its amplitude. That is, it can be faint or loud. For lifelike reproduction, the system must be able to reproduce in proper relationship, the loud thud of the bass drum, which can be as high as 24 watts, or the gentle whisper of the flute, which can be as low as .0035 watt. This, incidentally, is acoustic power, not amplifier power. As we shall see in discussing loudspeakers, there is a great difference between them.

Reflections. One thing that affects the amplitude of a sound is the amount of reflection. When a sound wave strikes a solid object, it is reflected; the amount of reflected energy depends on the material of the object, particularly the surface texture and density. The point of reflection is like another source of sound vibration, and waves project outward from it. The reflected sound-wave motion can interfere with the direct or original wave motion and can reduce and increase the amplitude of the original wave. Reflected sound is a considerable problem in stereo installations.

Decibels. Sound amplitude is measured in decibels. You have been introduced to logarithms and decibels in earlier lessons. The use of decibels in sound systems is universal. As you learned, engineers working with telephone installations introduced this unit of power measurement. Since the human ear responds to variations in loudness in an approximately logarithmic manner, it is convenient and logical to have a unit that can be used to express the ratio between two signals in a logarithmic manner.

It is important that you fully understand the use of logarithms and decibels. Decibels are utilized to indicate frequency response, hum levels, tone-control operation, separation, and many other characteristics of high-fidelity systems.

Sound and Hearing. In any discussion of sound, it is important to understand its relation to human hearing. In any such discussion, it is inevitable that the names "Fletcher-Munson" and the graph shown in Fig. 5 will be brought up. This graph, known as Fletcher-Munson curves, is a family of equal loudness contours that show the average results of tests on a very large number of individuals.

In these tests, each person was subjected to a reference tone of 1000 cps at a specific level of loudness. Then tones at all other audible frequencies were reproduced, one at a time, and the loudness was adjusted until the person being tested judged the tone to be equal in loudness to the original 1000 cps reference tone. The test procedure was repeated over and over, each time varying the amplitude of the 1-kc reference tone from the just-audible point to the threshold of pain.

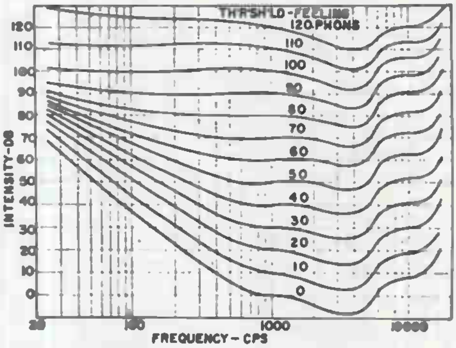


FIG. 5. The Fletcher-Munson loudness level curves.

The resulting curves then show the response of the human ear at different amplitude levels. Each curve is for a certain loudness level. The level is measured in units called "phons." For example, the top curve is for 120 phons. This means that all the sounds along this curve sound as loud to the average human ear. It is evident from these curves that the frequency response of the human ear varies with the loudness level; the louder the sound, the better the ear response. For example, the curve for 120 phons is much flatter than the curve for 10 phons.

Let us examine the curve indicated as a loudness level of ten phons. By moving across the 10-db intensity level, given on the left side of the graph, you will notice that this 10-db line crosses the 10-phon curve in only two places: 1000 cycles and about 5500 cycles. This means that if all audible sounds were produced at a level of 10 db, the average human ear would hear only the tones at 1000 cycles and 5500 cycles at equal intensity or loudness. Now look at the point at which the 10-phon curve crosses the 10-kc line. This is at 20 db. Thus, in order to make the 10,000-cycle tone sound as loud as the 1000-cycle tone, it would be necessary to increase its intensity by 10 db, which is a considerable amount. Similarly, the 10-phon curve crosses the 100-cycle line at approximately 44 db, which means that the 100-cycle tone would need to be increased 34 db in order to sound as loud as the 1000-cps tone.

The conclusions drawn from this graph are that the human ear is most sensitive to sound between 2000 and 5000 cycles, is less sensitive to sounds at higher frequencies, and still less sensitive to sounds of lower frequencies. As the amplitude increases, the response of the ear becomes more linear, particularly at low frequencies. These loudness contour curves, as mentioned above, were made on many different individuals, and can be considered fairly typical.

Another factor that affects hearing is age. It is quite normal for the average ear to begin to lose high-frequency sensitivity after the age of twenty-three years. Tests have shown that at the age of fifty-six, this difference can be over 20 db. Also, the female ear is normally roughly 5 to 10 db better than the male ear. This occurs at all ages but is more pronounced in old age. It is not unusual to find that women tend to reduce the treble control of an amplifier when men would prefer it slightly boosted. Women are consequently also much more critical of strident high-frequency response.

You might think from the Fletcher-Munson curves that it would be desirable to boost the bass and treble response of an amplifier. This assumption is open to some debate. If the system reproduces the sound of an orchestra perfectly, the human ear would hear the output of the speakers just as it would hear the output of the live orchestra. Consequently, compensating the reproducing system so that the ear would, in effect, respond in a linear fashion would be unnatural.

Of course this assumption is true only if the reproduction loudness level is equal to the original orchestra level. Since it is not possible to reproduce music in the home at the same level at which the orchestra is playing in a concert hall, more natural reproduction can often be obtained by boosting the low and high frequencies. Unfortunately,, improper boosting can more often result in unnatural sound.

Dynamic Range. In a high-fidelity system, we speak of amplitudes in terms of dynamic range. The dynamic range of the system is the range of volume between the lowest sound not obscured by noise and the loudest sound that does not overload the system.

The dynamic range of an orchestra is very large indeed, extending from a fraction of a watt to well over 20 watts.

The dynamic range of an orchestra is important to us in the reproduction of sound. Since the reproducing system must be capable of handling this dynamic range in order to obtain perfect reproduction, this is one of the limiting factors of attaining perfect reproduction. The softest level produced by an orchestra in a concert hall is often a great deal lower than the noise level in an average home. Therefore, reproduction at this level would not be audible. Increasing the volume is not the answer to the problem, since this would cause the loudest levels to reach the threshold of pain.

In order to obtain the maximum dynamic range in any reproducing system, it is essential to keep unnecessary noise at a minimum level. This pertains to every component in the system from dust on the records to the hum level of the amplifier. Such problems will be treated separately in the

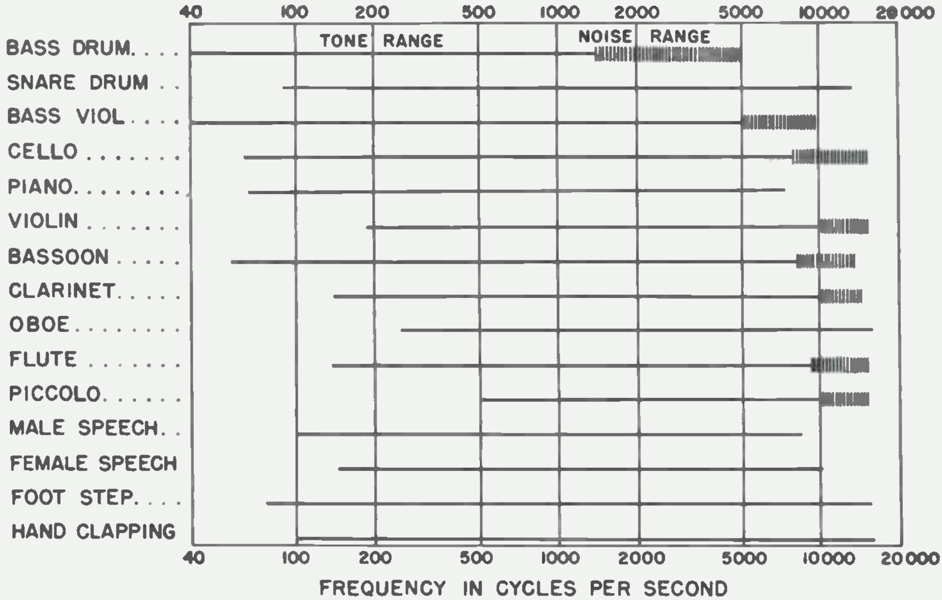


FIG. 6. Frequency range of common musical instruments.

sections of your lessons pertaining to the individual components.

Another great problem encountered in reproducing sound is the fact that these very loud levels do not occur over extended periods of time but rather only for short intervals.

Therefore, the reproducing system must be capable of handling abrupt and extreme changes of loudness. The quality of doing so is called transient response.

FREQUENCY RANGE

Another important characteristic of sound is its frequency. Since we are mainly concerned with reproducing music in a high-fidelity system, we are mainly concerned with reproducing frequencies produced by musical instruments. These frequencies vary from about 20 cps from large bass drums (36″ x 15″) to about 11 kc from large cymbals (15″). Actually, large theatre-type pipe organs have been constructed that go down to 16 cps, but these are not popular in orchestras. Besides the basic range, it is necessary to reproduce much above 11 kc to capture the harmonic output of the high-frequency instruments, such as the cymbal. In addition, as we will see when we study amplifiers, satisfactory transient response of some components of the high-fidelity system can be achieved only when the high-frequency response extends well above the musical spectrum.

Most sound information is made up of fundamental tones and harmonic overtones. For example, an examination of the sound being produced by the open G string of a violin being played with medium intensity would show that only .1% of the output energy occurs at the fundamental frequency of G (196 cps). There are approximately 19 overtones or harmonics of consequential output. The 19 overtones combine with the fundamental (196 cps) to form the sound we hear.

Fig. 6 shows the range of most musical instruments including their accompanying noises. By this, it is meant the blowing, or scraping noises that are very prominent in some musical instruments.

There have been a number of tests over the years in relation to determining the preferred listening range of the public. The figures resulting from a number of these tests seem to indicate, from the point of frequency range alone, that the public prefers a system having restricted frequency range. One of two conclusions can be rightfully drawn from these tests. These are: first, the public does not prefer live music; or, second, that there was distortion present in the systems used for the tests which was not measurable. The latter is the logical explanation, and seems to be borne out by the fact that other tests made with a live orchestra and adjustable acoustic filters to restrict the frequency range resulted in an overwhelming indication of preference for wide range. Another factor that must be considered in judging the conflicting results of these tests is that during the tests a monophonic reproducing sytem was used. The "live" tests, which indicated a preference for wide frequency range, were, as all natural sound is to the human ears, stereophonic.

DISTORTION OF SOUND

There are many types of distortion in even the finest high-fidelity systems. Some components in the system are more subject to distortion than others. In addition, certain types of distortion are more prevalent in some components than in others. As we discuss each component separately, we will also discuss the types and amounts of distortion that can be expected. However, the following is a short explanation of the types of distortion that you can expect to encounter in a high-fidelity system.

Harmonic Distortion. Harmonic or non-linear distortion produces sounds that are harmonics of the original sound. For example, harmonic distortion of a 200-cycle tone would produce sounds of 400 cycles, 800 cycles, 1200 cycles, etc. This type of distortion is not particularly serious in small amounts, since the harmonics produced are musically related to the fundamental sounds. That is, they resemble the natural harmonics produced by the musical instruments themselves. However, excessive harmonic distortion will degrade the system and should be avoided if at all possible. It is not particularly difficult to keep the total harmonic distortion in an amplifier below 1% at the average listening levels. Harmonic distortion in other components such as the loudspeaker and cartridge generally runs a little higher than in other sections of the system.

Inter-Modulation Distortion. Intermodulation or IM distortion produces sounds that are the sums and differences of two or more frequencies. Thus, a 60-cycle tone and a 7000-cycle tone passing through the system would produce 6940 cps $(7000-60)$ and 7060 cps $(7000+60)$ cycles respectively. These sounds have no musical relationship to the original, and thus are more annoying than harmonic distortion.

Obviously the situation can become worse if the non-linearity produces multiple components. Then, we would not only have the original sum (7060 cps) and difference (6940 cps) but these tones could then beat together and produce another set of sum and difference tones. Since excessive non-linearity also causes harmonic distortion, each new tone produced would mean a new set of harmonics produced. Then we would have not only the inter-modulation product of the two original tones but also the products of the harmonics of each tone, the harmonics of one beating with the harmonics of the other, and the sum and difference products of the inter-modulation sounds themselves.

It is generally considered adequate to keep the total inter-modulation distortion below 2%. Very high quality systems keep the inter-modulation distortion below 1%.

Transient Distortion: As pointed out previously, one of the chief characteristics of music is the production of quick, loud bursts of sound; the ability to reproduce these bursts is called transient response. If any portion of the reproducing system is resonant or unstable enough to be near resonance, the system may generate or produce sounds of its own when triggered by these loud bursts. Transient distortion is most apt to occur in power amplifiers and speaker systems, although it can occur in any part of the system.

There are some other types of distortion which we will not discuss now, but will wait until we encounter them in the individual components.

Of particular interest will be spatial and phase distortion encountered in stereophonic systems.

Sources of Sound for High-Fidelity Systems

There are three main sources of sound for high-fidelity systems today: records, tape, and broadcasting. Since tape recorders are fully covered in other lessons of your course, we will not discuss this source here, but confine our discussion to records and broadcasting.

RECORDS

Without a doubt, records are the most popular source of sound for high-fidelity systems. There are two major types of records today: the 7-inch, 45-rpm, and the 12-inch, 33⅓-rpm. The latter make up about 80% of the industry's output. Both are available in monophonic and stereo versions. In addition, there are 16⅔-rpm recordings available, particularly for the spoken word. Although most record companies have ceased production of 10-inch records, some are still made, mostly by small companies.

We are not particularly concerned with the manufacture of records, only with the effect the recording technique has on the "playback."

Methods of producing a record vary. In general though, the original music is first recorded using special tape machines. Even for monophonic records two separate channels are often recorded. These are then combined and edited to form one complete and final tape. In stereophonic recording, two or three, or more, separate channels are recorded. These are combined and edited for the final tape, which contains two channels or tracks. The final tape is then used to cut a disc which is sometimes called the "mother" disc. It, in turn, is used to make a "master" form for stamping records for the market.

Sometimes vinyl "biscuits" are used for the record material in the stamping process. Sometimes powdered vinyl and a heating process is used for the stamping and forming. There are also other variations on this process of making a record, depending on the manufacturer and even on the type of music.

The resulting sound from a stereo disc depends greatly on the skill of the audio engineers.

Microphone Placement. Fig. 7A shows one possible microphone arrangement for recording for stereo. Here two separate microphones are used, one for each channel. It is obvious from the microphone placement and pickup pattern that the sound from the left side of the orchestra

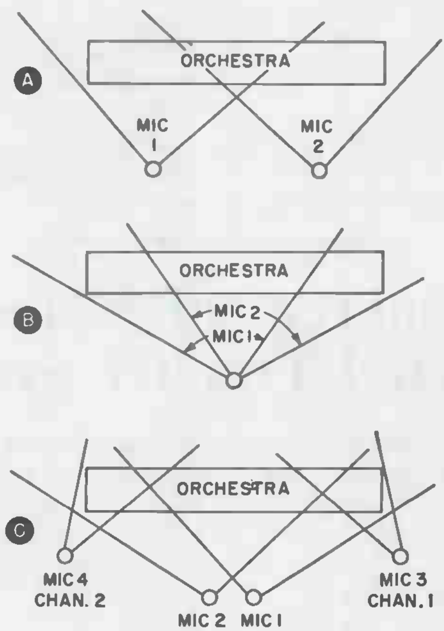


FIG. 7. Different ways of placing microphones for stereo recording.

The quality of the playback or reproduction from the disc, disregarding the musicians or choice of program, depends on the equipment used in the original taping, the characteristics of the studio or auditorium, the placement of microphones, the skill of the audio engineers, the skills and techniques in editing, etc.

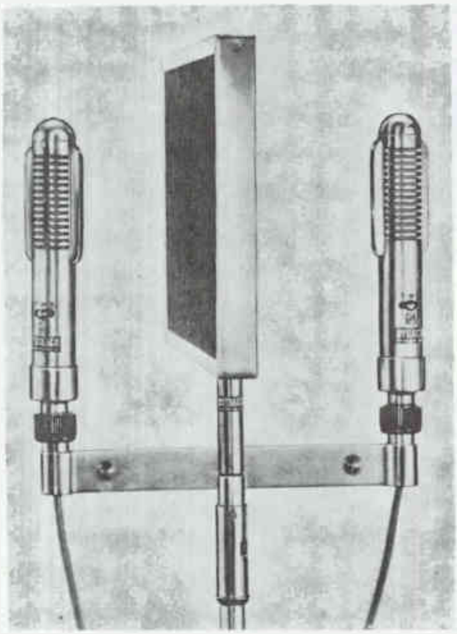
The microphone placement and editing techniques are particularly important in stereophonic recording.

will be picked up only by microphone No. 1. In playback the speaker on the left-hand side of the listener would contain this information. Conversely, the sound from the right side of the orchestra would be picked up by microphone No. 2; in playback this would come only from the right-hand speaker.

A recording made with this sort of microphone placement would result in great separation. That is, the instruments on the right-hand side of the orchestra would be heard only from the right-hand speaker and, of course, the instruments on the left-hand side of the orchestra would be heard only from the left speaker. Little sound would be common to both channels. If the speakers were separated too widely, there would be a resulting "hole" in the middle, which would be most distracting and unnatural.

Fig. 7C shows a more typical arrangement for stereo recording. Four microphones are used, two for each channel. Microphones 1 and 2 can either be close together as shown, or can be coaxially mounted as in Fig. 7B. One widely used microphone setup for these two microphones is shown in Fig. 8.

Microphone 3 in Fig. 7C picks up only the right-hand side of the orchestra while microphone 4 picks up only the left-hand side of the orchestra. The tape made from this arrangement might use four separate tracks, or the output of microphones 3 and 4 could be carefully controlled by engineers and fed to their respective channels. The editing and mixing of such tapes is done with close cooperation between engineers and musicians.



Courtesy Dynaco

FIG. 8. A typical stereo microphone arrangement.

Another method of recording a stereophonic disc is to use two microphones very close together or directly over each other (a coaxial setup) as shown in Fig. 7B. Of course, directional microphones must be used in all cases. It is evident in Fig. 7B that more of the orchestra will be picked up by both microphones than in Fig. 7A. That is, the separation of the channels is not as distinct. The resulting playback will have more "depth" and less separation.

It is evident that the recording technique in Fig. 7C is better than the

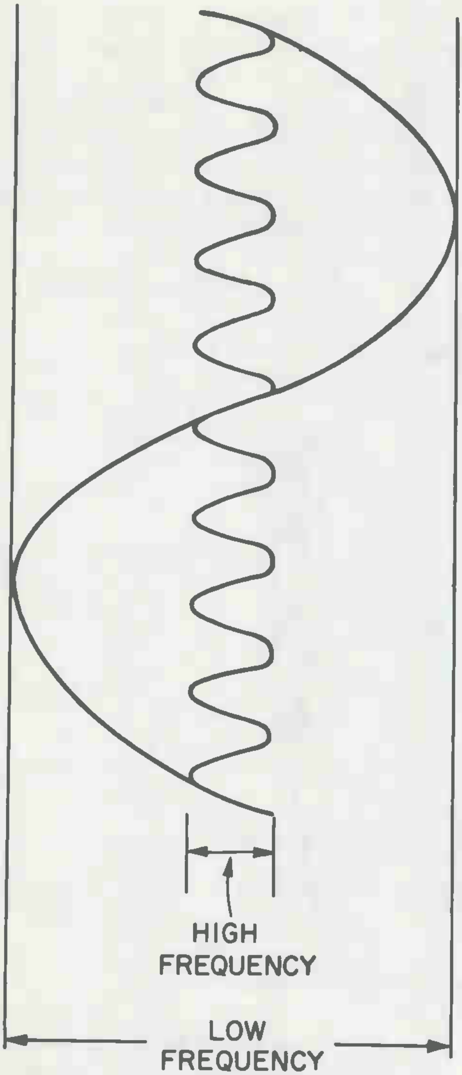


FIG. 9. Comparison of high-frequency and low-frequency grooves recorded with a constant-velocity method.

ones in Fig. 7A or 7B since it is possible to have greater depth in the recordings, and yet it is also possible to have complete separation when necessary. A more natural record is the result.

Another method, called the mid-side or MS microphone technique, is becoming popular. In this technique a special stereo microphone, which consists of a self-contained two-microphone unit with crossed cardioid and figure-8 patterns on one axis, is used. In addition to breadth and directionality illusions, the MS method produces a tremendous depth.

Recording Characteristic Curves. In the early days, the high-fidelity enthusiast, or "audiophile," was greatly concerned over letters such as AES, ORTHO, LP, FFRR, NARTB, RIAA, etc., which related to the record equalization curves used by record companies to make their discs.

The standard method of recording, as pointed out previously, utilizes tapes and discs. The original disc is cut by a heated chisel-shaped stylus coupled to a special magnetic head. The program to be recorded is fed to the coils in the head, which operates on what is known as a constant-velocity principle.

In this method, the movement of the cutting stylus is determined by the frequency of the applied voltage. When a voltage of constant amplitude is applied to the coil of the cutting head, the cutting stylus will move in one direction until the voltage is removed, or the direction is reversed. Then it will move in the opposite direction. The velocity of the movement is the same, so a higher frequency will reverse the direction of the cutting stylus sooner than a low frequency. Consequently, the distance the stylus travels in a given direction is shorter for a high frequency.

This is shown in Fig. 9. This shows the movement of the stylus for two different frequencies of the same amplitude, a high frequency and a low frequency. It is evident from this illustration that low-frequency sounds result in a much greater lateral movement of the stylus than high-frequency sounds. In fact, if this relationship

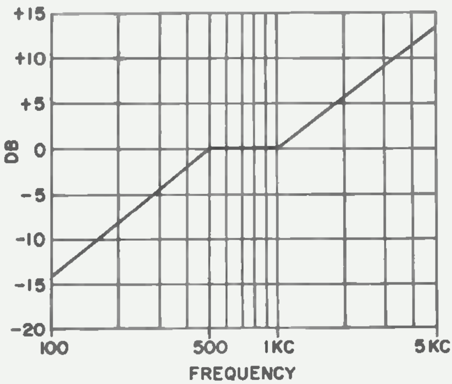


FIG. 10. Recording curve with bass response reduced and treble response increased.

between stylus movement and frequency is maintained, it will mean that the amount of movement at 20 cycles would have to be 1000 times as great as the amount of movement at 20,000 cycles. In addition to this problem, the lateral or sideways movement of the stylus is also affected by the amplitude of the signal that is being recorded. Since low-frequency signals are usually much louder than high-frequency signals, the resulting record grooves are in danger of being too close together or actually running into each other.

To prevent this from happening, the gain of the amplifier driving the cutting head is reduced at low frequencies. Thus, when the record is played back it is necessary to increase the low-frequency gain the same amount.

As can be seen in Fig. 9, high-frequency sounds produce very small lateral movement. This by itself would result in a very low output. Besides this, the noise of the record material, in addition to the noise in the reproducing system would be higher than some of the high-frequency sounds recorded. This problem is solved by simply boosting or increasing the high frequencies as they are recorded. Thus, in order to get a flat frequency response when playing back the record, it is necessary to reduce the high-frequency response the same amount that it was increased.

Fig. 10 shows a recording curve in which the bass response is reduced at the rate of 6 db per octave starting at 500 cycles, and the treble response is increased at the rate of 6 db per octave starting at 1000 cycles. It is evident that in order to obtain linear reproduction, the playback curve would need to be the opposite of this recording curve. Such a playback curve is shown in Fig. 11.

This method of eliminating overcutting and of overriding noise is obviously quite simple. The fly in the ointment, though, is that, in the beginning no two record manufacturers agreed on how much bass-cut or treble-boost was needed, nor at what frequency it should begin. Thus, different record companies used different methods of equalization, which made playback equalization a problem.

The equalization or recording curve that the companies followed was characterized by the letters previously mentioned. For example, most American records were made according to the AES (Audio Engineering Society)

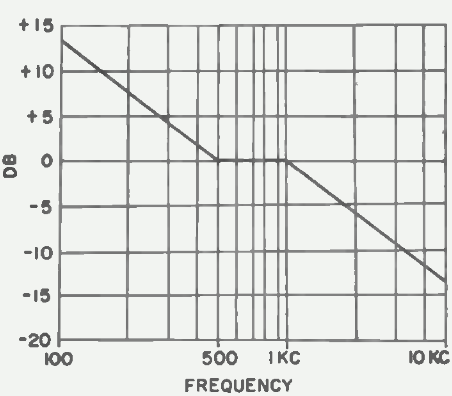


FIG. 11. Playback curve that is the opposite of the recording curve in Fig. 10.

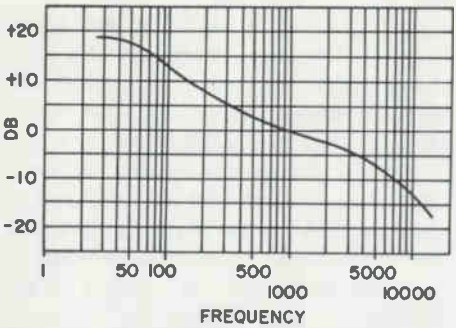


FIG. 12. Standard RIAA playback curve.

and NARTB (National Association of Radio and TV Broadcasters) recording curves.

Now, however, the major record companies have agreed on one equalization curve, the RIAA (Recording Industries of America, Associated). Since 1954, all records made in the United States, and those exported to the United States from Europe have utilized this curve for monophonic records. All stereophonic discs also follow this curve. Thus, unless one has a substantial collection of 78-rpm records or of old LP records, special equalizers for the other curves are not necessary.

The standard RIAA playback curve is shown in Fig. 12. You will notice that although there is a boost on the low end and a loss at the high, there are no straight lines as in the other curves shown. Such straight lines are easily drawn but are not easily obtained by simple R-C circuits. The curve specified by the industry is one that is obtainable with simple R-C circuits.

The Stereophonic Record. In modern recording methods, lateral movement of the stylus is used for both amplitude and frequency. Earlier records used a "hill and dale" method. That is, changes in frequency and amplitude produced up and down movements of the stylus.

Now, we can see, it would be possible to make a stereophonic record, containing two channels, by combining both recording techniques: the stylus could move up and down for one channel, and left and right for the other channel.

In fact, such a stereo disc was devised decades ago. However, the method is not acceptable, since the laterally cut channel would be far superior to the vertically cut channel. Experience has shown that stereophonic reproduction must have two channels of equal quality to be acceptable.

The present method of stereophonic recording is actually very similar to this early vertical-lateral method. However, instead of modulating the

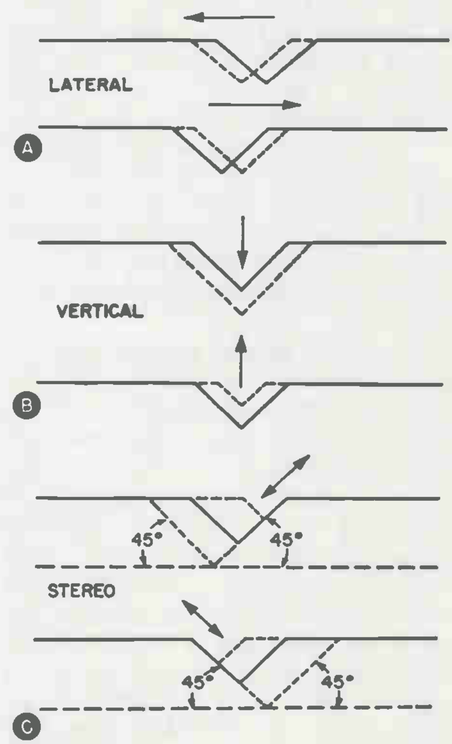


FIG. 13. Cross-section of record grooves for (A) lateral modulation; (B) vertical modulation; and (C) 45/45 stereo modulation.

groove laterally for one channel and vertically for the other channel, the modulation for each channel is applied at a 45° angle to the record surface.

Fig. 13 shows cross-sections of the groove for the various systems of modulation, Fig. 13A shows lateral modulation, such as used on all present-day monophonic records. The solid line shows the groove with no modulation applied. When modulation is applied, the stylus will move first to one side and then to the other as shown by the dashed lines to the left, then to the right. In other words, it will move laterally.

than monophonic disc distortion, but the level is still quite acceptable.

This method of stereophonic recording is knows as Westrex (after the company that developed it) or 45-45 since the channel modulation is applied at 45° angles to the surface of the record.

All stereophonic records use the constant-velocity method for cutting, and the standard RIAA equalization curve.

PINCH EFFECT

The stylus used to cut records is chisel shaped for its task rather than

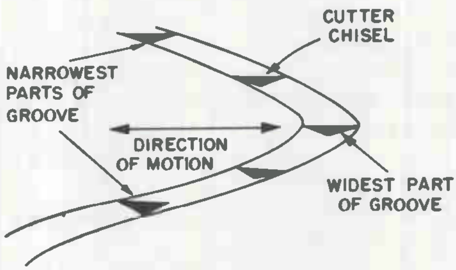


FIG. 14. Pinch effect on record groove caused by the shape of the cutter.

Fig. 13B shows vertical modulation. Here the stylus moves below the zero-modulation point and then above. In other words, it moves up and down instead of from side to side.

Fig. 13C shows how the stylus moves for stereo modulation, in which each channel is applied at a 45° angle. The movement of the stylus point will be complex—it will move both laterally and vertically at the same time which it can do since these movements are in different planes. Although this type of movement is similar to that used on the lateral-vertical stereo disc, the distortion is equal in both channels and meets the requirement of equal channel quality. It is evident, of course, that stereo disc distortion is higher

round like the reproducing stylus. Since it does not turn as it cuts, it will not cut a groove of constant width. Instead, as shown in Fig. 14, the width of the groove varies throughout the cycle and is the same width as the cutter only at the peaks of the groove. The groove shrinks to a minimum as it passes through the zero position. The variation in width depends upon the angle that the center line of the groove makes with the face of the cutter and thus will be greater on waves of large amplitude or high frequency. The rounded tip of the reproducing stylus will consequently ride lower in the groove at the tips of the wave, and will rise as the wave passes through the zero.

This trouble is appropriately known as "pinch effect," and may result in the introduction of a double frequency component into the signal if the pickup design is unsuitable. This difficulty can be largely overcome by permitting vertical movement of the entire stylus assembly on monophonic records. If the cartridge is designed to produce no output for vertical movements, then any distortion caused by the pinch effect will not be heard in the output.

However, since the stereo cartridge is designed to produce output with vertical movement of the stylus, if it is used for monophonic records, the pinch effect will result in distortion. When playing monophonic records with a stereophonic cartridge, it is important to connect the outputs of the cartridge together, which will cancel the distortion caused by the pinch effect.

BROADCASTING AS A HIGH-FIDELITY SOURCE

The second most popular source for high-fidelity systems is broadcasting: AM, FM, and stereo.

AM Stations. Because of the frequency response limitations imposed by the FCC on AM broadcast stations, because of the overcrowding of the broadcast band, it is difficult to obtain satisfactory reproduction from this source. Generally, an AM station does not transmit frequencies above 5000 cycles.

Although there are a number of AM stations that broadcast higher frequencies when the locations of nearby stations permit, unfortunately, most AM receivers and tuners are not designed to receive these higher frequencies. Some AM tuners specifically designed for high-fidelity systems have a switching sytem that permits narrow or wide-band response.

Reception of stations that broadcast high frequencies even when using a wideband tuner is not particularly satisfactory, because the dynamic range of an AM system is limited. It is usually necessary to boost weak passages to bring them above noise levels, and attenuate the very strong passages to prevent overmodulation and other distortion.

FM Stations. Most FM stations broadcast wide-range sound. In addition, the FM system permits much greater dynamic range. The FM system is capable of high-quality reproduction. Unfortunately, there are other limiting factors. For example, the quality of the sound received on an FM system depends not only on the quality of the FM tuner and other components in the receiving system, but also on the quality of the components used in the FM station. The quality and care of records, the type of cartridge and turntable, the quality of the transmitting equipment itself, and other factors are involved. Satisfactory results can be obtained when the FM station broadcasts live sound. However, when network programs are broadcast, telephone lines are used to carry the program to the studio. The quality of the sound is obviously then determined by the quality of the phone lines. Although it is possible to design lines to carry full fidelity, most networks or stations use the "continuity only" type of lines.

Even the best FM system, of necessity, has more equipment between the original music and the listener in the home than a record system does. Since each piece of equipment produces some distortion, the FM system cannot equal the best records.

Stereophonic Broadcasting. The most obvious method of obtaining stereo broadcasting is to broadcast one channel on FM and the other on AM, and use two tuners or receivers to reproduce the entire pickup. Unfortunately, as pointed out, AM broadcasting is not nearly as good as FM, so one channel would be reproduced poorly and the resulting sound would not be very enjoyable.

Another method of stereo broadcasting is FM multiplexing where only one FM station is required. In this system, one channel is broadcast in the regular way, while the second channel is broadcast on a higher-frequency carrier signal superimposed on the regular channel. In order to play back such a stereo broadcast, a multiplex unit capable of decoding or picking off the second channel is needed in addition to a standard FM tuner. Naturally, two amplifiers and two speakers are also needed. The quality of such a stereo broadcast is much superior to the AM-FM type but is, as explained above, inferior to stereo discs.

Pickup Cartridges

The phonograph cartridge or pickup converts the mechanical energy of the record groove to electrical energy; in other words, it is a transducer.

Since there are two different types of recordings, stereophonic and monophonic, there are stereophonic and monophonic cartridges. In addition, these two types can be further classified into two other distinct types: the crystal or ceramic and the magnetic. Stereophonic cartridges must, of course, contain two generating systems actuated by the single stylus in order to reproduce both channels of the stereo record. The stereo cartridge can be used to reproduce monophonic records simply by connecting the two outputs together. Monophonic cartridges, however, cannot be used on stereo records, as we will see.

CRYSTAL OR CERAMIC CARTRIDGES

Crystal or ceramic cartridges operate on the piezo-electric principles you learned in an earlier lesson when you studied crystal oscillators. When utilizing a crystal, such as quartz, for a cartridge we apply a mechanical stress to the crystal to obtain an electrical output. This is done by attaching the needle, or stylus, to the crystal. As the stylus is moved to the right or left by the modulated record groove, it twists the crystal and produces a corresponding electrical output.

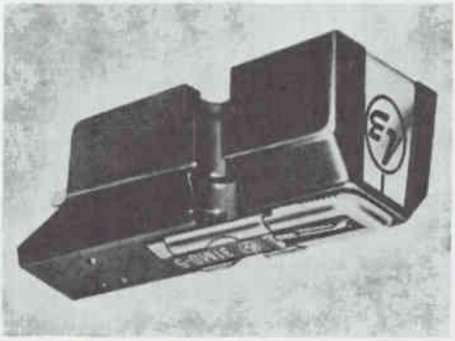
Ceramic cartridges use a ceramic element, such as barium titrate or zirconium titranate, instead of a crystal. These particular ceramic materials (as well as others) exhibit the same piezo-electric effect as quartz. The advantage of using ceramic is that it is not as susceptible to damage by heat and humidity. However, ceramic is less efficient than quartz, and the cartridge thus has less output.

For many years the crystal pickup has been the most common type because of its high signal output and its easy adaption for small, low-priced record players. Most of these early crystal cartridges were quite poor so far as the quality of response is concerned. This, however, was a hidden advantage. Little care had to be taken with the quality of the phonograph turntable and arm since the cartridge could not reproduce the low-frequency rumble and noise. Similarly, mishandling of records and the resultant noisy surfaces were not a problem since the cartridge could not reproduce high-frequency noise.

The crystal, though, had a built-in disadvantage in that it was susceptible to humidity and heat—by absorbing moisture it destroyed itself. This latter difficulty was solved by introduction of the ceramic type of cartridge. In general, ceramic cartridges are superior to crystal types. They have better frequency response and cause less distortion. However, since they have less output, the crystal cartridge will undoubtedly be used for many years in low-priced phonographs. Its 3 to 5-volt output is sufficient for two or even one-tube amplifiers. The output of a ceramic cartridge is usually from .5 to 1 volt, and requires at least one amplifier stage before the power output stage.

There are a number of ceramic cartridges that are deliberately intended to have high output and poor frequency response. Such cartridges, of course, have no place in high fidelity. Other ceramics vary in quality from the mediocre to the exceptionally good.

As pointed out previously, most package-type systems have ceramic cartridges. There are a number of component systems that have them also. Since crystal cartridges have a high electro-mechanical efficiency (80% or more) the output is much higher than from the magnetic cartridge, which has an efficiency of 10% or less. Thus, systems which are troubled with hum problems or other noise difficulties can take advantage of the high-output ceramics. In addition, the coils in magnetic cartridges tend to pick up hum inductively from neighboring magnetic fields. When it is not possible to position the phonograph away from these magnetic fields, a ceramic cartridge such as the one in Fig. 15 must be used.



Courtesy Electro-Voice, Inc.
FIG. 15. A high-quality stereophonic ceramic cartridge, the Electro-Voice 31MD-5.

Theoretically, there is no distinct advantage of one type over the other. However, there are many audiophiles that claim ceramics sound harsh compared with magnetics. Since this is an intangible characteristic, there is no way of proving or disproving this opinion. There is no doubt, though, that there are some ceramics superior to some magnetics. On the other hand, it's hard to overlook the fact that the best (in cost and over-all quality) high-fidelity systems use magnetic cartridges. So do most FM and high-quality AM broadcast stations.

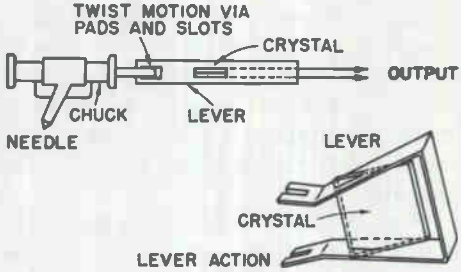


FIG. 16. Interior of a crystal monophonic cartridge.

The interior of a crystal or ceramic monophonic cartridge is shown in Fig. 16. As can be seen, the stylus is attached to a yoke assembly which is in turn attached to the slab of crystal or ceramic material. The yoke assembly couples the stylus to the crystal and it also serves as a lever to accentuate the minute twists of the record groove.

Fig. 17 shows the operation of a simple stereophonic crystal cartridge. In this illustration the yokes have been omitted for simplicity. As can be seen, two separate crystal slabs are used and are coupled to the stylus. The slabs are at 45° angles to each other, corresponding to the groove modulation of the stereophonic record. When the stylus is modulated by one side of the groove, one of the crystals is twisted, and this results in a corresponding output. Similarly, when the stylus moves in the opposite direction, the other crystal is twisted.

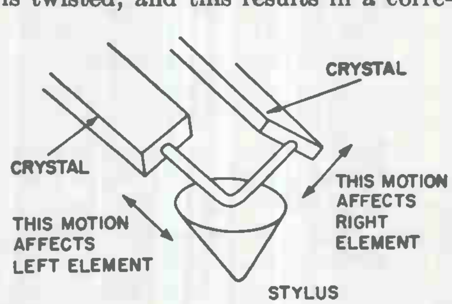


FIG. 17. Operation of a stereophonic crystal or ceramic cartridge. Motion in one direction flexes the right crystal, causing it to generate a voltage; motion in the other direction flexes the left crystal, causing it to generate a voltage.

Still another method of using a crystal for stereophonic reproduction would be to connect the stylus to the crystal with a special yoke capable of twisting the ceramic element in both directions. Then, only one crystal would be needed since the yoke would provide twisting in both directions.

MAGNETIC CARTRIDGES

At the present time there are many types of magnetic cartridges, and no doubt many more will be developed. We will look at the types most often used.

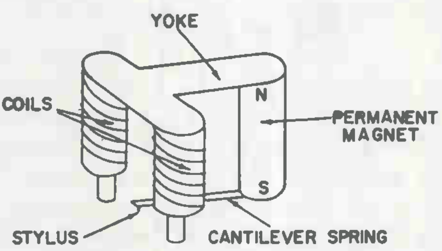


FIG. 18. A variable-reluctance cartridge.

Variable Reluctance. One of the earliest types of magnetic cartridge was the variable reluctance. One version of this type of cartridge is shown in Fig. 18. As can be seen in Fig. 18 the stylus is mounted on a cantilever arm which moves between two coils. The other end of this arm is connected to the south pole of a permanent magnet. A T-shaped yoke connects the other end of the magnet to two pole pieces on which two coils are wound. The flux path is from the magnet through the yoke to the two pole pieces and then across the air gap to the cantilever spring. As the stylus follows the record grooves, it moves from side to side, nearer one or the other of the two coils. As it does so, the air gap on one

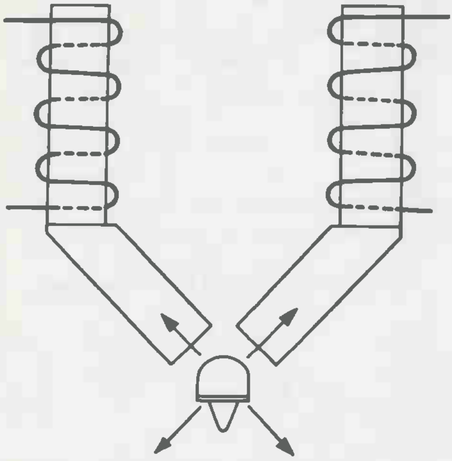


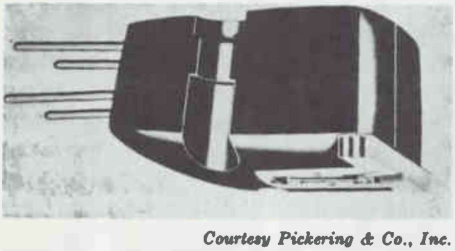
FIG. 19. Front view of a stereophonic variable-reluctance cartridge.

side decreases and the flux increases. At the same time, the air gap on the other side becomes wider, increasing the reluctance and decreasing the flux. Since the flux changes are in opposite directions, the voltages induced in the two coils will be of opposite polarity. By connecting the two coils in series-opposition, the two voltages are added in the output.

Simply then, lateral movements of the stylus will cause a varying output, because of the varying reluctance in the magnetic gap.

One advantage of this variable reluctance type of pickup is that it responds only to lateral motion of the stylus. Consequently, there is little needle scratch or surface noise picked up. Since vertical motion of the stylus causes the same flux change in both coils, the induced voltages are of the same polarity and are canceled in the output.

Fig. 19 shows how the monophonic variable reluctance-type cartridge is easily changed to a stereophonic type. In the stereophonic version, the ends of the coil pole pieces are bent at 45° angles to the stylus and disc and are at 90° angles to each other. Instead of being connected to each other, each coil provides the signal for a separate channel.



Courtesy Pickering & Co., Inc.

FIG. 20. The Pickering Fluxvalve stereo cartridge.

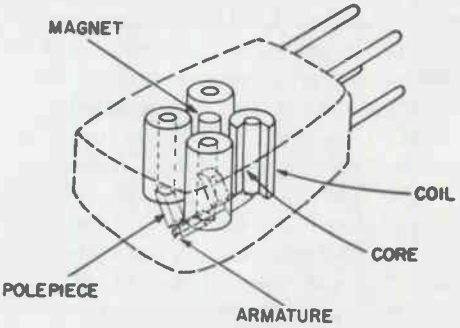


FIG. 21. A phantom view of the Pickering Fluxvalve stereo cartridge.

Since only one coil is used for each channel, it is evident that there will be less signal output. In fact, in the example shown, the output level of the stereo version will be exactly half the output level of the mono version. In practice, however, improvements in the coil and magnet assemblies have resulted in more output than this, although it is still below 10 millivolts (.001 volt) per channel.

Another variable reluctance stereo cartridge, the Pickering, shown in Fig. 20, operates in a slightly different way. As can be seen in the phantom view of Fig. 21, this cartridge uses four coils, two for each channel. The magnet is

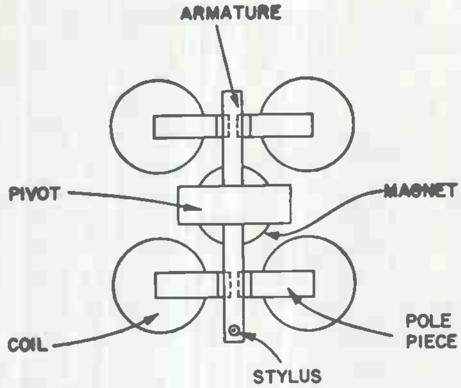
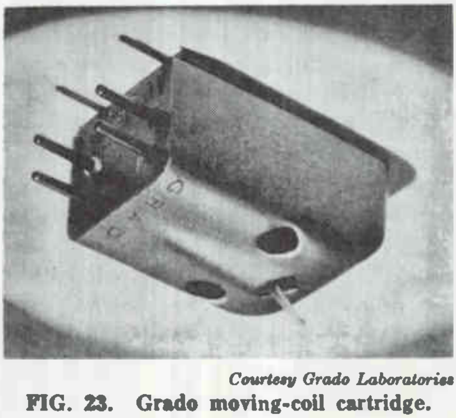


FIG. 22. Simplified plan view of the bottom of the cartridge shown in Fig. 21.

in the center of the group of coils, and is coupled through a pivot to the armature, a thin straight tube with the stylus mounted at one end.

Fig. 22 is a simplified plan view, looking up at the bottom of the pickup. The armature is pivoted at its center in a bearing that allows the stylus end free motion in all directions in the plane perpendicular to the record surface. The front end of the armature carrying the stylus is coupled to the magnetic circuit through the two 45° pole pieces at the front end of the cartridge. The reverse end of the armature is coupled to the magnetic circuit also, through identical pole pieces at the rear of the cartridge.



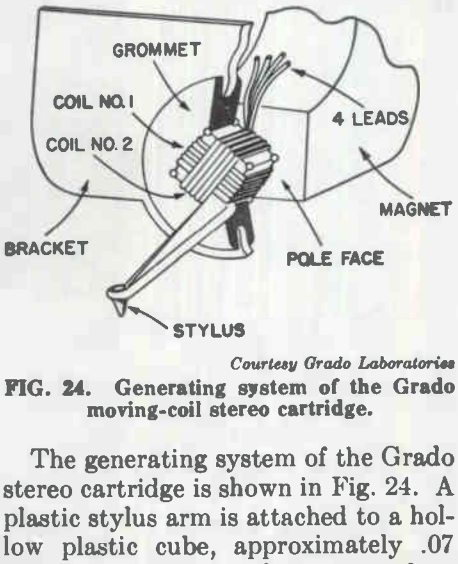
Courtesy Grado Laboratories

FIG. 23. Grado moving-coil cartridge.

The moving armature modulates the magnetic circuit at the rear of the cartridge with an amplitude equal to the modulation at the front of the cartridge, and 180° out of phase with it. The coils are phased so that the two signals in each channel are added. It is evident that this push-pull arrangement, with the armature pivoted at its center, has a higher signal level.

THE MOVING-COIL CARTRIDGE

Another type of high-quality stereo cartridge is the moving coil, such as the Grado Cartridge, shown in Fig. 23.



Courtesy Grado Laboratories

FIG. 24. Generating system of the Grado moving-coil stereo cartridge.

The generating system of the Grado stereo cartridge is shown in Fig. 24. A plastic stylus arm is attached to a hollow plastic cube, approximately .07 inch square. Two coils are wound on the flats of the cube at 90° to each other.

This generating system is mounted within a grommet made from a special rubber, compounded to minimize cold flow or hardening tendencies. The grommet, as shown in Fig. 24, has a groove around its edge, which is used to mount the complete coil system in a metal bracket. The generator and bracket are then assembled to a highly-damped plastic base.

The coil assembly is placed within a magnetic gap, so movements of the stylus cause the coils to break flux lines and produce voltages. Both coils are rotational and electrically balanced, and since there is only one moving mass within a single magnetic gap, the reproduction from both channels is exactly the same. Each coil generates equally on either a vertical or lateral movement. The coils can also generate mixed components as dictated by the groove. Each coil contains 1000 turns of silver-copper-alloy wire, .0004 inch in diameter, triple-gold-plated to prevent corrosion. The four leads of the two coils are thermal-welded to four silver contact pins, which are color-coded to facilitate the proper electrical connections.

Variations of the moving coil design shown here were also used in monophonic cartridges. In such an application, of course, it is necessary to have only one coil instead of two.

MOVING-MAGNET CARTRIDGES

A typical moving magnet cartridge is shown in Fig. 25. This particular type of cartridge is very similar to the moving-coil type cartridge, except, as the name implies, the coils are stationary and the magnet moves according to the stylus movement.

Fig. 26 shows a high-quality moving-magnet stereo cartridge. The interior is shown in Fig. 27. It is evident that such cartridges are extremely complicated, since they are so small. However, the operation of the cartridge is not particularly difficult to understand.

Although the following discussion refers specifically to the Audio Empire 88 stereo cartridge, the general operation is applicable to all moving-magnet cartridges.

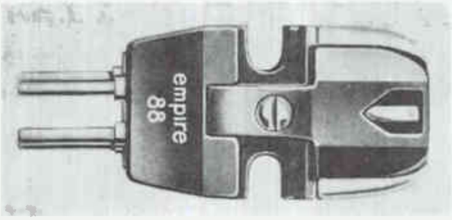
As can be seen in Fig. 27A, the stylus lever is firmly attached to a small magnet. This magnet is actually .04 by .1 inch long.

Courtesy Shure Brothers, Inc.

FIG. 25. A typical moving-magnet cartridge.

The stylus magnet assembly is pivoted at the center. Fig. 27B shows a diagram of the way in which it works. Coils A and B, wound in series-opposition, form one coil structure, which develops signals from the inner groove wall (left channel) modulation. Coils C and D, also wound in series-opposition, develop the outer-wall signal (right channel).

When the stylus picks up modulation from the left channel, it will create a force (F1) which will rotate the poles of the magnet toward and away from the pole faces of coils A and B and create a variable flux in the coil structure. This force, F1, how-



Courtesy Audio Empire

FIG. 26. The Audio-Empire 88 moving-magnet stereo cartridge.

ever, has not caused any air gap variation relative to poles C and D, since the magnet is moving parallel to these pole faces. Therefore, there is no current generated in the C and D coil combination.

Conversely, a signal in the right channel will create a force F2 which will in turn cause a flux variation in the C and D coil structure while isolating the A and B coil structure.

Since it obviously would not be possible to mount the four coils as shown in B of Fig. 27 (the stylus arm from the magnet to the record would be too long), the coils are positioned vertically as shown in C of Fig. 27, and a metal structure called a quadrature structure is used to couple the magnet movements to the coils.

As might be expected, this moving magnet system can also be utilized in monophonic cartridges simply by using one set of coils instead of two.

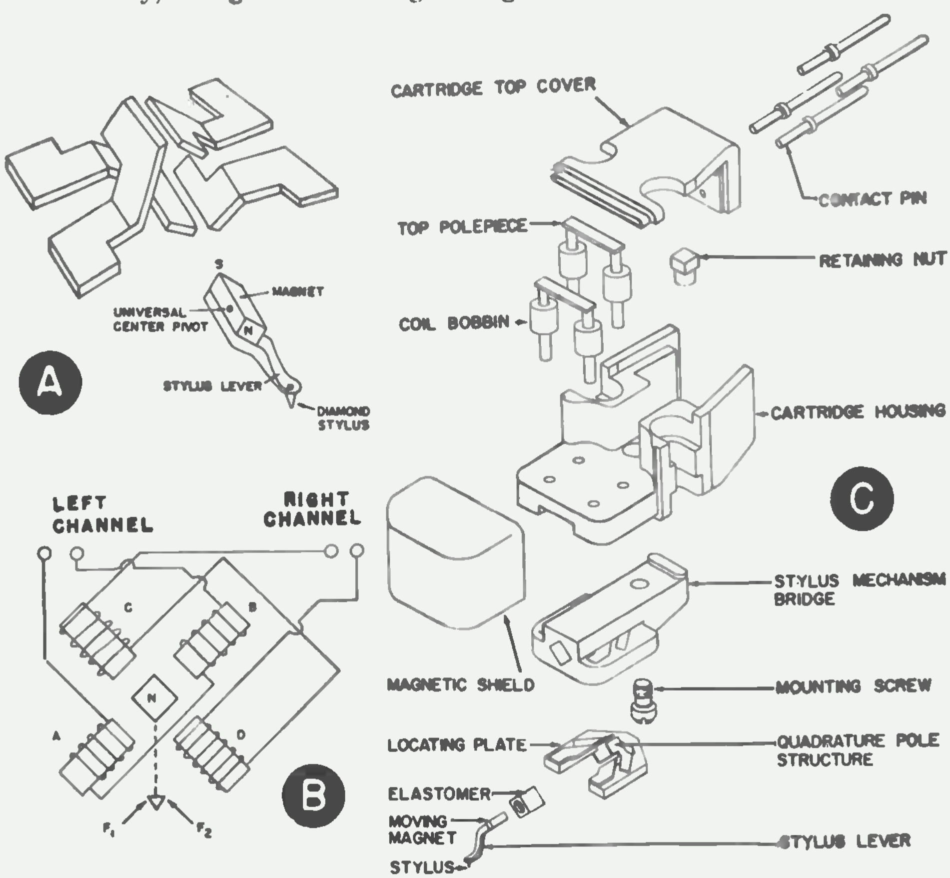


FIG. 27. Construction and operation of the Audio Empire 88 moving-magnet stereo cartridge.

CARTRIDGE CHARACTERISTICS

As pointed out previously, the cartridge is a transducer, since it converts the minute record-groove undulations to an electrical signal. This is an extremely difficult job, and as a result, the cartridge and the loudspeaker, another transducer, are usually less perfect than the remaining parts of the over-all high-fidelity system.

There are many characteristics that affect the over-all quality of a cartridge among which are the dynamic mass, compliance, frequency response, and resonance. In fact, these key characteristics of a cartridge are dependent upon one another for the over-all performance of the cartridge.

Compliance. The compliance indicates how easily the stylus will move; in other words, it is the opposite of stiffness. Low compliance will cause excessive record wear, reduce high-frequency response, and impair transient response. The compliance figure normally specifies the fraction of a centimeter that a stylus will move when a certain amount of force, measured in units called dynes, is applied to it. Normally the force is 10^{-6} (.000001) dyne. Although it was considered as an achievement just a few years ago to reach a compliance of $1. \times 10^{-6}$ centimeters per dyne, it is normal and acceptable now to expect a compliance of 2×10^{-6} centimeters per dyne or more. The Audio Empire cartridge in Fig. 26, for example, has a compliance of 5×10^{-6} centimeters per dyne.

Since the stereo cartridge must move horizontally and vertically, it is rated at both vertical and horizontal compliances.

Mass. The compliance of a cartridge depends on the structure of the stylus mechanism and on its mass.

The mass is determined by the physical size of the stylus system and the density of the material used in the system. The mass figure is generally in grams or milligrams (one gram = about 1/28 oz.), and indicates the mass reflected to the stylus tip. In very high-quality cartridges, this mass should be 1 milligram (.001 gram) or less. The Grado cartridge of Fig. 23, for example, has a mass of .7 milligram (.0007 gram).

Resonance. All phonograph cartridges exhibit mechanical resonance at both upper and lower ends of the frequency spectrum due to vibration of the mechanical parts of the cartridge. A typical cartridge will resonate at 12 cycles per second and 18,000 cycles per second.

Inexpensive and poorly designed cartridges will have these resonant peaks within the audible spectrum, that is, between 20 cycles per second and 15,000 cycles per second. When this occurs, it is necessary to introduce mechanical damping of the cartridge system in order to deflate these resonant peaks. No matter how well the damping does reduce the peaks, it is generally of such a nature that it cannot recover rapidly. Thus, a damped system, although it would not cause peaks in the response, could destroy transient response. Excessive damping to reduce audible resonances is generally found in low-cost magnetic cartridges and in ceramic and crystal cartridges. Of course adding damping material to the stylus mechanism will increase its mass and reduce compliance.

Thus, it is evident that a cartridge can have superlative frequency response and still be considered totally unsatisfactory. Remember that the ability to reproduce loud bursts of music is probably more important than a flat frequency response.

Tracking Pressure. The stylus force or tracking pressure specification of a cartridge indicates how much downward pressure must be exerted on the cartridge to keep the stylus riding properly in the record groove. The required tracking pressure depends upon the design of the cartridge, just as a vacuum tube's bias voltage depends on the tube design. It is desirable to have the cartridge designed to operate with as light a pressure as possible, since this reduces friction between the stylus point and the record groove, and reduces wear. Excessive friction smooths out the microscopic waves of the groove, thereby wiping out the high-frequency modulations. In addition, the noise content rises excessively.

Excessive wear of a stereo record not only eliminates the high frequencies and increases the noise level, but the channel separation is reduced. If the wear continues, the separation will be reduced to the point where the record will no longer be "stereophonic."

Since the stereo cartridge uses a smaller stylus radius, .0005 to .0007 inch, than the regular monophonic .001-inch cartridge, there is more pressure per square inch when using the same stylus force on both. It is more important, therefore, for a stereo cartridge to be designed for optimum operation with less stylus force.

Stylus Material. The material used for styli is generally of three types: metal, sapphire, and diamond.

Metal styli, often plated with other materials like osmium, were very popular with 78-rpm records, and are still widely used in inexpensive phonographs. A metal stylus is entirely unsatisfactory because it wears too quickly even on the relatively soft modern vinyl records. In fact, when playing a standard 12-inch LP record, the metal stylus will become worn before the record is completely played, and will thus begin to wear out the record grooves before the entire record is heard.

Synthetic and real sapphire styli are very popular, particularly because of their moderate cost. However, even though these styli are much harder than metal, they will generally last only thirty hours before beginning to wear. Naturally, less stylus pressure will result in longer playing time before wear, and more pressure will result in less playing time before wear. This means that approximately 15 to 20 records can be played before the stylus will begin to deteriorate the records. A diamond stylus is generally considered to last approximately 1000 times as long as a sapphire stylus. It is the best buy.

Incidentally, the above hourly ratings are relative. The actual life of any stylus will depend upon the compliance of the cartridge, the necessary stylus force of the cartridge, and is also affected by the tone-arm quality and other factors.[1] Probably the most important single factor is the dust on the record. Very fine dust particles in the groove act as an abrasive and wear both the groove and stylus. Keeping records clean can extend the life of the stylus and record considerably.

PICKUP TERMINATION

For the best possible frequency response, a cartridge must be terminated correctly at the input of the amplifier. The manufacturer of a cartridge will recommend an optimum resistance value for that particular cartridge. This value generally ranges from 47,000 ohms to 100,000 ohms for magnetic cartridges, and from 1 megohm to 4 megohms for ceramic cartridges.

Using a higher resistance than recommended for a magnetic cartridge will result in excessive high-frequency response. This, by itself, is not particularly undesirable since the tone control can compensate for the problem, but the high resistance will also reduce necessary electrical damping on the cartridge system and cause peaks in the response.

Using too low a resistance to terminate a magnetic cartridge will always result in reduction of the high-frequency response.

The resistance value used to terminate a ceramic cartridge has the opposite effect as that used with a magnetic cartridge; that is, it affects the low-frequency response. Using too small a resistance will reduce the low-frequency response, while using too high a resistance will increase the low-frequency response. Some ceramic cartridges require more elaborate R-C networks for proper equalization.

Using Input Transformers. Because of the extremely low output of some types of magnetic cartridge design, it is necessary to use an input or step-up type of transformer between the cartridge and the pre-amplifier. All transformers suffer, to some degree, from frequency, phase, wave form and other types of distortion. In addition, step-up type transformers tend to pick up hum from magnetic fields inductively. The use of such transformers should be avoided if at all possible. However, many of the input transformers available today are very high-quality units, and distortion is kept at a minimum. It is possible to have a low output cartridge of such high quality that it would offset any slight troubles from the transformer as compared to a high-output cartridge of less quality that would not need a transformer.

Step-up transformers designed for these applications are generally liberally shielded by a special alloy called Mu-Metal, to prevent hum pickup. Even so, the transformer should be mounted as far away as possible from hum-producing transformers and motors.

Tone Arms

The quality of a tone arm is very important in high-fidelity monophonic systems; it is even more important in high-fidelity stereophonic systems. The tone arm can be considered as a "negative" component in that it is intended to neither add to nor affect the signal in any way. In fact, any way in which it does affect the signal is undesirable.

TRACKING

The primary job of the tone arm is to hold the cartridge so that the stylus will ride properly in the record grooves. This is not a simple job, since the stylus must ride in the groove in a certain way.

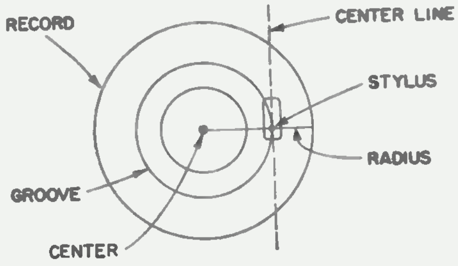


FIG. 28. Ideally, the reproducer stylus should move along a radius, as shown here.

The lathe used to cut records moves the cutting stylus along the radius of the record from the outer edge toward the exact center. Ideally then, the reproducer stylus should move along a radius, as shown in Fig. 28, in order to maintain the cartridge at the correct angle to the groove. As shown here, a center line drawn through the cartridge would then form a tangent to the groove being played. This center line would be at a 90° angle to the radius of the record. It is evident that this could be achieved only if the cartridge were held by a parallel guide-support similar to that used in the recorder. This solution is not only expensive, but is actually unnecessary. In practice, the reproducing cartridge can be mounted in a tone arm pivoted at one end. The cartridge would then move along an arc, as shown in Fig. 29, instead of following the radius. Incidentally, the pivoted arm has the important advantage that the frictional forces are much lower than in any parallel-bar support, and thus the sideways pressure on the groove and stylus is reduced. This is particularly important in stereophonic reproduction.

The main result of the reproducer stylus following an arc rather than the radius followed by the cutting stylus is the appearance of even harmonic distortion. In addition, this will also reduce the stereophonic effect.

The difference between the true tangent shown in Fig. 28 and the actual center line of a cartridge mounted in a pivoted tone arm is called the "tracking error." This tracking error can be seen in Fig. 30. Notice that it is the angle between the true tangent and the actual cartridge center line.

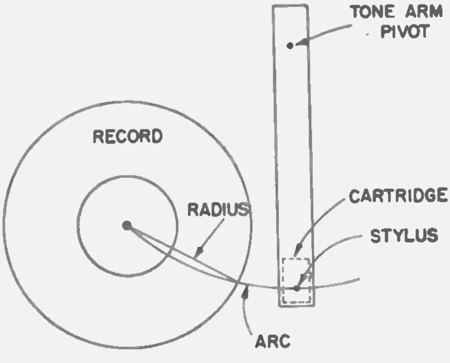


FIG. 29. When stylus is mounted on a pivoted tone arm, it moves on an arc rather than a radius.

If a stereo cartridge is mounted in this manner, left-channel modulations will not only cause the stylus to move laterally, but also up and down. The resultant force will change the 45° stylus movement and result in less output from the left channel and "leakage" of left channel signal to the right channel.

As can be seen in Fig. 31, the tracking error is highest at the outer edge of the record and decreases toward the center. This is somewhat of an advantage since distortion from cutting increases toward the center of the record as the groove velocity decreases. It is best to design a tone arm to have less tracking error at the center of the record than at the outer edge.

There are many methods of reducing this tracking error, such as lengthening the tone arm, offsetting the end of the tone arm containing the cartridge, and permitting the stylus to overhang or extend past the center of the record.

It is evident from the illustrations that if the tone arm were lengthened, the arc would flatten out and thereby decrease the tracking error. This is not a very satisfactory solution to the problem, since there is generally in-

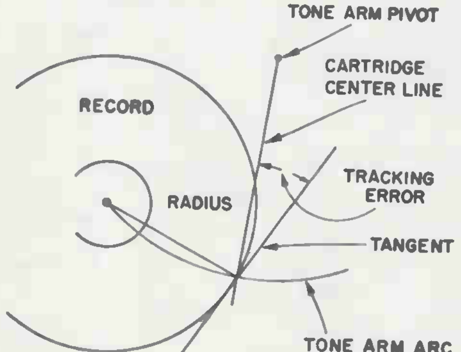


FIG. 30. Tracking error is the difference between a tangent to the record groove and the center line of the cartridge.

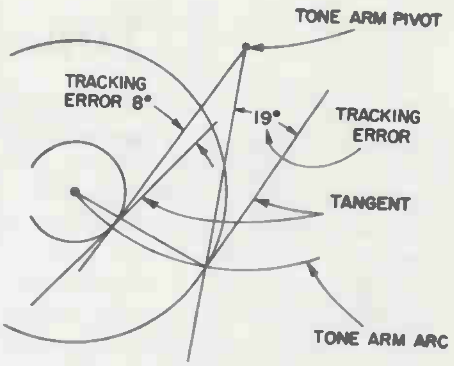


FIG. 31. Tracking is highest at the outer edge of the record and decreases toward the center.

sufficient room to mount a long tone arm. Also, lengthening of the tone arm would present other problems with resonances and pivot friction. In practice, both "overhang" and "offsetting" are used to reduce tracking error.

Fig. 32 shows clearly how tracking error can be reduced by overhang and offsetting.

In this illustration the stylus "overhangs," that is, extends past the center of the record. In addition, the end of the tone arm containing the cartridge is at an angle to the center line of the arm. It is clearly evident that this configuration is best since the tracking error is reduced considerably below the value shown in Fig. 30.

Two different sizes of tone arms are available, 12-inch and 16-inch. These sizes refer to the size of the record for which they were designed rather than the length of the tone arm. Although 12-inch diameter records are the largest size commercially available, 16-inch transcription records are used in studios for programming. In order to play the 16-inch disc, a longer tone arm is necessary. Since the tracking error is naturally less on these longer arms, many are available for high-fidelity systems.

The 12-inch type of tone arms generally vary from 6 to 9 inches from the pivot to the stylus, while 16-inch arms run from 8 to 12 inches from the pivot to the stylus.

MOVEMENT OF TONE ARM

In addition to its length and the angle at which it holds the cartridge, the tone arm has several other important characteristics. First of all, in order for the cartridge stylus to track the groove of the record, the tone arm must be free to move laterally across the record. Lateral friction in the tone arm must be minute and should not be affected by climatic conditions. Almost all high-quality tone arms have ball bearings in the main pivot structure to keep the friction low.

When playing monophonic records, it is important that the tone arm be free to move vertically. Otherwise, warped records or records with uneven surfaces will cause the stylus to cut through the high spots and skip over low spots. This, of course, will damage both the record and the stylus, to say nothing of the effect on the listener.

When playing stereophonic records, it is evident that the vertical movement of the tone arm is just as important as its lateral movement. As might be expected, some very excellent tone arms that were designed for monophonic reproduction are almost useless on stereophonic reproduction because of excessive vertical friction.

Most tone arms utilize vertical pivots at the main lateral pivot so that the entire tone arm is free to move up and down (except where it is attached to the main pivot). Other tone arms are vertically rigid along the length of the arm while the head of the arm is free to move vertically. An example of this type of tone arm is shown in Fig. 33.

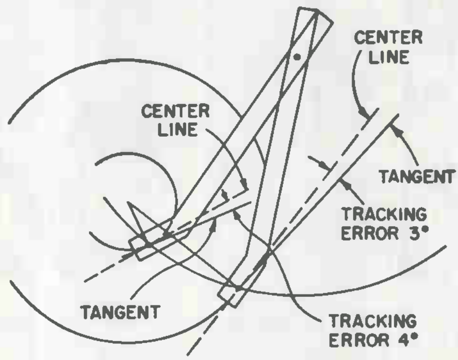
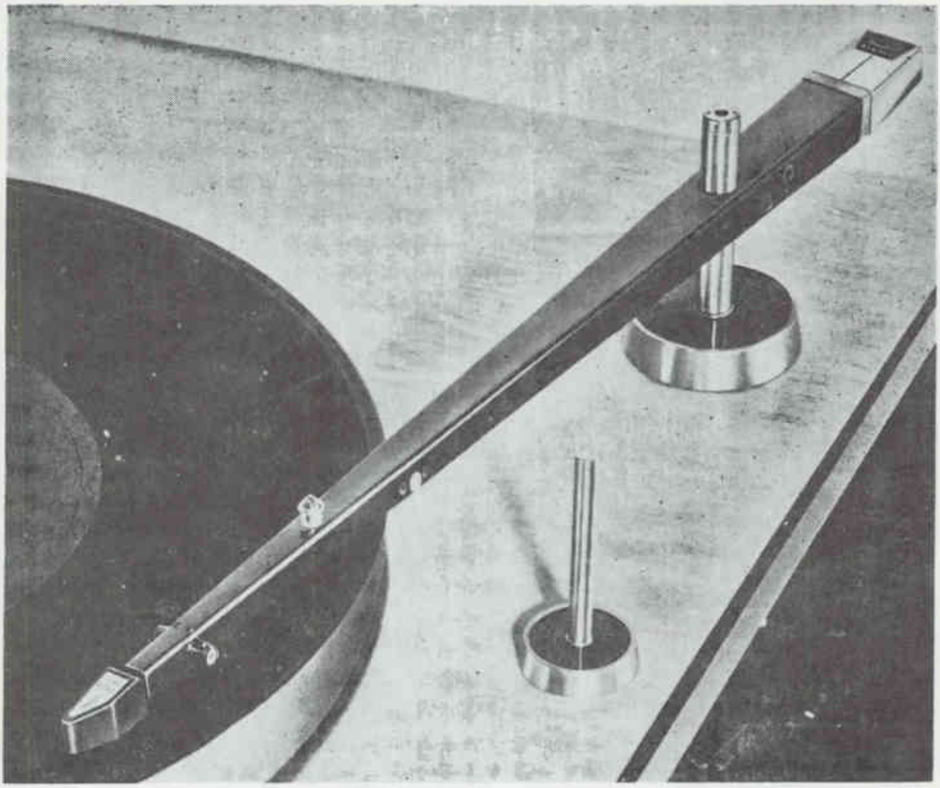


FIG. 32. How tracking error can be reduced by overhang and offsetting.

BALANCE

Although the tone arm must be free to move in any direction for stereophonic reproduction, it must also be laterally balanced. That is, if the tone arm tends to move to either the right or left, it will press against, or apply uneven pressure to, one of the modulated side walls of the record groove. This will not only wear the groove excessively, but could, in many cases, cause high output or peaks from that particular channel because of difference in pressure on the stylus and cartridge mechanism.



Courtesy Shure Brothers, Inc.

FIG. 33. A tone arm in which the head is free to move vertically, but the rest is rigid.

Static Balance. Static balance is a method used in slightly different ways by many tone arms to achieve balance. As shown in Fig. 34 there are two movable weights at the back end of the tone arm. The larger weight is used to balance the arm. After the cartridge is installed in the tone arm, the thumb screw attached to the large weight is rotated, causing the weight to move toward and away from the pivot. As the weight is moved away from the pivot, the front of the tone arm will move up, and as it is moved toward the pivot, the front of the tone arm will move down. By adjusting

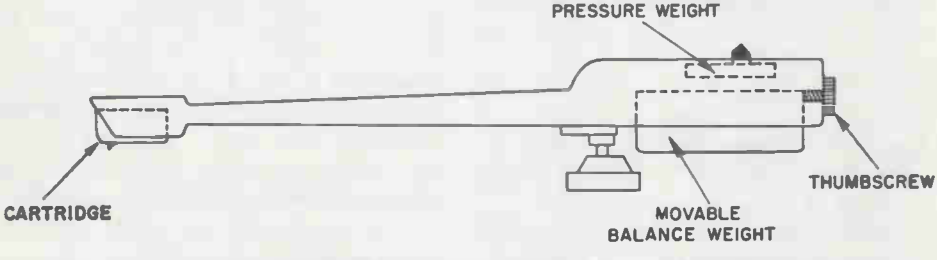
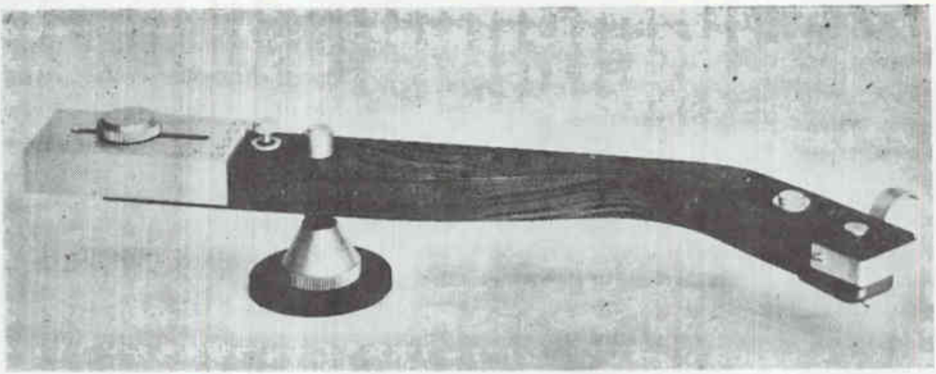


FIG. 34. A tone arm in which two movable weights are used to balance the arm.



Courtesy Grado Laboratories

FIG. 35. A tone arm in which one movable weight is used for balancing.

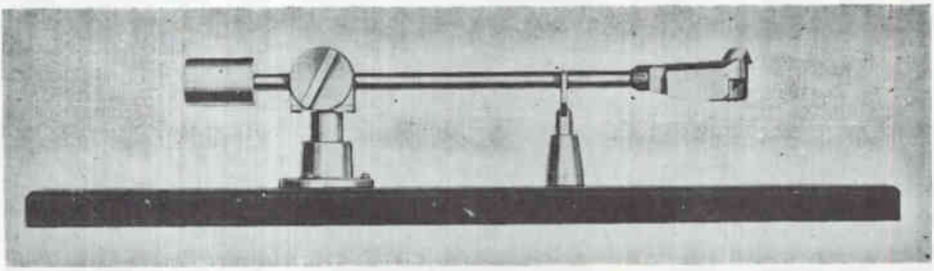
this weight to compensate for the weight of the arm and cartridge in front of the pivot, the arm can be made to balance vertically. Then, to provide for a specific stylus pressure, the small weight on top of the tone arm is adjusted toward and away from the pivot. This small weight generally provides any stylus pressure up to about 8 grams. Very often this second weight lever will be calibrated to show the pressure without the necessity of using a separate pressure gauge.

Besides the balancing arrangement shown in Fig. 34, several other variations are used. In many only one weight is used, and after balance is achieved, the weight is moved further toward the pivot to provide stylus pressure.

This method of balancing and pressure adjustment is quite satisfactory, providing the turntable is kept properly balanced. An example of an arm using this type of balancing system is shown in Fig. 35.

Dynamic Balancing. Dynamic balancing consists of balancing the arm with weights or springs and then using the downward pressure of a spring system near the front of the arm to provide proper stylus force. This type of balancing is unique in that turntable leveling is not necessary for proper tracking. An example of an outstanding tone arm using this type of balancing system is the Empire 98, shown in Fig. 36.

Spring Balancing. Spring-balanced arms use spring systems to achieve



Courtesy Audio-Empire

FIG. 36. A tone arm using dynamic balancing.

balance and stylus pressure by pulling down the part of the arm projecting behind the main bearing. Spring systems are almost always used in record changers.

Although it might at first seem that a spring system is not desirable since springs are generally affected by climatic conditions, the difference in the spring quality in a high quality tone arm and the spring quality in an inexpensive record changer is considerable.

RESONANCE

Like all other mechanical equipment, the tone arm has a natural period of vibration or resonance. At frequencies much below its resonant frequency, the entire tone arm tends to follow the groove, and the output from the cartridge will fall off. At the resonant frequency, the tone arm still moves, but it is about 90° out of phase with the stylus. This movement of the tone arm then adds to the movement of the stylus and causes a peak in the output at the resonant frequency. As the recorded frequency increases above the resonant frequency of the tone arm, the tone arm becomes unable to follow the groove and acts as a rigid arm, as it should. For a good tone arm, the natural resonant frequency should be well below the lowest recorded frequency. Most high-quality tone arms do resonate below 20 or 30 cps. A resonance below 20 cps is highly desirable.

In addition to the resonant frequency of the arm as a whole, other resonant frequencies appear for each small part or change in the arm material or change in the shape of the arm. Each of these resonant frequencies has the same effect as the resonant frequency of the arm as a whole. In order to keep the number of the secondary resonant frequencies as low as possible, the best tone arms are formed or cast as one continuous piece with either straight or smoothly curved sides. Generally, cast aluminum is used for tone arms, although some tone arms are made of wood. In addition, braces or struts are often cast into the arm or separately placed along the length of the arm to damp out resonances. Often rubber, nylon, or other such very low-resonance material is used along sections of the arm for the same purpose.

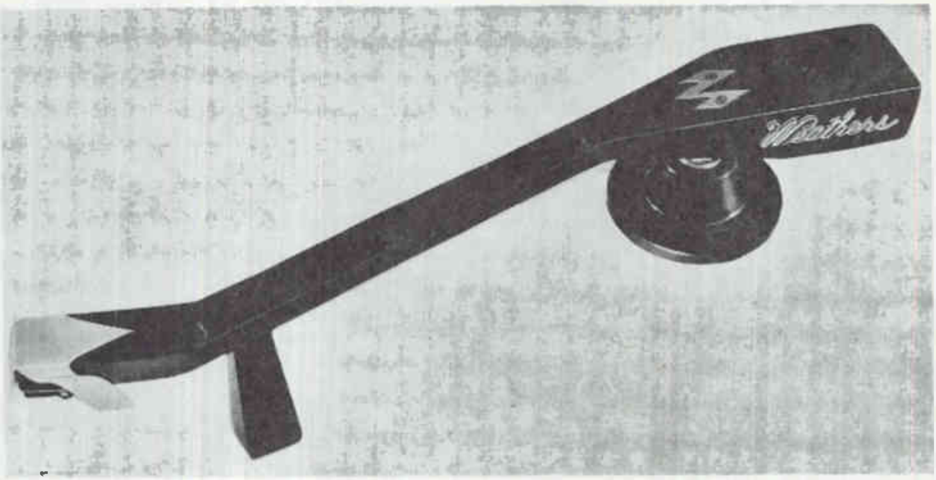
Damping. One method of combating resonance effects is by damping. Damping of a tone arm can be accomplished by using special thick fluids in the pivot mechanisms to provide a gentle braking action against rapid movement. The thick fluid also effectively damps the entire arm to reduce resonances and to minimize the effects of exterior vibrations. This is called "viscous damping." One type of viscous-damped tone arm is shown in Fig. 37.

INTEGRATED TONE ARMS

In some tone arms, the arm and cartridge are one inseparable unit. Since the quality of the tone arm can seriously detract from the cartridge quality, some manufacturers take no chances and offer both together. These are called integrated tone arms. Such arms cannot usually accommodate another type of cartridge. An example of such a combination is the Shure M216 in Fig. 34.

Many component-type tone arms and some changer tone arms have a separate plug-in head for the cartridge. This is quite convenient when changing cartridges or replacing the stylus when it becomes worn.

However, the use of separate plug-in heads arose from the time when both LP and 78-rpm records were popular.



Courtesy Weathers

FIG. 37. A tone arm in which viscous damping is used.

Cartridges designed for these different records could be used in separate plug-in heads. Then, when the owner wished to play either type of record, he could simply unplug the head on the tone arm and plug in another head with the appropriate cartridge. Since 78-rpm records are no longer made, such an arrangement is no longer necessary unless the user owns and uses a substantial collection of 78-rpm records. However, if this is the owner's first real acquaintance with high fidelity in his home, the vast difference in sound quality between modern stereophonic records and old 78-rpm records could, and almost always does, mean that the 78-rpm records will very shortly do nothing but gather dust!

WIRING

As explained previously, stereophonic cartridges have three or four output terminals. As might be expected, the tone arms designed for stereophonic record reproduction must also have either a three- or four-wire system. Actually, many tone arms have a five-wire system, the fifth wire being attached to the tone arm for hum-shielding purposes. The five-wire system is the safest, although satisfactory results can be obtained with either the three- or four-wire systems.

It is quite possible to use many of the very high-quality tone arms designed for monophonic reproduction for stereo. As mentioned, however, some high-quality monophonic-type arms cannot be used because of insufficient vertical compliance or excessive vertical pivot friction. In such cases, the arm should be replaced with a new arm, specifically designed for stereophonic reproduction. Otherwise, the stereophonic records soon would be ruined, and four or five records would pay for a new tone arm.

To use a tone arm designed for monophonic reproduction in any stereophonic system, it is necessary to change the wiring system. Monophonic tone arms utilize two or three wires, so additional wires will need to be added. Most of the manufacturers of the monophonic arms that can be used for stereo have conversion kits available that contain the necessary additional wires.

In the case of monophonic tone arms with plug-in heads, it is often necessary to replace both the head and the jacks or plug arrangement in the tone arm in order to provide the additional paths. Again, most manufacturers have conversion kits available which, although expensive, are almost always less expensive than an entirely new tone arm.

The physical construction of tone arms varies from one manufacturer to another. Some tone arms are perfectly straight with the head offset to reduce tracking error, while other tone arms may be bowed along the entire length to reduce the tracking error. A great number of arms are made of cast aluminum to reduce resonance, while others have successfully made use of non-resonant wood for this purpose. There is no "right" way to build a tone arm—it is only the results that count.

Lesson Questions

Be sure to number your Answer Sheet 29B-2.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. Why does stereophonic reproduction sound better than monophonic reproduction?

2. What is the name given to that characteristic of sound that describes its loudness or softness?

3. What do the Fletcher-Munson curves show?

4. What type of distortion in a high-fidelity system is most annoying to listen to?

5. Which record-equalization curve is used in making modern recordings?

6. How are the two channels applied to a stereo record?

7. Name three different types of magnetic cartridges.

8. Two different cartridges have specifications of $.95 \times 10^{-6}$ centimeters per dyne and 4×10^{-6} centimeters per dyne. What characteristic does this rating specify? Which is the better cartridge in this respect?

9. (A) If a magnetic cartridge is terminated with too high a resistance, what will happen to the high-frequency response?
   (B) If a ceramic cartridge is terminated in too low a resistance, what will happen to the low-frequency response?

10. What is the purpose of using cast-aluminum, wood, or viscous damping in a tone arm?

"WISHERS" AND "DOERS"

How often have you said, "I wish I had more money?" Thousands of times, possibly. But do you realize that if you are living in a town of, let us say, 5000 inhabitants, there are exactly 4999 others in your town who are saying exactly the same thing?

And yet, of these 5000 "wishers," only about 100 are going to do something about it. The others are going to continue being "wishers."

Now, any man who shows enough "get-up-and-go" spirit to undertake this course proves that he is not a mere "wisher." When you enrolled, you showed that you wanted to be a "go-getter." Your job now is to keep going forward on the road you have mapped out for yourself.

Every lesson in this course, every servicing job you work hard to get, is a step along this road. So don't let yourself wish that the lessons were easier, or that you could become successful without studying, or that jobs would come looking for you. Stay out of the class of the "wisher," and stay in the class of the "doer."

J. E. Smith

HIGH-FIDELITY SYSTEMS

30B-2

RADIO-TELEVISION SERVICING

PIONEER HOME STUDY RADIO-TV SCHOOL

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NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE NO. 30

☐ 1. **Introduction** .... **Pages 1-2**

A look at what this lesson will cover.

☐ 2. **Record Changers and Turntables** .... **Pages 2-8**

Here we take up the advantages and disadvantages of different types of record players.

☐ 3. **The Preamplifier** .... **Pages 8-19**

You will learn about the various circuits and controls in the preamplifier section of a hi-fi system.

☐ 4. **The Stereo Preamplifier** .... **Pages 19-28**

We take up various circuits and controls necessary or desirable in a stereo system.

☐ 5. **The Power Amplifier** .... **Pages 29-37**

Here we study the Williamson Amplifier and modern variations of it. We also take up voltage amplifiers and phase splitters.

☐ 6. **The Power Supply** .... **Pages 38-39**

You will study the requirements of power supplies for both monophonic and stereophonic systems.

☐ 7. **Loudspeaker Systems** .... **Pages 39-52**

You study various types of loudspeakers and learn how problems of high-fidelity reproduction are handled.

☐ 8. **Answer Lesson Questions.**

☐ 9. **Start Studying the Next Lesson.**

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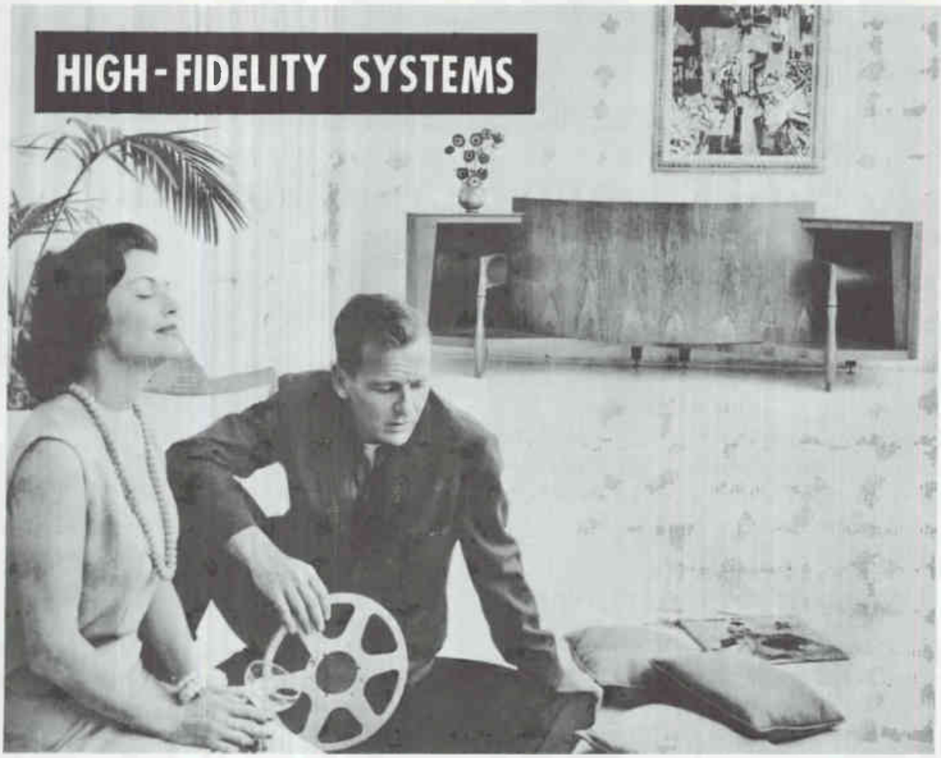
HIGH-FIDELITY SYSTEMS



IN THIS lesson we will continue our study of the individual components in a complete high-fidelity system. These components will include: turntables and record changers, preamplifiers, power amplifiers, loudspeakers, and loudspeaker enclosures.

As we look at each individual component we will, as before, study its construction, operation, and characteristics. We will examine typical examples of components made by different manufacturers to become familiar with the many different features they offer.

In addition to examining the individual components that we have not yet covered, we will also look at the over-all system—the combination of the components.

The sound from a high-fidelity system depends not only upon the quality of each individual component in the system but also on the choice of components that are suitable together. For example, a system might contain the best cartridge, tone arm, turntable, and amplifier, but if it has a speaker specifically designed for an infinite baffle installed in a bass-reflex enclosure, the sound can be quite poor.

In addition, a high-quality stereophonic system must not only have high-quality components throughout the system, but also loudspeakers must be positioned properly in the room for satisfactory reproduction. The components, then, must match each other, the musical tastes of the listener, and even the room in which they are used.

The best sounding high-fidelity systems are not necessarily the most expensive. Although it is normal, and naturally expected, that quality costs money, each component in a system must complement the good qualities of the other components and minimize the deficiencies. Remember, no high-fidelity component is absolutely perfect.

Record Changers and Turntables

As pointed out previously, records are by far the most popular source of musical reproduction in the home. In order to play a record, it is necessary to have a cartridge, a tone arm, and a means of holding the record and rotating it at the correct speed. We have already studied cartridges and tone arms. We will now look at some of the methods devised to rotate the record.

TYPES OF RECORD PLAYERS

There are three types of equipment available for playing records: separate turntables and tone arms, manual players, and record changers.

Courtesy Pickering & Co., Inc.

FIG. 1. A high-fidelity turntable is shown at A, and the same turntable with a tone arm is shown at B.

Courtesy Audiogersh Corp.

FIG. 2. A manual record player, the Miraphon XMS-210.

The turntable is simply a motor, a drive system, and a flat, round surface (or table) on which to place the record. A typical turntable is shown in Fig. 1A. Turntables are available either with or without a base; some are in kit form. In order to use a turntable in a high-fidelity system, a tone arm must be mounted on the motor-board or base in its proper position, as shown in Fig. 1B.

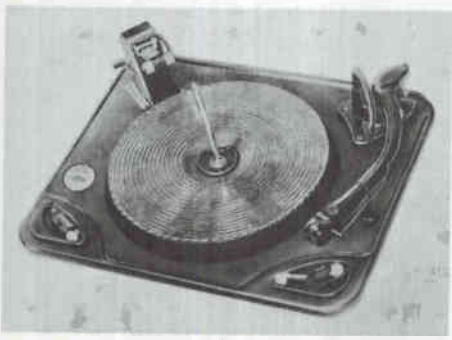
The cost of turntables varies quite a bit, but when the cost of the necessary additional tone arm is considered, this is usually the most expensive record player.

A manual player is between a changer and a turntable. That is, although it comes complete with a tone arm, it does not change records. Manual players generally fit into the price class between turntables and record changers. The manual player, too, is available with a base, or the base may be an accessory. A typical manual player is shown in Fig. 2.

The record changer changes records automatically. A typical high-quality record changer is shown in Fig. 3. Since you will study changers in other lessons of your course, we will not go into the details of operation here. All record changers are furnished with their own tone arm, which is an integral part of the changing mechanism. Some changers are sold with a base; the base is an accessory with others. Record changers are also sold in kit form. Many record changers are designed so that they can be used manually.

Generally speaking, turntables with separate tone arms offer the highest quality in a system. As may be expected, though, there are some record changers and manual players better than some turntables.

The choice between these three different methods of playing records depends largely on the listener. The automatic record changer was almost a necessity in the days of 78 rpm records with only three to four minutes of music available on each side of a 12-inch disc. LP records with up to 25 minutes on each side of the disc have made record changers largely unnecessary, except for background music. However, a great number of people, having used changers all their lives, still prefer them to manual players. Also, anyone who plays 78 or 45 rpm records still has good reason for buying a changer.



Courtesy Garrard Sales Corp.

FIG. 3. The Garrard RC-88 high-fidelity record changer.

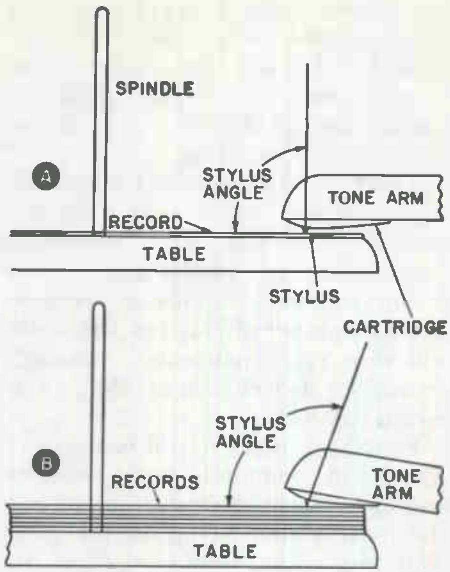


FIG. 4. How the angle of the stylus changes as records stack up on a changer.

It is not unusual to find both a changer, for background music and 78 and 45 rpm discs, and a turntable for serious listening, in a high-quality system.

DISADVANTAGES OF CHANGERS

There are a number of drawbacks to automatic changers that should be seriously considered.

First, loading records on a changer can often become quite a chore, depending on its design. This is especially annoying when playing a single LP record that could be more easily handled on a turntable. The complexity of loading a changer varies from model to model.

Second, as the records pile up on a changer turntable after playing, the stylus comes down on each succeeding record at a different angle. This not only increases the wear of both stylus and record, but will increase the cross talk when playing stereo records. This effect is shown in Fig. 4. In Fig. 4A, when one disc is being played, the stylus angle is correct; in Fig. 4B, it is quite evident that the stylus angle has changed considerably as the records stack up on the table. Of course, not all changers are as bad as shown in this illustration.

Third, in most record changers, the center spindle stands still while the turntable rotates. This will cause friction at the center hole of the record and tend to enlarge the hole. After a number of playings the record will then rotate off-center, causing a "wow," or slow change in pitch, as the record rotates.

Fourth, in older record changers, it was not uncommon to find a considerable increase in the stylus pressure as the records stacked up on the table. This particular disadvantage of the changer has largely been defeated in recent changer designs although the pressure still tends to increase. Even when the pressure does not seriously increase, most record changers require a higher stylus pressure than separate component arms do, since the tone arm is a part of the changer and must actuate the cycling mechanism. Because of the fact that the arm is a part of the mechanism, it tends to transmit noises or vibrations originating in the changer to the cartridge and thus through the entire reproducing system.

These disadvantages vary in seriousness depending on the over-all quality of the changer. As pointed out, it was almost necessary to have an automatic record changer to play 78 rpm records, especially for listening to lengthy forms of music such as symphonies, operas, or stage plays. Otherwise, it would have been necessary to interrupt the music and change the record every three or four minutes. The advent of the LP record eliminated this necessity, and the changer could then provide hours of relatively uninterrupted music. However, the LP record imposed what is probably the most serious disadvantage on a record changer. That is, when lengthy music, such as just mentioned, is recorded on an LP, it is continued from one side to another. Thus, when playing such music on a record changer it is necessary to turn the record over to hear the end of the musical selection. The only advantage of the record changer then becomes a disadvantage since it is much easier to flip over a record when using a turntable than when using a changer.

DISADVANTAGES OF MANUAL OPERATION

Although a turntable and tone-arm combination are inherently capable of causing less damage to the record, it is necessary to exercise much more care when using them. Accidentally jarring the tone arm during play, or carelessly setting the arm to start play invariably results in scratching the record. The record changer, of course, is less pt to damage records this way since manual operation of the tone arm is unnecessary. This is one reason both a turntable and changer are included in some high-fidelity systems, particularly when children may play the records.

Manual players are generally in between turntables and record changers in both quality and price. A manual player is actually a turntable with which the manufacturer has supplied a tone arm. Very often the turntable and tone arm are not available separately although some companies offer their turntables and tone arms both separately and together, and the combination may be offered at a lower price.

No matter which type of unit is used to play records, it is a "negative" device just as the tone arm is. That is, it should not directly contribute anything to the signal picked up by the cartridge. Unfortunately, but not surprisingly, all record players do contribute to the signal. In particular, they may introduce three undesirable effects, wow, flutter, and rumble. Record players are rated in their specifications according to the amount of wow, flutter, and rumble they introduce. Let's look at these characteristics now.

RUMBLE

The low-frequency vibration and noise transmitted to the cartridge by the rotating motor and associated parts is called rumble. The term is quite descriptive, since the vibrations do cause a rumbling sound to be mixed with the desired signal. The rumble figure indicates just how much noise is transmitted to the cartridge.

This specification, which is given in minus db, indicates how far below the output level of the cartridge the rumble level is for a groove modulated at a given velocity. Therefore, the higher the figure the better. Unfortunately, the rumble figure is affected by the cartridge response, by the arm characteristics, by the reference level chosen, and by the measurement method. These conditions are rarely stated in the specifications, and the figure may therefore be meaningless. It can, of course, be used to compare the rumble levels of different turntables made by the same manufacturer.

Since broadcast stations use turntables for recorded music and programming, the NARTB (National Association of Radio and Television Broadcasters) has specified a required rumble rating of −44 db for turntables used in broadcasting. Most turntables offered for the high-fidelity market feature rumble figures exceeding this minimum specification.

The rumble transmitted to the cartridge is generally considered to be of two types: horizontal and vertical. Before stereophonic records, the vertical rumble content of a turntable was not important, since the cartridge was specifically designed not to be sensitive to vertical movement. However, since a stereophonic cartridge responds to both vertical and lateral movement, any vertical rumble will be reproduced along with the lateral rumble.

As might be expected, some very high-quality turntables designed for monophonic reproduction have excessive vertical rumble. All modern turntables, since the advent of stereophonic records, are specifically designed with low vertical and lateral rumble.

Isolating Motor Vibrations. Since rumble is generally due to vibrations transmitted from the motor, many methods have been utilized to prevent the motor vibrations from reaching the cartridge. Practically all high-quality units now have the motor suspended by rubber or some other resilient material rather than bolted directly to the turntable base or motor plate. Such a suspension method is shown in Fig. 5. Springs are also used for this purpose, and sometimes a combination of rubber cushioning and springs is used.

To further isolate the cartridge from the motor vibrations, the turntable bearing must be properly de-

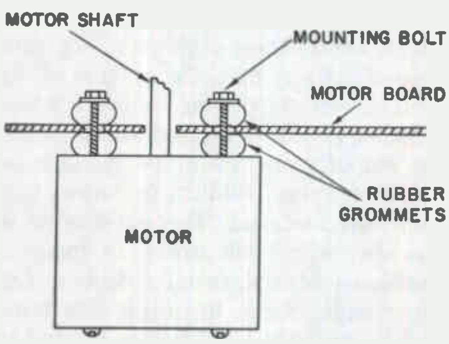


FIG. 5. One method of suspending the motor board to reduce vibration.

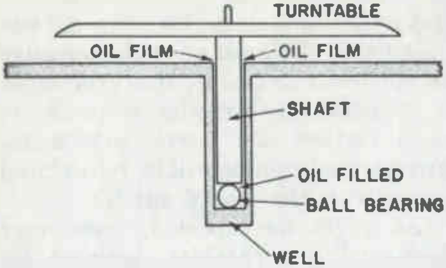


FIG. 6. How to reduce vibration with an oil film.

signed. One popular method is shown in Fig. 6. An oil film covers both the ball-bearing and the turntable shaft, providing damping and, of course, reducing friction. Generally the shaft and well are machined so closely that the lubricant will also act as a viscous damping element similar to the viscous damping employed in some tone arms, described previously.

Drive Systems. Much thought has gone into drive systems for turntables in an effort to reduce rumble as well as to provide a constant speed of rotation. Probably the most popular type of drive system is the use of an idler wheel with a stepped motor shaft, as shown in Fig. 7. The different diameter sections on the end of the motor shaft, shifted into position with a lever, provide the different speeds. Of course, if the turntable is designed to operate at only one speed (33⅓ rpm) then these "steps" are not needed. At any rate, the portion of the motor shaft contacting the idler wheel is either precisely ground and polished for smooth operation, or it may be made of nylon, rubber, or some other such soft material. The outer edge of the idler wheel will always be made of resilient material, usually rubber. The inner edge of the turntable rim must also be smoothly polished or ground to reduce noise and provide constant speed.

By using systems and methods such as these, there is isolation between the vibration of the motor and the turntable, and hence the cartridge will not as easily pick up the motor vibrations.

Another popular drive system is the belt drive, shown in Fig. 8. As shown in this illustration, an endless belt couples the motor shaft to the outer rim of the turntable. A step system is used for changing speeds. There are many variations of this system. For example, instead of having the belt around the motor shaft as shown, a system could have the belt around an idler wheel which would, in turn, be driven by a wheel on the motor shaft. Speed changes would be made by shifting in idler wheels of different diameters.

Motors. The amount of rumble in any turntable system not only depends on the quality of the drive system parts, the method of supporting the turntable, and the isolation between the motor and the turntable, but also on the quality of the motor itself. The rotor of the motor must be precisely balanced, not only to provide constant speed, but to keep the vibrations to a minimum.

Many different types of motors are used in record-playing equipment. Generally inexpensive phonographs

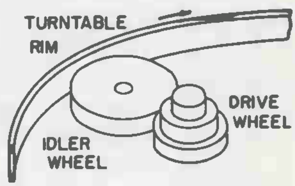


FIG. 7. A popular drive system. The stepped idler wheel provides for different speeds.

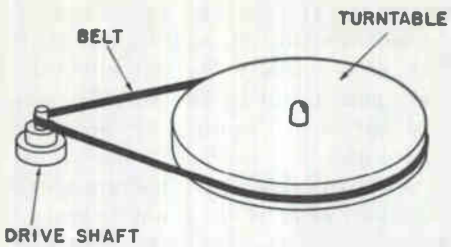


FIG. 8. A belt-drive system.

have 2-pole motors. However, 2-pole motors are totally unsuitable in any high-fidelity application because of their high rumble and poor speed consistency. The only motors capable of proper operation for high-fidelity turntables are 4-pole induction motors and synchronous motors. The 4-pole motor is amplitude sensitive, whereas the synchronous motor is frequency sensitive. That is, the exact speed of the 4-pole motor will depend on the amplitude of the line voltage, whereas the speed of the synchronous motor will depend on the frequency of the line voltage. Synchronous motors are therefore inherently capable of more constant speed. Furthermore, the frequency of vibration depends on the type of motor, and is predominantly 30 cycles per second for the 4-pole induction motor and 20 cycles per second for synchronous motors. Since the rumble frequency is lower for the synchronous motor it is less undesirable, because few speaker systems can reproduce 20 cycles per second. However, as might be expected, a well-designed and built 4-pole motor can be better than a poorly designed and built synchronous motor. The rumble or vibration of either type of motor depends on its design and the care in which it was constructed and balanced.

WOW AND FLUTTER

Wow is a variation in speed that occurs less than 10 times per second; flutter is a variation in speed that occurs more than 10 times per second. The wow and flutter specifications are given in per cent, and indicate the percentage of change in speed. The NARTB specifies that the total wow and flutter should be plus or minus .2% or less.

A great number of record players actually have a much higher wow and flutter percentage than .2%. However, unless it is unusually high, wow and flutter is not as important as rumble. Variations in speed, up to about .5%, are usually detectable only by trained ears, and then only during sustained passages in music where the frequency of the tone does not change, which seldom occurs.

When excessive, however, wow and flutter can be quite annoying. Since wow is a slow change in speed, it is more apt to affect the low and medium frequencies, although flutter will affect them also. Excessive flutter will generally cause a blurring of mid and high frequencies, and is considered more annoying than excessive wow by many people.

If a record player constantly plays at the wrong speed, it will not cause wow and flutter, but it will change the pitch of all of the music.

In order to reduce wow and flutter and maintain constant speeds, it is important that all parts of the drive system be accurately constructed. The diameters of the motor shafts, idler wheels, and turntable especially must be accurate, since the diameters determine the speed of rotation.

The turntable itself is generally extremely heavy so that the flywheel effect will keep it rotating at the correct speed despite any slight momentary changes. Just how heavy the turntable must be depends on the rest of the system. The comparative qualities of record-playing units cannot be determined simply by measuring the weight of the turntables.

Courtesy Weathers Industries

FIG. 9. The Weathers MC-1 turntable.

SPECIAL FEATURES

There are innumerable features and accessories available on turntables, record changers, and manual players. As with most other mechanisms, many of these features are unnecessary accessories. Some do contribute to ease of operation, while others are simply selling points. As in choosing an automobile, the choice of accessories depends directly on the user. However, a record-playing unit should never be chosen for its accessories. Accessories do not determine quality, but can actually be detrimental if they contribute to the rumble, wow, and flutter of the unit, or shorten its useful life.

One turntable that deserves special mention, since it does not operate in the same manner as most other high-fidelity turntables, is the Weathers turntable shown in Fig. 9. It has a very small 12-pole synchronous motor, which has a natural vibration frequency of 10 cycles per second. The drive system consists of a small, pure gumrubber wheel placed on the motor shaft directly driving the inner rim of the turntable. The turntable speed is determined by the distance between the motor shaft and the turntable shaft. Since the motor is light, the turntable is also light, made of drawn aluminum. Despite the unorthodox system, the rumble, wow, and flutter easily meet high-fidelity standards.

The Preamplifier

In order to produce sound in the high-fidelity system it is necessary to drive the loudspeaker system with the signal from the record or other source. You have learned previously that dynamic loudspeakers are power-driven devices, and it is generally considered necessary to have at least

Courtesy Harman Kardon

FIG. 10. A complete amplifying system, the Harman Kardon A230. It contains on one chassis, a two-channel stereo preamplifier and two power amplifiers.

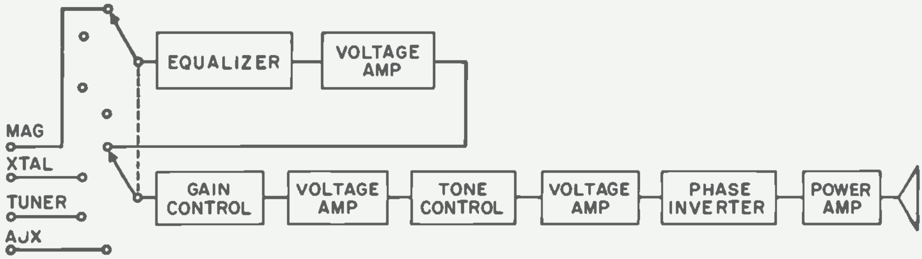


FIG. 11. Block diagram of a typical amplifying system.

10 watts of power available for even the most efficient loudspeaker system. The phonograph cartridges which we have studied, however, are voltage-producing devices and produce very little power. Even a highly efficient ceramic-type cartridge might develop only about one volt (when loaded with 1 megohm), and this is the equivalent of only .0000001 watt! The output of a high-quality magnetic cartridge would be a very small fraction of even this minute power.

The main job of the amplifying system, then, is to build up this very small signal to one sufficiently large to drive the speakers. A typical amplifying system is shown in Fig. 10.

In addition to this amplifying job, the amplifying system is also called upon to modify the output of the cartridge. As you have learned in your previous studies, one of the first jobs the amplifying system must do is to equalize the output of the cartridge, since the record is recorded with reduced bass and preemphasized treble.

In addition to this equalization, it is also necessary to provide other modifying characteristics. First, the tastes of listeners vary considerably; some like emphasized high frequencies, while others prefer more bass. Besides, the acoustics of the rooms in which the high fidelity is heard vary considerably. Even the largest living room cannot have the same acoustics as the auditorium in which the record was originally produced.

Clearly then, to satisfy the listener, because of his tastes, the quality of the recording, the room acoustics, and the recording acoustics, tone controls of some sort are necessary. Also, a volume or gain control must be provided in all amplifying systems.

A block diagram of a typical monophonic amplifying system is shown in Fig. 11. As shown here, the signal from the various input sources is first fed to a selector switch and then, according to the type of source, to the other sections. If the source is a magnetic cartridge, it is necessary to feed the input signal to an equalization network and then to at least one more amplifier stage, since equalization lowers the over-all signal level. Ceramic cartridges, tuners, and other such high-level devices can usually be fed as shown, directly to the gain control, although they too may be further amplified before being fed to the gain control. Because of the natural frequency response of ceramic or crystal cartridges, which have a loss of high frequencies, their output does not need to go through the equalizer. The output of the voltage amplifier used with the magnetic cartridge can be fed to either another voltage gain stage or to the gain control.

From there, the signal progresses through one or more voltage-amplifier stages, and then to a tone-control network. This will generally contain both a bass and a treble tone control. Since tone-control networks reduce the over-all level, it is generally necessary to build the signal back up again with more voltage-amplifying stages. Finally, the signal is fed to a phase-inverter stage, and then to the power-output stage. Sometimes another amplifier stage will be used between the phase inverter and the output stage. The secondary of the output transformer will drive the loudspeaker system.

The stereo amplifying system, since it must handle two separate signals, will contain a duplicate of each of these sections plus some additional controls.

All the stages shown in Fig. 11 up to the power amplifier stage are called the "preamplifier." It is evident from Fig. 11 that the preamplifier in a high-fidelity system does more different jobs than any other portion of the system. Since the preamplifier, or preamp as it is commonly known, contains most of the means of controlling the system operation, it is often called the preamplifier-control unit.

It is called a "preamplifier" because it must provide a preamplification of the very low signals fed to it before they can be applied to the power amplifier. In the early days of high fidelity, when magnetic cartridges first appeared, a separate small chassis containing one or two tubes was available specifically for this purpose. The unit often did not contain controls. However, with universal use of low-level magnetic cartridges, most modern preamplifier-control units do not require such an auxiliary preamplifier unit.

Besides amplifying the signal, the preamplifier must equalize the signal delivered to it. That is, it must restore the natural balance that was

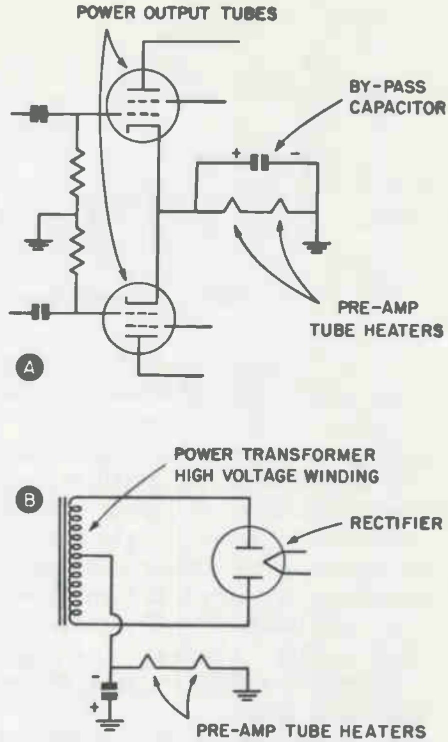


FIG. 12. Methods of using dc to heat the preamplifier tube filaments.

deliberately introduced in the recording process.

Despite the present universal use of the RIAA curve in recording, many preamplifiers are still available with other switch-selected equalizations for anyone wishing to play older records.

As mentioned previously, the preamplifier must also provide a means of tone control and gain or volume control, and it must provide a selector switch for choosing between several available sources.

In addition to these necessary functions, the preamplifier may also provide other features such as switches and networks to reduce rumble or scratch, equalization and preamplification for tape heads, a means of monitoring or feeding a tape recorder, etc. Let's take up each of the functions of the preamplifier.

AMPLIFICATION

Since the output of a ceramic or crystal cartridge varies from .5 to 1 volt, special preamplification is not necessary with them. However, the 2 to 20-millivolt output of magnetic cartridges requires considerable amplification. The output of magnetic cartridges varies from type to type, but generally runs from 2 millivolts for some stereo units to 30 millivolts for some monophonic types. There are some stereophonic cartridges with outputs as low as 1 millivolt. With such extremely low-level cartridges, step-up transformers are generally required before the signal can be applied to the preamplifier.

The power amplifier section of the amplifying system generally requires from one-half to 2 volts input for full output. Since the output of a magnetic cartridge averages about .005 volt, it is easy to see that a gain of at least 400 is necessary to satisfy the input sensitivity of 2 volts for a power amplifier. Furthermore, in order to provide equalization and tone control it is necessary to have much more gain than this. The over-all voltage amplification of a preamplifier is generally at least 10,000 times to provide for the losses in equalization and tone control systems.

Hum and Noise. The problems of obtaining high gain would not be particularly complicated except that hum

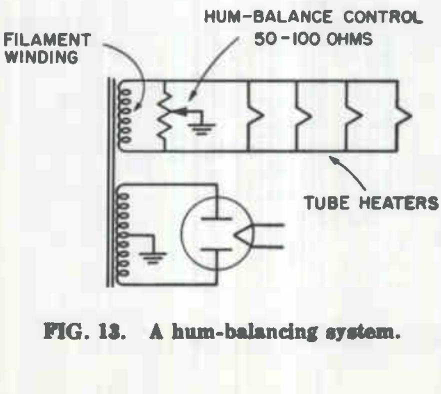


FIG. 13. A hum-balancing system.

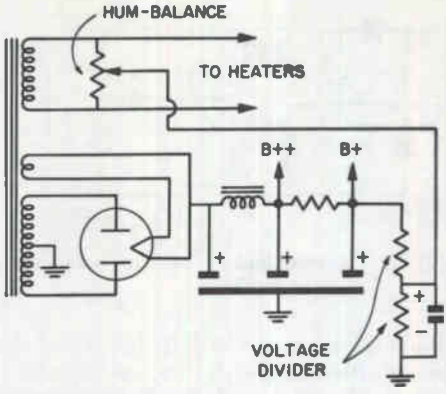


FIG. 14. Another method of reducing hum.

and noise enter the picture. To be completely inaudible, the total hum and noise should be at least 50 db below the signal level.

There are many methods used to reduce hum in preamps. We will look at the most popular ones.

One of the best is to supply a direct current instead of an alternating current to heat the tubes. This can be done with a separate rectifier-filter circuit, or in the case of a preamplifier and power amplifier on one chassis, it is often possible to utilize the total dc current drawn by the power output tubes or the entire amplifier to heat the preamplifier filaments. In this case, all of the tubes in the preamplifier section may be heated by dc or just the first tube. Examples of this method are shown in Fig. 12.

It is often possible, by careful design, to reduce the hum to an acceptable level simply by providing a hum balancing system such as shown in Fig. 13. This will provide perfect balance between the two halves of the tube filament circuits, and the hum will be largely cancelled out.

Another method of reducing hum is to apply a positive bias to the filament supply, as shown in Fig. 14.

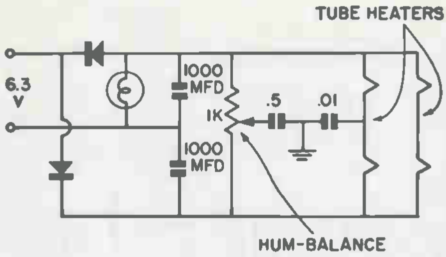


FIG. 15. A combination of hum-balancing methods.

This can be done either by using a voltage divider as shown, or by connecting the slider of the hum-balancing potentiometer to the bypassed cathodes of the power output tubes. Biasing by this method generally provides an additional improvement over the hum balancing.

Sometimes a combination of these methods is used. Fig. 15 shows such an application in the Dynaco stereo preamp. Here the heaters are supplied dc through a voltage-doubler supply, and a hum-balancing potentiometer further reduces hum.

Most of the noise produced in the preamplifier stage comes from the tube itself. To combat this problem many types of tubes have been especially developed for use in low-level, high-gain stages. When these special low-noise tubes are not used, the tube that is used is generally carefully selected for its low noise content.

Current flow through a resistor can produce thermal noise. Because of this, it is not uncommon to find high-wattage or special metal-film type low-noise resistors in the first stage.

Since the low-level signal usually passes through a switch or even a control in the first few stages, many preamps use special switches with gold-plated contacts and special "low-noise" potentiometers.

No matter which of these different methods or combinations of methods is used in the first stage, it is always of utmost importance to observe careful wiring techniques. Usually all ground points in at least the first stage are brought to a single ground point on the chassis to prevent hum-producing ground loops. The tubes in the first stage are invariably shielded with external metal shields, and the chassis itself may be constructed so as to provide shielding.

EQUALIZATION

When you studied records and cartridges, you learned that it was necessary to modify the signal, so the output of the record does not have a flat frequency response. According to the RIAA recording curve, shown in Fig. 16A, the low frequencies are suppressed, and the high frequencies are emphasized. Thus, the equalizer net-

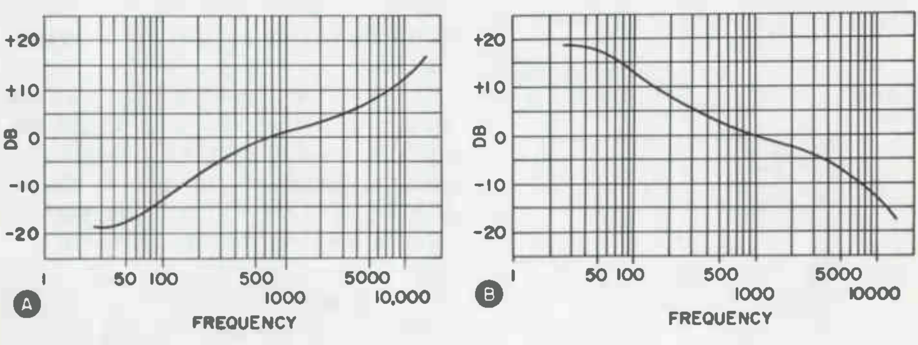


FIG. 16. The RIAA recording and playback curves.

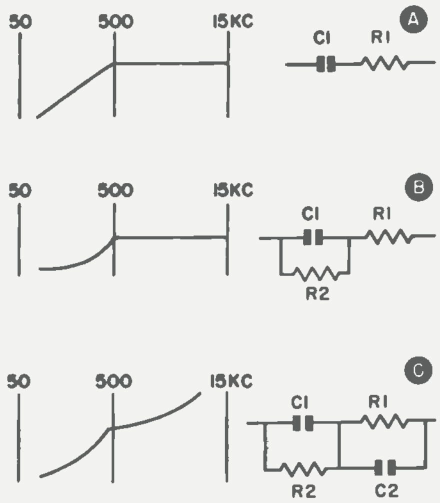


FIG. 17. How the frequency response can be controlled.

work of the preamplifier must have a response opposite that of the RIAA recording curve. This playback curve in Fig. 16B indicates that the equalizer must provide bass boost and treble cut. We will now investigate how this can be done.

As can be seen in Fig. 16, and has been explained previously, the RIAA recording curve reduces bass response below 500 cycles at the rate of 6 db per octave, and increases high-frequency response above 1000 cycles at a rate of 6 db per octave.

This rate of 6 db per octave is used because it is inherent or natural in certain audio component combinations and thus can be easily achieved.

As can be seen in the curves of Fig. 16, the bass response is not truly 6 db per octave below 500 cycles. If this rate of attenuation were kept all the way to the lowest limit of audio response, the reduction at 20 cycles would be approximately −28 db. When playing back the record, so much emphasis or boost would be needed that difficulties would be encountered with 60-cycle hum and turntable rumble in the 20-30 cycle range. To minimize these difficulties, the 6 db per octave attenuation is somewhat reduced below 100 cycles.

Fig. 17 shows how it is possible with simple components to control the circuit response.

In Fig. 17A, a capacitor is connected in series with a resistor, and thus the combined impedance of the circuit will change with frequency. The lower the frequency, the more opposition there will be to the signal, since the capacitor reactance will increase with a decrease in frequency. Thus, the frequency response of the circuit will be as shown, and the attenuation rate will be approximately 6 db per octave. The point of turnover, or the point at which the attenuation of the lower frequency begins, depends on the exact value of C1 and R1. If the reactance of C1 is equal to R1 at 500 cycles, then the attenuation will begin at that point.

Since we want to flatten the slope of this response curve below 100 cycles, we can simply connect a resistor R2 across the capacitor C1. This will result in the curve of Fig. 17B.

By connecting this resistor in parallel with the capacitor, the signal below 100 cycles will divide between them, and since the signal will seek the path of least resistance, it will pass through R2, which remains constant at all frequencies. Thus, the attenuation slope will be flattened out as is desirable.

It is evident that resistor R2 and capacitor C1 will take care of the low-frequency compensation. To provide for high-frequency compensation, all we need to do is place a small capacitor across resistor R1. As the frequency increases, capacitor C2 is reduced in reactance and thus it becomes the "easy" path for the signals. The result is that as the frequency is increased, the attenuation is decreased,

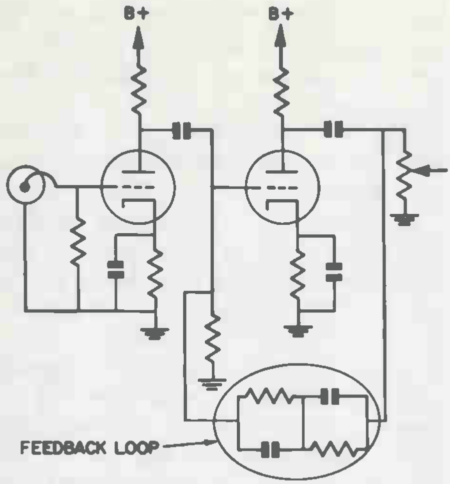


FIG. 18. A feedback network for equalization.

and the resulting curve is shown in C of Fig. 17.

Notice that this resulting curve in Fig. 17C is like the RIAA recording curve. Therefore, in order to have the response of the preamplifier the same as the RIAA playback curve, the network we have just discussed must be used as a feedback network as shown in Fig. 18. The feedback will vary the gain of the stage according to frequency. Since the network has a rising response at high frequencies, more high frequencies will be fed back, and the gain of the stage will be reduced, resulting in the necessary high-frequency roll-off. Similarly, the network will feed back little low-frequency signal, and the stage gain will then be maximum at the low end, resulting in the necessary low frequency boost. The frequency response of a stage with a feedback loop is exactly opposite the frequency response of the feedback network itself.

A feedback loop such as we have just discussed is the most popular method of equalization, since feedback results in reduced distortion, noise, and hum. However, this is not the only way that equalization can be accomplished in a preamplifier. It is also possible to utilize what is known as a "bypass" or "shunt" method. In this method a network is inserted between two amplifying stages as shown in Fig. 19. As shown here, two RC networks are shown connected from the signal path to ground. By the correct choice of component values, the mid and high frequencies can be bypassed to ground, and the correctly balanced resultant signal will be fed to the next stage. Naturally, the same component values cannot be used in this method as was used in the feedback method.

As explained previously, the RIAA curve is not the only one that has been used in making records. It is possible by changing the component values in both types of feedback network to change the cross-over frequencies (frequencies at which the slopes begin) and the rate of attenuation. By doing this, the various recording curves that have been previously used can be exactly duplicated. When a preamplifier features selection of different recording curves, some or all of the network component values are changed by switches to provide the different curves.

Such a system is shown in Fig. 20. Notice that two switches are used, one

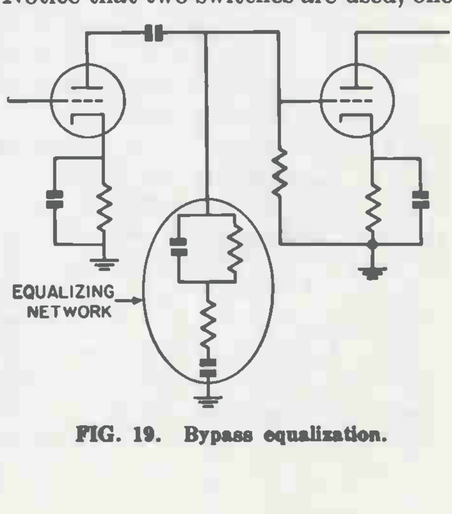


FIG. 19. Bypass equalization.

for bass equalization, and the other for treble equalization.

These equalization networks we have discussed refer only to systems utilizing magnetic-type phonograph cartridges. A crystal or ceramic type cartridge does not need such elaborate equalization. The natural frequency response of the crystal cartridge is characterized by a loss of high frequencies. Therefore, it is only necessary to connect a certain resistance in parallel with the crystal cartridge in order to get an output that follows the RIAA curve. The necessary resistance generally runs from 2 megohms to 4 megohms, and serves to boost the low-frequency response.

However, these networks are not designed to control the tone of the system in the most satisfactory manner. The main purpose of the equalization is to compensate for the record characteristics, and the attenuation slopes and cross-over points are far from the best in controlling tone so far as the over-all listening is concerned.

Another method of controlling tone in a multi-speaker reproduction system is to use attenuator pads connected to the mid and high-frequency speakers, and thus the output of the loudspeaker system itself could be controlled in a frequency-selective manner. However, this too is not ideal since the rate of attenuation would depend on the pad characteristics, and the frequencies that could be controlled would depend on the frequency response of the cross-over networks and the speakers.

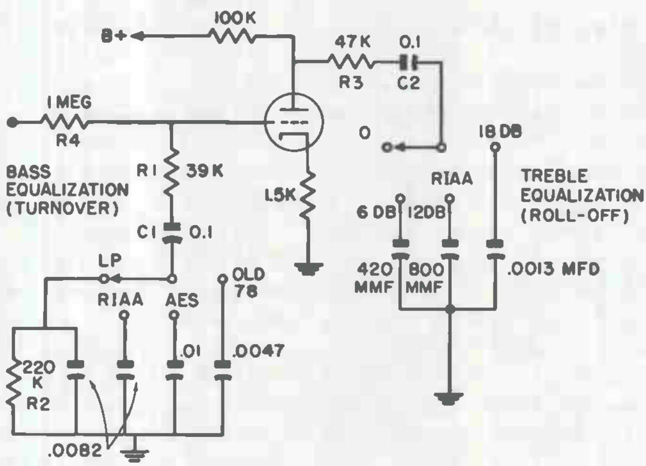


FIG. 20. A preamplifier in which different equalization networks can be selected for different recording curves.

TONE CONTROLS

Control of the frequency response of a reproducing system can and, in fact, is actually accomplished in several sections throughout the system. For example, it is evident that we could control the tone of the system by choosing different equalizing networks such as we have just studied.

In order to control the tone of a system, with respect to both the frequency and rate of attenuation, specialized tone control networks are used in the preamplifier section. Both

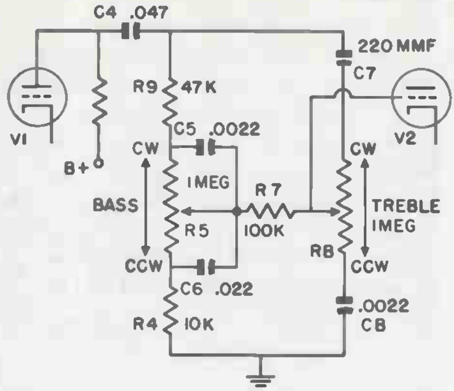


FIG. 21. A losser-type tone control circuit.

a bass control and a treble control are necessary for complete control of the system response.

Although there are many ways of changing the component values in a circuit to provide control of the frequency response, there are only two types of tone controls in common use: the "losser-type" and the "Baxandall" type. As might be expected, there are many variations of these circuits, most of which are simply changes in the individual component values.

R-C networks are used in both types of tone control circuit, with potentiometers as part of the networks. The R-C networks are the frequency-selecting devices, and the potentiometers, one for the bass and another for the treble, provide the control.

A typical losser-type tone control is shown in Fig. 21. As can be seen here, a network of resistors, capacitors, and potentiometers is connected between ground and a plate-to-grid signal path between two stages.

The values of the parts are chosen so that the attenuation of the low frequencies can be varied by the bass control and the attenuation of the high frequencies can be varied by the treble control. To reduce, or cut, the bass or treble response in relation to the mid frequencies, the attenuation is increased; to increase, or boost, the bass or treble in relation to the mid frequencies, the attenuation is decreased.

The tone-control network components values are usually chosen so that an essentially flat frequency response is obtained with the bass and treble control potentiometers set to their mid positions, and rotating the controls permits a variation in attenuation of from 20 to 40 db.

As can be seen in Fig. 21, the signal from tube V1 is applied through coupling capacitor C4 across both the bass and the treble tone control networks.

In the bass control circuit, most of the low-frequency signal will appear across the bass control R5, since its resistance is so much larger than R9 or R4. Capacitors C5 and C6 have little effect on the low frequencies because of their high reactances. The amount of low-frequency signal, then, applied to tube V2 will depend on the position of the bass control. The high-frequency signals applied across the bass-control network will divide between resistors R9 and R4, but will be bypassed around the bass control R5 by capacitors C5 and C6, whose reactance is low at high frequencies. Therefore, rotating R5 will affect only the bass frequencies and will have no effect on the high frequencies.

The treble control network operates

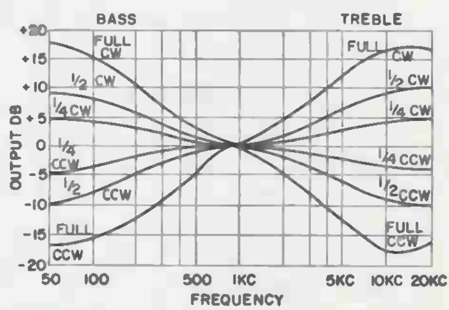


FIG. 22. Frequency response for circuit in Fig. 21 for different positions of the controls.

in a similar manner. High frequencies applied across this network will divide between C7, R8, and C8. Because the reactances of both C7 and C8 are low, most of the signal will be across R8, and therefore the high frequencies applied to tube V2 will depend on the position of the treble control R8. Low frequencies applied to this network will also divide between C7, R8, and C8, but because of the very high reactances of C7 and C8 at low frequencies, little signal will appear across R8. Therefore, the position of this control will not affect the bass frequencies.

Resistor R7 simply serves to decouple both networks.

The frequency response of such a losser-type tone control system is shown in Fig. 22 for different positions of the controls. Notice that the amplifier gain at the 1000-cycle mid-frequency point is essentially constant for any adjustment of the bass and treble tone controls. However, the frequency response above and below this 1000-cycle point changes according to the adjustments of the tone control. As can be seen, the boost and cut at both frequency extremes exceeds 15 db. As mentioned previously such boost or cut is rarely ever used but is inherent in the type of control that is easily constructed.

This tone control arrangement is actually quite satisfactory for most applications. However, it can be seen in Fig. 22 that it is not possible to boost frequencies, say below 100 cycles or above 10,000 cycles, without considerable boosting of frequencies between these points and 1000 cycles. Such a "hinge" arrangement of the tone controls can often be undesirable in high-fidelity reproduction, particularly when high-quality speakers are used. Most modern, high-quality speaker systems have very satisfactory response down to 100 cycles and up to 10,000 cycles. However, it is often

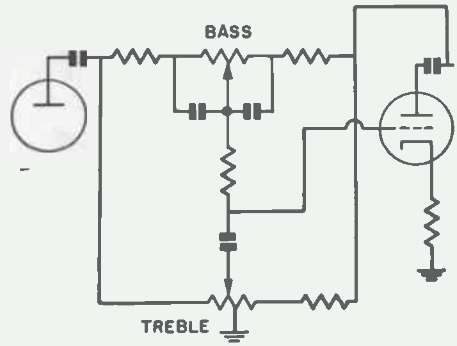


FIG. 23. A "Baxandall" type tone control.

desirable, particularly when the overall gain is turned down, to emphasize bass response below 100 cycles and emphasize treble response above 10,000 cycles. It is evident from the frequency response of the tone control network shown in Fig. 22 that such boosting would be impossible without boosting other frequencies between these limits and the center 1000-cycle frequency. Unfortunately, boosting of frequencies between 100 and 1000 cycles will most often cause a very "boomy" sound, particularly on human voice. Similarly, modern tweeters do not normally require any boosting below 10,000 cycles, and boosting between 1000 and 10,000 cycles can very often cause a shrillness or harshness to the sound or, even worse, emphasize record noise.

To provide better tone control, in relation to these problems, many modern high-quality preamplifiers use a feedback type of tone control—similar to the feedback equalizers previously discussed. One such very popular type tone control is the "Baxandall" (named after the designer) shown in Fig. 23.

Notice that there is similarity between this tone control and the losser type. Some circuit values are different but the main difference between the tone controls is that this

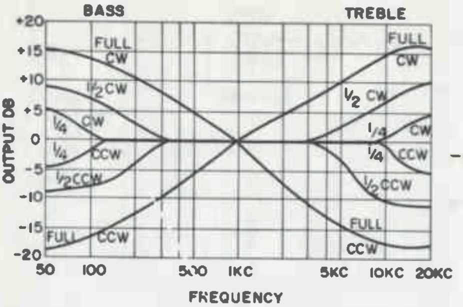


FIG. 24. Response for the circuit in Fig. 23 for different positions of the tone controls.

Baxandall type, as shown in Fig. 23, is connected between the output of the stage and its input. Thus, from the feedback type connection it is evident that this circuit will not only provide control of the frequency response but will also automatically insert negative feedback, which will lower distortion.

The Baxandall type of tone control is characterized by the fact that the point at which boost or cut is started depends on the rotation of the controls. This is clearly seen in Fig. 24. Notice that at a slight rotation of the bass control, the response below 50 cycles is affected, while at even more increase or decrease of the control the response at 100 cycles is affected. The same sort of situation occurs at different rotations of the treble control.

It is evident from the frequency response curve in Fig. 24 that it is possible to boost frequency response below 50 cycles or above 10,000 cycles with a feedback type tone control and yet not affect the other frequencies which would cause an unnatural sound.

Generally speaking, the Baxandall or some similar feedback tone control system is desirable. However, low and medium cost reproducing systems can effectively use the losser-type control with little audible effect. High-quality systems utilizing two or three-way speaker systems should utilize a preamplifier featuring the feedback tone control system.

LOUDNESS CONTROLS

As you have learned, the frequency response of the ear changes with loudness level. As the loudness level is reduced the ear is most sensitive to the mid-frequency range, whereas it is less sensitive to high frequencies and even less sensitive to low frequencies. To compensate for this characteristic of the ear, many preamplifiers use a special control, called a loudness control, which will automatically boost the low and high frequencies as the over-all loudness of the system is reduced.

There are many types of loudness controls in use. One typical type of loudness control is shown in Fig. 25. Notice that networks of resistors and capacitors are connected from taps of this control to ground. The parts values are chosen so that the frequency response of the control varies according to the position of the slider. The response of such a control is shown in Fig. 26. It is evident from the response curves in Fig. 26 that as the control is turned counterclockwise, as it normally is to turn down the gain of the system, the mid-frequency re-

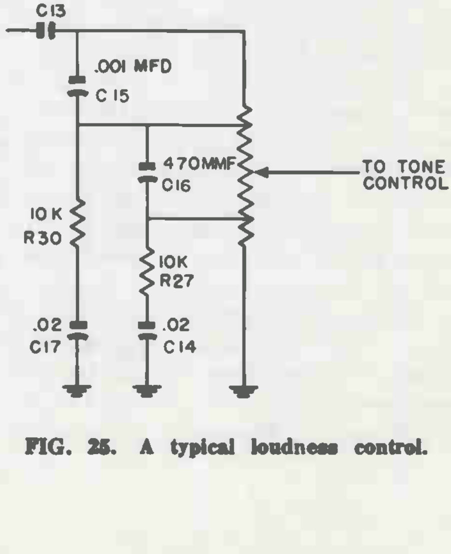


FIG. 25. A typical loudness control.

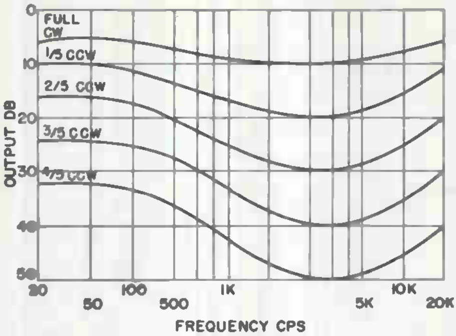


FIG. 26. Response of the circuit shown in Fig. 25 for different positions of the loudness control.

sponse is reduced more than the low and high-frequency response. The similarity of this control circuit and the Fletcher-Munson curves discussed in a previous lesson is quite evident.

Some preamplifiers utilize a loudness control such as the one shown in Fig. 25 as the only gain control in the circuit, whereas other preamplifiers feature both a loudness control as shown here and a standard gain or volume control.

In addition to this continuous type of control with additional circuits connected to taps, there are other types of loudness controls. Fig. 27 shows three other types often used. The circuit in Fig. 27A simply shows a single path from the volume control with an R-C network connected from the tap to ground. This is a simple ABC (automatic bass compensation) circuit in which the bass response of the unit is increased as the gain is turned down. The treble response is not increased with this circuit.

Fig. 27B is similar to Fig. 27A in that a single tap is used, but additional high-frequency compensation is inserted by the R-C network connected from the top of the control to the switch. Thus, the circuit of 27B offers high-frequency compensation as well as low-frequency compensation, although the curves do not follow the Fletcher-Munson curves as closely as the continuous control of Fig. 25.

Fig. 27C shows a switch-type control, which in effect is quite similar to Fig. 25. However, instead of a continuous control as shown in Fig. 25, a switch is used to select the different steps. Some preamplifier systems utilize a switch with as many as six or seven positions, while others have only three positions. For example, low level, normal level, and high level, referring to over-all loudness of the system.

Of course, it is possible to compensate for the Fletcher-Munson effect in a system when it is "turned down" simply by boosting the bass and treble controls.

A high-quality preamplifier does not have to include a loudness control of any of these types, but its use is very often desirable.

FIG. 27. Three types of loudness control.

The Stereo Preamplifier

So far we have discussed the circuits and controls found in every preamplifier. In a stereo preamplifier, duplicates of each of these circuits must be used, one for each channel. In addition, there are other specialized

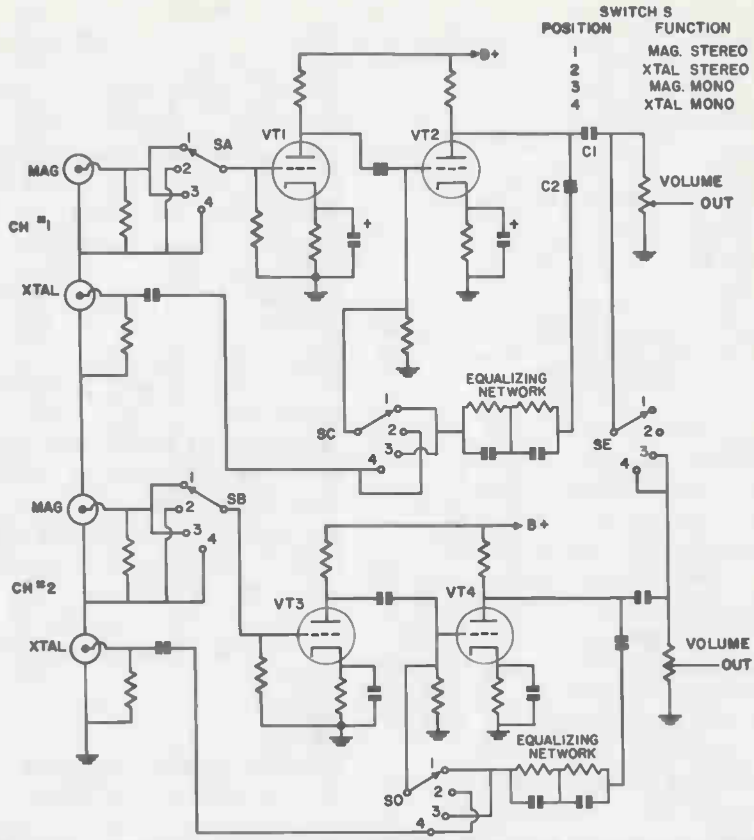


FIG. 28. A single-switch system for selection and mode in a stereo preamplifier.

circuits that are necessary for stereophonic reproduction.

SELECTOR AND MODE SWITCHES

Some sort of switch system is necessary in any preamplifier control unit to select the type of input and its equalization, if needed. In a stereo preamplifier, it is also necessary to select the type or mode of operation —stereophonic or monophonic.

If a stereophonic source is used, then the sections or channels of the preamplifier will operate independently; if a monophonic source is used, the signals will be combined somewhere in the preamplifier. It is particularly important to do this on disc reproduction, since the stereo cartridge will respond to pinch distortion and vertical rumble on monophonic records. Combining the signals in the proper phase will cancel these undesirable signals. Of course, if the stereophonic preamplifier is to be used only to reproduce stereophonic records, then such a switching system is not necessary, but this is rarely the case.

These functions of the input switching system can be combined in one switch, or they can be divided among two or three switches. It is generally more economical to use at least two switches, otherwise the single switch becomes complicated and expensive.

Fig. 28 shows how a single-switch system for selection and mode might be incorporated in a stereo preamplifier. This is a simple preamplifier input stage for phonographs featuring both a magnetic input jack and a crystal input jack for each channel. Each channel consists of two triode stages, with equalization being provided in the second stage for use with magnetic cartridges. In the output of each channel is a gain control. The signal is fed from it to tone control stages and then to the power amplifiers.

A single five-section, four-position switch is used as input selector and function or mode switch. The five sections are all on one shaft so that they rotate together. The four positions provide for both magnetic and crystal cartridges to be used for either stereophonic or monophonic reproduction.

The switch in Fig. 28 is shown in position 1, or the "magnetic-stereo" position. In this position, the input signal to channel 1 feeds through switch section SA to the grid of the first stage. The amplified version of the signal then appears in the plate circuit of the stage, and is sent through the coupling capacitor to the grid circuit of the second stage. The second stage amplifies the signal and feeds the resultant output both through the coupling capacitor C1 to the volume control, and also through capacitor C2 in the plate circuit down through the equalization network to switch section SC. With this section also in position 1, the equalization feedback signal is fed through the switch to the grid circuit of tube VT2. By proper choice of components in the equalization network and the grid circuit, RIAA equalization is accomplished. The signal path through the channel 2 section is the same as through the channel 1 section, except, of course, the input switch section is SB, and the equalization switch section is SD.

Switch section SE performs only one function: to determine stereophonic or monophonic operation. In positions 1 and 2, the stereo positions, the switch is effectively opened. However, in positions 3 and 4, the monophonic positions, the output signals of tubes VT2 and VT4 are combined.

When switch S is turned to position 2, the grids of tubes VT1 and VT3 are grounded. This prevents any undesirable hum pickup from being amplified and fed to the next stages. The signal from the crystal is fed through a coupling capacitor to switch section SC in channel 1 and to switch section SD in channel 2.

This input signal is coupled to the grid circuit of tube VT2 and to the remaining stages in the amplifier. When a crystal is used, it is not necessary to provide the extra gain of tubes VT1 and VT3. Furthermore, equalization is not necessary, so the feedback network is switched out of the circuit. The same switch sections, SC and SD, that choose the equalization for the magnetic cartridge are used to feed the signal from the crystal cartridge to the grids of the second stages in each channel.

The switching system shown in Fig. 28 is not actually used in any commercial preamplifier, but does show the general operation of many switching systems. Actually, in most commercial preamplifiers the switching system would be more complicated, since they usually have more than two input jacks for each channel, such as for tuners, auxiliary equipment, TV, tape, etc. With a tape input, additional equalization networks would be required, since tape heads require different equalization from magnetic cartridges. The equalization, however, is quite similar, so the same sort of network would be used, but with different values.

Some preamplifiers feed back from the plate of the second amplifier stage to the cathode of the first amplifier stage. In such a case, the cathode resistor of the first amplifier stage would not be bypassed as shown in Fig. 28. When feedback is used over two stages, different component values would be used in the feedback network.

When more than one pair of input jacks are provided for each channel, the preamplifier usually has two switches, one for input selection and the other for function selection.

BALANCE CONTROLS

In Fig. 28, the output of each preamplifier channel is fed to a volume or gain control. If the potentiometers shown were the only gain controls in the system, the volume of each channel would be controlled independently. In order to adjust the loudness of the entire stereo system, it would be necessary to adjust two controls.

It is also possible to use a dual gain control in which the two potentiometers are coupled to the same shaft, and then the gain of both channels is controlled by one knob. However, this is not always an ideal situation. Because of the variations of tube and parts characteristics and the slight unbalance inherent in records and cartridges, equal output is not obtained from both channels even if identical components are used throughout the systems. In addition, many stereo reproduction systems utilize different power amplifiers and different speakers in the two channels, and the speaker efficiencies and amplifier gain characteristics might not be equivalent. A single gain control for both stereo channels is therefore not desirable. However, if two separate gain controls were used as in Fig. 28, it would be necessary to adjust both very carefully whenever the system was adjusted.

Several methods have been devised to eliminate this troublesome procedure. One simple and effective method is to use coaxial gain controls for the two channels, with some sort of clutching mechanism. In this system, both gain controls are mounted on a dual shaft mechanism similar to the "channel selector-fine tuning" or "volume-contrast" systems in most television receivers. In such a system the outer knob would control the gain of one channel while the inner controlled the gain of the other amplifier. This is a convenient arrangement, as both knobs can be grasped together and rotated. Special controls have been devised with clutch mechanisms so that the outer knob can be pulled away from the inner knob, and either can be adjusted independently of the other when desirable. If loudspeakers of different efficiency are used, this system is quite ideal, since once the gain controls are set for equal output for both channels, they can be ganged together by pushing the outer knob in and thereby engaging the clutch mechanism. Thereafter the gain controls can be controlled together with no effort.

Some stereo preamplifiers also have a "balance" control. Such a control system is shown in Fig. 29. The output of each gain control here feeds another control. This control, the balance control, consists of two potentiometers controlled by one shaft. The controls however, are connected in the opposite way for each channel. As the shaft of the control is rotated clockwise, the signal fed to the tube in channel 1 will be increased, whereas the signal fed to the tube in channel 2 will be decreased. Similarly, as the balance control is rotated counterclockwise, the signal fed to channel 1

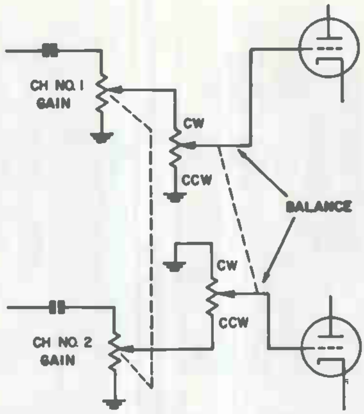


FIG. 29. A balance control for a stereo preamplifier.

will be decreased, whereas the signal fed to channel 2 will be increased.

There are many other types of balance controls in stereo preamplifiers. The one shown in Fig. 29 permits the output of one channel to be completely decreased to zero. Many balance controls have a single potentiometer connected between the grids of the tubes in channels 1 and 2. By grounding the center terminal or slider of the potentiometer, balance can be achieved, although it is not as satisfactory as the method shown in Fig. 29.

TONE AND LOUDNESS CONTROLS

Each channel of a stereo preamplifier should have both bass and treble controls. In the most versatile preamplifier, separate bass and treble controls are provided for each channel. However, a single dual-type potentiometer could control the treble in both channels simultaneously, and a single dual-type potentiometer could control the bass in both channels simultaneously. Such a system is used in the less expensive preamplifiers.

The dual-type controls with clutch mechanism, previously discussed for volume or gain controls, can also be used for tone control. Since tone controls are generally not operated as often as gain controls, such clutch-operated systems are generally regarded as quite acceptable.

By using multi-deck switches or dual-type potentiometers, loudness controls can also be provided for both channels.

SPECIAL CIRCUITS

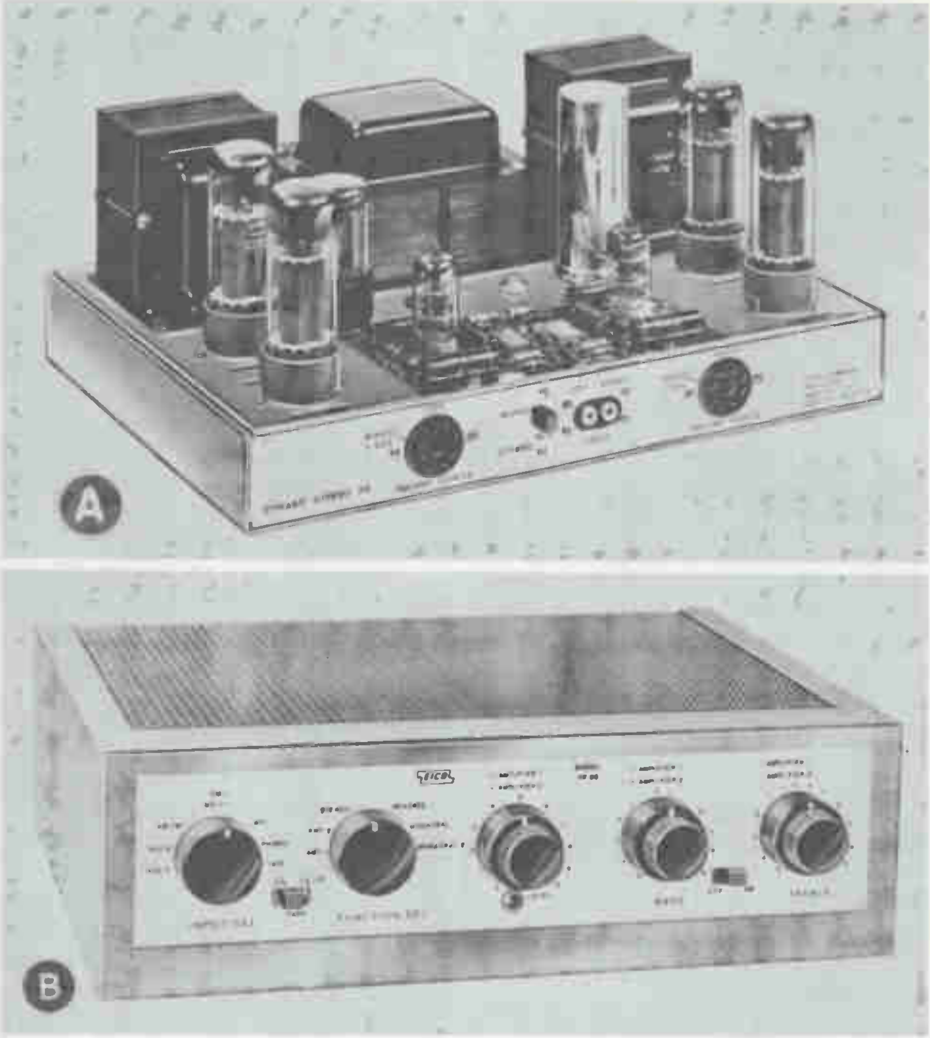
In addition to the necessary basic circuits and stages we have discussed so far in monophonic and stereophonic preamplifiers, there are a number of special circuits that have been developed and are used in commercial units. Some of these circuits have been developed because of the advent of stereo and its special problems, while others were used in monophonic systems long before stereo. We will look at some of the more popular circuits.

Separate Chassis. In some of the highest quality reproducing systems the preamplifier is on one chassis, and the power amplifier is on a separate chassis, as shown in Fig. 30.

There is less danger of damage of the somewhat more delicate and critical input sections by heat from the power output tubes and large rectifier tubes. Also, such a setup has one of the major advantages of component high fidelity, either unit can be replaced with an improved unit as advanced circuitry is developed.

The preamplifier can be designed in a smaller case more pleasing to the eye, which would fit more easily into room decor, and the larger power amplifier can be tucked away in a closet, another room, or even in the basement.

If the output of the power amplifier is a low impedance, lines up to 50 feet can be run from the power amplifier to the speakers if sufficiently large



Courtesy EICO and Dynaco

FIG. 30. A stereophonic amplifier system in two separate units. The EICO HF-85 stereo preamplifier-control unit is shown above, and the Dynakit Stereo 70 power amplifier, below.

wire is used. Such a physical placement of the components in a system would require an ac line from the preamplifier to the amplifier to turn it on or off, and signal lines from the preamplifier to the power amplifier. In a stereophonic system, two signal lines would be required.

If a standard grounded-cathode-type amplifier circuit were used as the last output amplifier stage of the preamplifier, the signal would be at a high-impedance level and this could lead to two types of trouble. First, the high-impedance line would tend to pick up hum even if it were properly shielded. Second, shielded coaxial cable is characterized by capacity between the center signal-carrying conductor and the shield. Excessive lengths of such cable would effectively connect a large capacity between the signal and ground, thereby reducing the high-frequency response considerably.

In order to eliminate these undesirable characteristics, the cathode-follower circuit can be used as the output stage of a preamplifier. By using the cathode follower, a long line can be run between the preamplifier and the main amplifier with less danger of hum pickup or loss of highs. For example, with a 1000-ohm output impedance, the output cable capacity would have to be more than 7500 mmf before its reactance would drop to 1000 ohms at 20,000 cycles.

In a cathode-follower circuit, the signal is fed between the grid and cathode and the output is taken between the cathode and ground, with the plate at signal ground potential. The chief characteristics of a cathode-follower circuit is that it has a high input impedance, a low output impedance, and a gain less than 1.

It is evident, of course, since the gain of the cathode-follower circuit is less than 1, any preamplifier using a cathode-follower circuit would have to have sufficient gain in the preceding stages to overcome this loss.

Phase-Reversing Switches. As we will see later on when we look at loudspeakers, it is important for the phase in the two channels in a stereophonic system to be the same, or musical instruments and voices will tend to jump from one side of the room to the other.

The phasing throughout the entire stereophonic system must be the same from the recording to the speaker. Any accidental phase reversal, either in the original recording, or in the connections to the cartridges, connections to the speakers, etc., will cause trouble.

In a preamplifier, the phase cannot be changed by a simple switching arrangement; it must be done electrically. The principle of most phase-reversal systems is quite simple. As you know, there is a 180-degree phase shift between the grid circuit and the plate circuit in a standard grounded-cathode tube circuit. Therefore, if the preamplifiers and power amplifiers in a stereo system have an equal number of stages, and the loudspeakers are connected accordingly, the phasing will be correct, if the original recording was correct. However, if a stereo preamplifier is used with two different numbers of stages, then the phasing will be incorrect. To correct this, some preamplifiers have a phase-switching system. This system has an additional stage in one of the stereo preamplifier channels that can be switched in or out. This additional stage, such as the one in Fig. 31, has a gain of 1 so that the output of both stereo channels will be equal whether or not the stage is in the circuit. However, since the stage provides a 180-degree phase shift, the phase of one channel can be changed with respect to the other.

Channel-Reversing Switch. A channel-reversing switch, as the name implies, simply interchanges the signals of both stereo channels. Symphonic orchestras, and even many bands, are normally set up with instruments in certain positions. If one is familiar with hearing the brass from the right-hand side, then it should sound as if it is on the right-hand side in stereophonic reproduction. Sometimes this normal placement is disrupted somewhere along the recording chain either in the recording itself or in the interconnections of the record player, preamplifier, power amplifier, and speakers. Such an error can be easily corrected by a channel-reversing switch, such as the one in Fig. 32.

The importance of channel-reversing and phase-reversing switches is rather dubious when equipment specifically

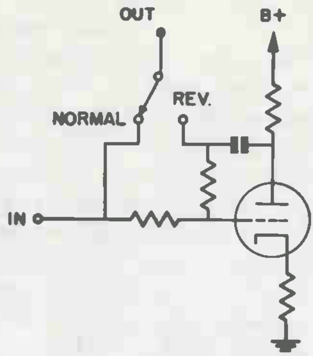


FIG. 31. A phase-switching system.

designed for stereo is used since standards have been set up by the recording and manufacturing industries. If the manufacturer's instructions for setting up equipment are carefully followed, there should be no trouble. If different preamplifiers or power amplifiers are used, the leads to one of the speakers can be reversed if necessary.

Blend and Center-Channel Controls. As you learned previously when you studied recording, it is possible to obtain too much separation in stereophonic reproduction if the microphones are placed too far apart in the original recording or the loudspeakers are placed too far apart in the listening room. To eliminate this "hole in the middle" effect of excessive separation, some preamplifiers are provided with a "blend" control. Such a control is shown in Fig. 33.

Here, two resistors, a potentiometer, and a switch are connected in series between the two channels. Just where this blend control is connected is unimportant, although it is best to have it close to the output of the preamplifier to avoid the possibility of hum and noise pickup in the sensitive low-level stages. Some controls, however, are specifically designed for the input of the system.

The blend control is a potentiometer with the center terminal connected to one of the outside terminals, and an on-off switch actuated by the potentiometer control shaft like a normal volume control on-off switch except that the control generally has a linear taper instead of a logarithmic taper. When the on-off switch is turned off, the blend control circuit is effectively open. When the on-off switch is turned on, channel 1 is connected to channel 2 through the potentiometer and the two fixed resistors. With resistors and potentiometer of the proper value, there will be some, but very little, leakage of signal between the two channels. However, as the potentiometer is rotated, its total resistance decreases, until in the full clockwise position, it is effectively short-circuited and the only resistance between the two channels is the two fixed resistors. With proper values,

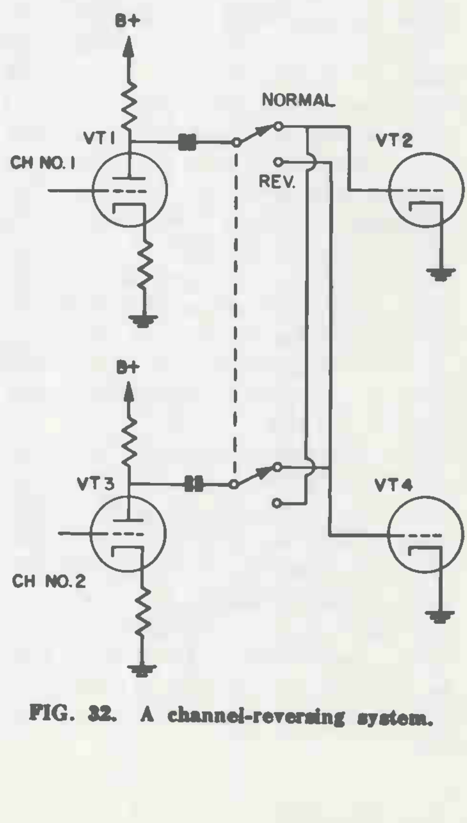


FIG. 32. A channel-reversing system.

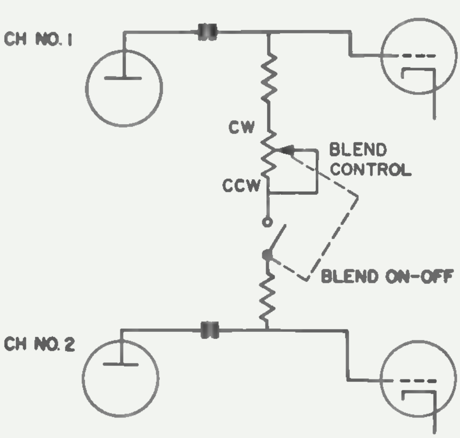


FIG. 33. A blend control.

the blend could almost be perfect—that is, the stereophonic reproduction would become monophonic. In fact, some blend controls are marked in this manner—the full clockwise position of the blend control is marked "Mono." Generally, the blend control is adjusted to some mid position when the disc being played is characterized by exaggerated separation.

The above method of filling up "the hole in the middle" is not always satisfactory. For example, a small instrument like a violin or guitar might be made to sound excessively "large." In order to eliminate this undesirable characteristic, it is better to use a third channel. In this system, the output of both channels is mixed and fed to a third channel, which can be controlled. By doing this, instruments that appear on the right would not be moved over to the left and thereby appear large by the "stretching" process. The music common to both channels and normally appearing in the middle would simply be reinforced. This problem will be examined in greater detail when you study loudspeaker placement for stereophonic reproduction.

In order to obtain a third or center channel it is necessary to mix the channels without causing leakage between the channels. To accomplish this, some preamplifiers provide a center channel output and control system right in the unit itself. Some methods of doing this are shown in Fig. 34.

Fig. 34A shows a simple method: resistors are connected from each channel to the center channel. With the proper choice of resistors, there will be negligible leakage between channels 1 and 2, and yet sufficient signal fed to channel 3.

The circuit in Fig. 34B replaces the two fixed resistors with a potentiometer. Notice that the input signal for channel 3 depends upon the position of the potentiometer slider. Moving this potentiometer toward either channel 1 or channel 2 will vary the output of the third channel accordingly. With such a versatile setup, it would be possible to regulate the output of channel 3, and the center speaker would then not need to be placed in the exact center. In addition, such a system would clear up any problems due to speaker systems of unequal efficiency. For example, if the mixer system in Fig. 34A is used with a high-efficiency speaker in channel 2, the signal fed to channel 3 would be predominantly the signal

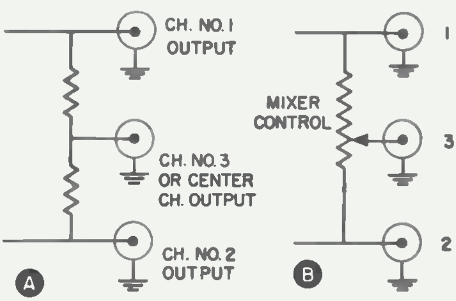
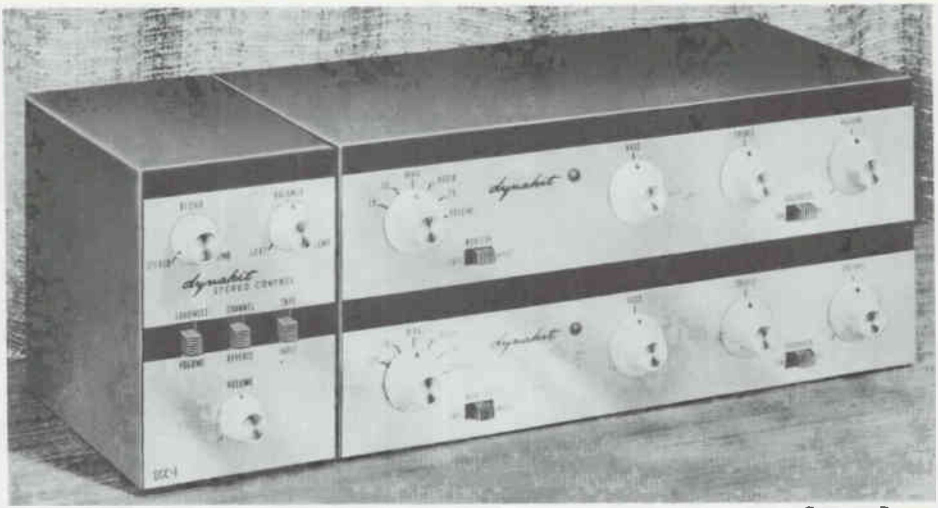


FIG. 34. Methods of mixing the two channels in a stereo system to obtain a third channel.



Courtesy Dynaco

FIG. 35. A monophonic preamplifier can be converted to a stereo system by adding another preamplifier and the adapter shown at the left.

from channel 1, because it would be necessary to adjust the gain control in channel 1 for more signal output. If such a speaker setup is used with the circuit in Fig. 34B, it would only be necessary to move the mixer control slider toward channel 2 until equal signals from the channels were applied to the third channel input.

Stereo Adapters or Control Units. As you have seen so far, a stereophonic reproduction system consists of two monophonic systems plus some additional controls. These controls, although not necessary, greatly simplify the operation of the system.

It is therefore possible to convert a monophonic high-fidelity system to stereophonic reproduction simply by obtaining a duplicate of each of the pieces of equipment in the monophonic system (with the exception of the turntable). However, although this might be an excellent stereophonic system, it would not have the special stereo controls. In order to provide these special controls and to simplify conversions, manufacturers have developed stereo adapters or control units containing some or all of the special controls we have discussed. Such a unit makes it possible to assemble a stereo system in steps. That is, a monophonic system could first be purchased and then later a duplicate of each section plus an adapter could be added to convert to a high-quality versatile stereo system.

Fig. 35 illustrates such a conversion. Two high-quality monophonic preamplifiers are shown at the right, one on top of the other. A stereo adapter unit is shown at the left. This unit has a master volume control, a balanced control, a blend control, and switches providing for loudness control, channel reversal and tape input.

Of course, it is not necessary to use a second preamplifier of the same type as the first when converting a monophonic system to a stereophonic type, but it does avoid confusion. Furthermore, the adapter unit and the preamps do not have to be assembled together, but can be separated. For example, it might be convenient to install the adapter right at the turntable.

The Power Amplifier

In addition to controlling the selection, the mode of operation, the tone, and the loudness of the signal, the amplifying system must also drive the loudspeaker so that we can hear the signal. As explained previously, the output signal from some sources can be as low as just a few millivolts and a very minute fraction of a watt. In order to drive the loudspeakers, we need a great amount of power. A power amplifier is therefore used as the final stage of the amplifying system.

The output signal of the preamplifier will depend upon the exact design of the preamplifier. Commercial preamplifier outputs generally range from 1 volt to 5 volts which is, of course, adjustable. Remember that although there are several high gain stages in the preamplifier, tone control and equalization introduce a great deal of attenuation.

The power amplifier generally consists of one or more voltage amplifier stages, a phase-inverter stage, and a push-pull output stage. The exact number of stages and type of amplifier and phase-inverter in the unit depends upon the designer.

From your previous study of low-frequency amplifiers, you know that the push-pull power output stage requires a certain amplitude and a phase reversal of the signal applied to one of the grids. The exact amount of voltage that is required depends on the tube type and the circuit. Some tubes are quite sensitive and require very little voltage, while others are quite insensitive and require a great deal of voltage. Triode tubes or tubes connected as triodes require more driving voltage than pentodes or tetrodes. The required drive also depends upon the connections between the tubes and the output transformer.

The sensitivity (the input signal voltage that is required for full output) of the power amplifier will depend upon whether it is on the same chassis as the preamplifier or on a separate chassis.

When it is on the same chassis with the preamplifier, its sensitivity only needs to match the preceding preamplifier stages. If the preamplifier has many high-gain stages, the power amplifier could be quite insensitive. However, a power amplifier that is offered separately for use with other preamplifiers generally has a sensitivity of from 1 to 2 volts input so that it can be used with many different preamplifiers. In order to get this sensitivity, all power amplifiers have one or more voltage amplifying stages before the phase splitter and output tubes.

WILLIAMSON AMPLIFIER

To understand the features of a power amplifier, let us consider the Williamson amplifier shown in Fig. 36. This Williamson amplifier probably did more to bring high fidelity into the average home than any other single development.

The Williamson amplifier when it was first brought out years ago was generally spoken of as something special. It was, but not because of any new or radical circuitry. The basic feature of the Williamson amplifier was the careful attention paid by the designer to all the small details necessary for top performance.

As can be seen in Fig. 36 the Williamson amplifier utilized two dual triode tubes and triode-connected tetrode output tubes. The circuit was

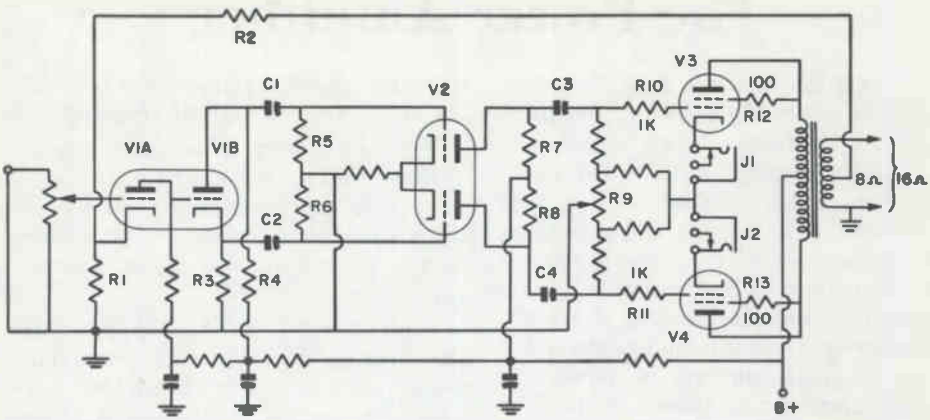


FIG. 36. The Williamson amplifier.

designed so that the individual stages operated on only the most linear portions of the tube transfer curves. The tubes were not operated at peak efficiency; instead, they were operated to produce the least distortion. The harmonic and intermodulation distortion of the Williamson amplifier was extremely low in comparison to other amplifiers of its era. It was a giant step forward in high-fidelity reproduction — a definite break - through.

Although developed years ago, the basic Williamson circuitry with some modern improvements is used in many commercial amplifiers.

As can be seen in Fig. 36, the input signal is fed to a triode stage, which is directly coupled to another triode stage. The second triode stage acts as a phase splitter, supplying the grids of a dual triode, which in turn drives the output tubes. Negative feedback is brought from a tap on the secondary of the output transformer to the cathode of the input triode. A balancing system is incorporated in the grid circuit of the output tubes.

Every single component in this Williamson amplifier and, in fact, in all good high-fidelity amplifiers is important. For example, in order to extend the low-frequency response, the coupling capacitors have a large capacity (and therefore a low reactance at audio frequencies). Direct coupling as used between tubes V1A and V1B is commonly used in amplifiers to further extend the low-frequency response and reduce phase-shift. However, the most important single component determining the low-frequency response of an amplifier is the output transformer itself. The primary of the transformer must have a very large series-inductance in order to present a high load to the tubes at low frequencies. This is generally accomplished by using a very large core of special steel. However, in addition to this large series-inductance the output transformer must also exhibit very low leakage inductance and low capacity between the windings in order to extend the high-frequency response of the amplifier. Further extension of the high-frequency response is also accomplished by careful control of the plate and grid resistances and lack of stray capacity and unnecessary shunt capacity in plate and grid circuits.

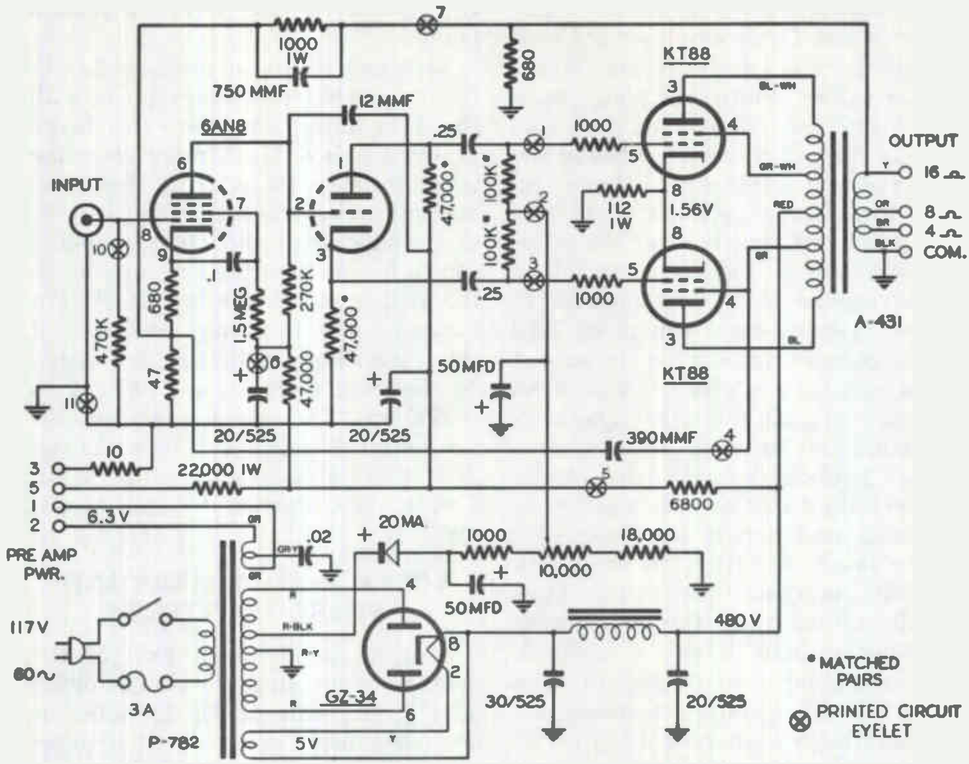


FIG. 37. A modern power amplifier, the Dynakit 60-watt power amplifier.

An extremely wide frequency response is essential in a high-fidelity power amplifier. Although very few people can hear above 15,000 cycles per second or below 30 cycles per second, it is essential that the amplifier have superb transient response. In order to amplify satisfactorily the steep wave fronts found in music, and to be extremely stable, its frequency response must be extended both below and above the normal audible range.

MODERN AMPLIFIER CIRCUITRY

A modern power amplifier is shown in Fig. 37. Notice the differences in circuitry between this amplifier and the Williamson in Fig. 36. First of all, the input tube in this Dyna amplifier is a pentode, whereas the Williamson used a triode. In both cases, however, the input tube is directly coupled to the next tube.

Although the Williamson utilized another dual triode stage to feed the power amplifiers, the Dyna amplifier does not require this additional amplification. The second stage is used as a phase splitter to feed the power output tubes. This is possible because the modern output tubes are much more sensitive than the original tubes used in the Williamson and, of course, the pentode input stage of the Dyna amplifier has much more gain than the triode input stage of the Williamson. Notice that fixed bias is used in the Dyna amplifier. A separate selenium rectifier power supply produces negative voltage, which is fed to the grid resistors of the power output stage.

The screen grids of the KT88 output tubes in the Dyna amplifier are connected to taps on the output transformer rather than to the plates as in the Williamson. This method of connecting the power output tubes to the power output transformer is known as the "ultra-linear" configuration, and was developed shortly after the original Williamson and incorporated in later versions of the Williamson. It is used in many other amplifiers. This sort of connection between the output tubes and the transformer makes the output tubes act somewhat like both pentodes and triodes. That is, distortion is lowered to the triode level, and yet the tubes are as sensitive as pentodes, and require less drive.

The feedback system in the Dyna amplifier is quite interesting. First of all, notice that the Williamson amplifier utilized a single feedback loop containing a single resistor. The Dyna amplifier, however, uses two feedback loops containing many parts. The main feedback loop extends from the 16-ohm tap on the output transformer to the cathode of the 6AN8 input tube. This feedback loop contains a resistor connected to ground and another resistor and capacitor in parallel. The shunt resistor from the 16-ohm output tap to ground is a stabilizing resistor, which limits the feedback. The capacitor in parallel with the 1000-ohm main feedback resistor increases the feedback at high frequencies to reduce oscillation and improve stability at the high end of the band. Further high-frequency limiting to improve stability and transient response is accomplished by another feedback loop. A 390-mmf capacitor is connected from the screen of one of the output tubes to the main feedback connection in the cathode circuit of the 6AN8 tube. In addition, a small 12-mmf capacitor is connected from the plate of the first stage to B+ (which is effectively at ground potential).

Although it was a problem to obtain extended frequency response with the Williamson amplifier, this is no problem today. Much more attention is paid today to reducing distortion and improving transient response. The characteristics of the Dyna amplifier shown in Fig. 37 are much superior to the Williamson shown in Fig. 36. For example, the frequency response of this particular amplifier is within ½ db from 6 cycles per second to 60,000 cps. The inter-modulation distortion is less than 1% at 60 watts and .5% at 50 watts. At a listening level of 1 watt, the distortion does not exceed .05%.

VOLTAGE AMPLIFIERS AND PHASE SPLITTERS

In spite of the high gain of the pentode input stage in the amplifier of Fig. 37, this power amplifier is not particularly sensitive—it requires almost 2 volts input for full output. This sensitivity is sufficient, since most modern preamplifiers will supply this much output voltage with no trouble.

Although the gain of the pentode stage is high, the phase-splitter stage has a gain less than one since it is a cathode follower. In addition, the feedback over the entire amplifier reduces the over-all gain considerably.

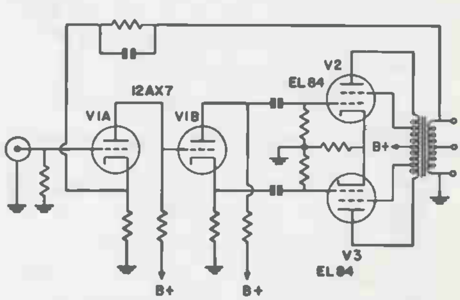


FIG. 38. A triode input stage, phase splitter, and power output stage.

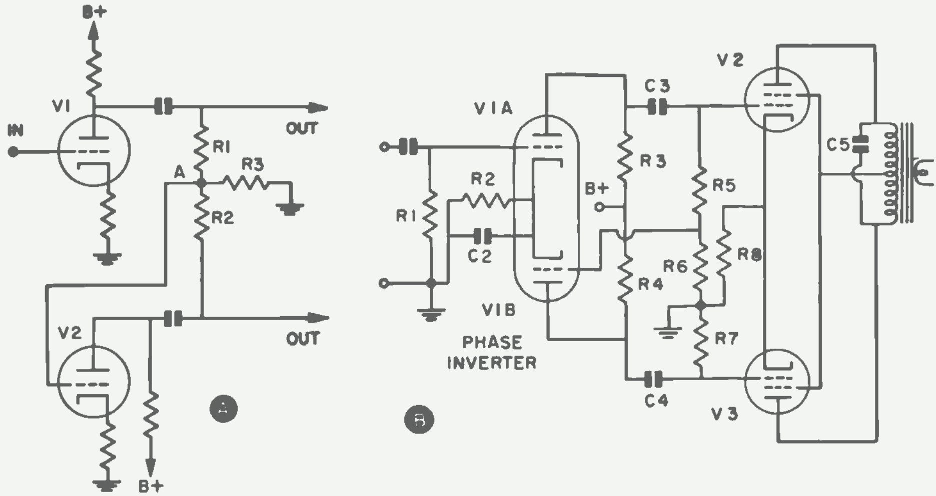


FIG. 39. A paraphase phase-splitter is shown at A, and a phase inverter is shown at B.

It is possible to construct a more sensitive power amplifier simply by using additional stages such as was used in the Williamson amplifier in Fig. 36.

Cathode-Follower Phase Splitter. It is possible to use a triode input stage followed by a phase splitter and the output tubes as shown in Fig. 38. Notice that this amplifier resembles both the amplifiers in Figs. 36 and 37 in that the first stage is directly coupled to the second and that feedback is brought from the secondary of the output transformer to the cathode of the input tube. Notice also that the output connections are ultralinear. That is, the screen grids of the EL84 output tube are connected to taps on the output transformer. The circuit shown in Fig. 38 is typical of low or medium powered amplifiers, since the EL84 tube is capable of from 12 to 17 watts continuous power output. Of course, when two such amplifiers are offered on one chassis as a stereo power amplifier, the power output rating is double this, or from 24 to 35 watts.

Besides the phase splitter shown in all three amplifiers of Figs. 36, 37, and 38, many other types are used in high-fidelity power amplifiers although this type shown is probably the most popular. It is known as the cathode follower type or "cathodyne."

Paraphase Phase Splitter. Another type of phase splitter is the paraphase or floating paraphase shown in Fig. 39A. Remember that the push-pull output tubes must be fed signals equal in amplitude but opposite in phase. Since a tube inverts the phase 180 degrees, it is only necessary to utilize another tube to feed one of the output tubes. The circuit in Fig. 39A does just this, as can be seen. The signal voltage for this second tube (V2) is obtained at junction A between resistors R1, R2, and R3. Resistors R1 and R2 are the grid resistors of the power output stage. These resistors, along with resistor R3, are chosen so that a small amount of signal voltage appears at point A to drive tube V2. Since a small amount of voltage must appear at point A, the output tubes are not driven with equal signals. That is, they are

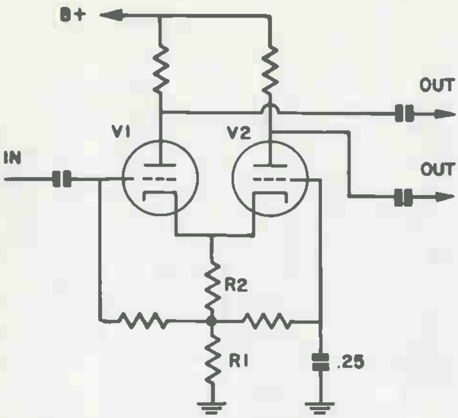


FIG. 40. A "long-tailed pair" phase splitter.

slightly unbalanced. However, the unbalance is very slight and, in fact, balance exceeding 99% is usually obtained.

Phase Inverter. Fig. 39B shows a circuit that is sometimes used. It is commonly found in phonographs and radios. Notice that the drive signal for tube V1B is obtained from the grid resistor of output tube V2. Satisfactory balance is achieved by this circuit although it is subject to unbalance as the tubes age since they will normally age differently. The cathode follower type of phase splitter shown in Figs. 36, 37, and 38 is not subject to this problem since both drive signals are obtained from the same tube.

Long-Tailed Pair. Another type of phase splitter is shown in Fig. 40. Because of the circuit appearance, this particular splitter is referred to as a long-tailed pair. Notice that the grid of tube V2 is effectively grounded through the .25-mfd capacitor. Thus, tube V2 is fed the signal through the common cathode resistor R1. Resistor R2 introduces degeneration and reduces distortion. Since a common resistor is used for both tubes, aging will affect both of them pretty much the same, and balance stays quite satisfactory for a long period of time.

There are, of course, many other circuit variations possible for high-fidelity power amplifiers. The ones discussed here are the most popular types and, in fact, have been popular for some years. Periodically, new amplifier types are devised, used for a while, and then discarded. For example, it is possible to connect the power output tubes to the output transformer in many other ways than shown here. In addition to the triode and ultralinear variations shown, pentode connections are used as shown in Fig. 41. Although this configuration generally produces higher distortion than either the triode or ultralinear, some modern tubes have been developed specifically for this purpose, and the over-all distortion is acceptably low.

Power Amplifier without Output Transformers. It is also possible to design a power amplifier without an output transformer as shown in Fig. 42. In this illustration two triode tubes are connected in push-pull to a speaker with a high-impedance voice coil. For such a circuit to work

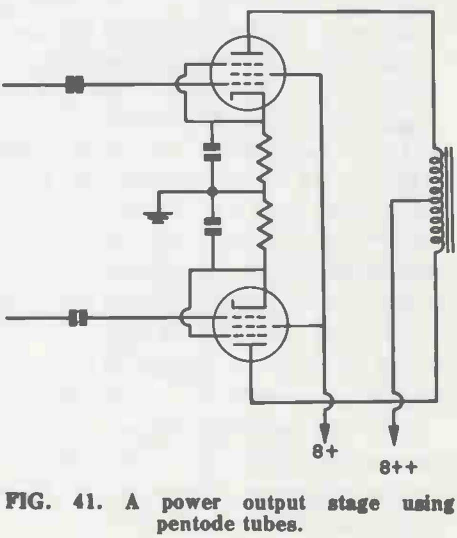


FIG. 41. A power output stage using pentode tubes.

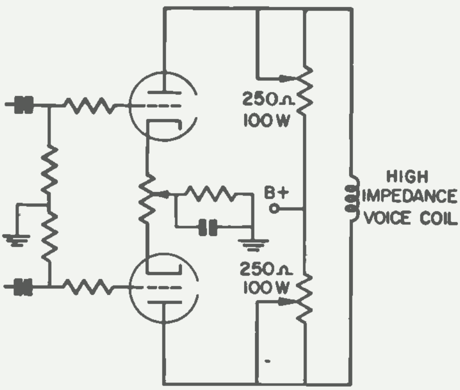


FIG. 42. A power amplifier without an output transformer.

properly, it is necessary to have tubes with very low plate resistance. Such circuits are rarely used, since most high-fidelity loudspeakers are available with 8-ohm or 16-ohm impedances. Therefore, in order to use such an output transformerless (OTL) amplifier, a special speaker would need to be obtained, and the expense would hardly justify any advantage of the circuit.

However, transistor output impedances are normally quite low, so it can be expected that some transistor OTL amplifiers will be introduced.

Single-Ended, Push-Pull. Another type of output circuit is shown in Fig. 43 and is known as the "single-ended, push-pull amplifier." In this circuit, tube V1 is a phase-inverting driver coupled to the output tubes V2 and V3. V2 and V3 are in series with the audio signal. When the tubes are matched, the ac plate currents add to the load in exactly the same way as a conventional push-pull circuit.

Since the primary of the output transformer in this circuit is not tapped, no distortion notch is generated when the tubes are driven to cutoff. In addition, no direct current flows through the primary, which would normally reduce the inductance, so a smaller transformer could be used to achieve satisfactory low-frequency response.

This particular circuit is used occasionally, but since very high-quality output transformers no longer present the problems they used to, the circuit is not particularly popular.

POWER-AMPLIFIER PROBLEMS

As might be expected, all power amplifiers have some types of distortion, principally harmonic and intermodulation. By choosing proper components, tube types, and a high-quality output transformer, these distortions can be reduced to a minimum. In addition, use of feedback will further reduce the distortions to levels where they are not bothersome.

Besides the harmonic and intermodulation distortion, power amplifiers also have troubles with stability and transient response. As you learned earlier, these characteristics can become more important than the actual distortion, since music is principally characterized by steep wave fronts.

Feedback. In order to reduce the over-all distortion of an amplifier it is necessary to use high amounts of feedback. Remember in the amplifier circuits we discussed, feedback was

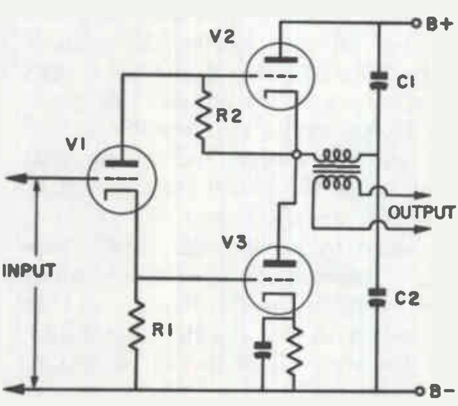


FIG. 43. A single-ended, push-pull amplifier.

applied over all or most of the stages. This feedback, however, can cause trouble if it is not applied properly. Remember that the signal voltage fed back must be out of phase with the input voltage if it is to reduce distortion. When the feedback becomes positive (in phase) the amplifier becomes an oscillator.

The feedback problem is brought about by the RC coupling networks and transformers. Although a tube causes a phase shift of 180° at all frequencies, RC coupling networks and transformers also introduce phase shift, but the phase shift changes with frequency. It is evident, then, that at some frequency the phase shifts will add up to 360 degrees, and a signal fed back at this phase will cause oscillation and instability. Thus, the phase shifts throughout the amplifier must be reduced to a minimum, and the feedback signal itself must be controlled so that the frequencies at which the phase shift has reached 360 degrees are not fed back. It is not uncommon to find RC networks shunted from a signal path to ground in order to reduce the gain of an amplifier at a certain frequency and thereby improve stability. The amplifier design is then a compromise. In order to have low distortion, frequency response must be extended so that sufficient feedback can be utilized within the audible range. If an amplifier were built simply to pass frequencies between 30 cycles and 15,000 cycles (the audible range) and cut off above and below that point, then the phase shift would be excessive, since RC networks would be necessary to accomplish this "chopping." Because of the excessive phase shift, very little feedback could be utilized without causing instability, and the over-all distortion would be too high.

Bias Balance. Distortion in the amplifier output stage depends on the balance of the output tubes since it is the push-pull action of these tubes that cancels the even harmonic distortion in the output transformer. This balanced operation of the output tubes is often accomplished by using a balancing potentiometer as shown in Fig. 44A. Notice that the cathodes of the output tubes are connected together with a potentiometer, (usually 25 ohms to 100 ohms). The main biasing resistor connects from the slider of this potentiometer to ground and is bypassed. By varying this potentiometer, perfect balance can be obtained in the output stage.

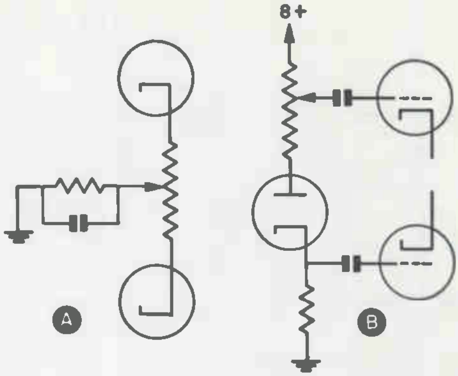


FIG. 44. Two circuits for balancing the output tubes. A shows bias balance; B shows drive balance.

If fixed bias is used, as was shown in the Dyna amplifier of Fig. 37, a potentiometer could be used in place of the two 100K ohm grid resistors, with the slider connected to the negative power supply.

Drive Balance. In addition to this bias balance, some amplifiers provide drive balance. That is, the balancing system shown in Fig. 44A simply balances the output tubes with respect to each other. However, in order to obtain perfect even-harmonic distortion cancellation, the signals fed to the grids of the output tubes must also be equal as well as opposite in phase. In order to provide equal output signals, the method shown in Fig. 44B can be used. Notice that one of the output tubes is fed from the cathode of the phase splitter, and the other is fed from a potentiometer in the plate circuit. The exact amount of signal fed to the output tube will be controlled by the setting of this potentiometer.

In addition to these methods, it is also possible to obtain specially selected output tubes that are balanced by the manufacturer.

Damping. Damping, by definition, is the ratio of the normal load impedance to the actual output impedance of the amplifier. The normal load impedance is the value in which the amplifier should be terminated for normal operation. For example, most high-fidelity power amplifiers offer a choice of 16 ohms, 8 ohms, or 4 ohms to match loudspeakers with the same impedance rating.

Triode amplifiers have long been considered superior to other types because of the high damping. That is, the plate-to-plate impedance of a push-pull triode stage is inherently much lower than the plate-to-plate impedance of a pentode or tet ode stage. This then provides a very low source impedance to the loudspeaker and improves the transient response. However, it is possible and normal to reduce the impedance of pentode and tetrode push-pull amplifiers by using negative feedback. Damping factors of 10 to 20 are normally accomplished by this method and it is generally considered sufficient to have a damping factor of over 5. Thus, although it may be possible to obtain a high damping factor with push-pull triodes inherently, it is also possible to obtain sufficiently high damping with pentodes or tetrodes. In fact, modern

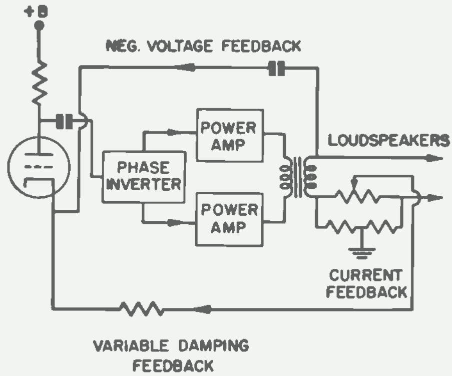


FIG. 45. A variable damping system using voltage and current feedback.

amplifiers rarely use triode tubes and yet are capable of reproduction superior to even the best of the triode amplifiers of only a few years ago.

It is possible to vary the damping factor of an amplifier by varying the feedback. Such a variable damping method is shown in Fig. 45. Notice that variable damping in this illustration is accomplished by using a combination of voltage and current feedback. Negative voltage feedback is used in its normal manner to reduce distortion, whereas positive current feedback is used to vary the damping.

By varying the damping of an amplifier it is possible to match it to the loudspeaker better. However, it is better to correct for loudspeaker defects in the loudspeaker system itself rather than in the amplifier. If the loudspeaker is properly enclosed, variable amplifier damping is not necessary, and, in fact, rarely makes a difference in listening performance. Variable damping does have more of an influence on the performance of small or mediocre loudspeaker systems.

Power Supplies

So far in our discussion of all the stages and sections of the amplifying system we have not considered the power supply. The power supplies in high-fidelity equipment are similar in many respects and yet vary widely as do the supplies in television and other large electronic equipment. Since preamplifiers and power amplifiers are available together and on separate chassis, there can be as many as four separate power supplies in a stereophonic system, one for each preamplifier and one for each power amplifier. Generally, however, in a system designed specifically for stereophonic reproduction there will be one or two power supplies.

Quality amplifiers require ac power supplies utilizing transformers and rectifier tubes or dry disc diodes. Silicon-type diodes are also used in both high and low-voltage power supplies.

A typical power supply setup for a stereophonic preamplifier - amplifier system is shown in Fig. 46. This is a rather expensive power supply. The high-voltage winding is fed to a full-wave rectifier tube, the output of which is fed to a capacitor-input choke filter. At the output of the choke, voltage is fed to the power output tubes. Each stage, or two stages, in the amplifier and preamplifier are decoupled from the others by a resistor and large electrolytic capacitor. In a stereo amplifying system, two different high-voltage sections might be used, or the same section might feed both power amplifiers and preamplifiers.

In addition to the high-voltage section, there are two separate filament windings. The first with a hum control provides 6.3 volts ac for the power amplifier tubes, while the second is a dc supply for the preamplifier tubes.

In the primary of the power transformer, several power outlets or convenience plugs are available so that other equipment can be plugged into the unit. For example, it would be

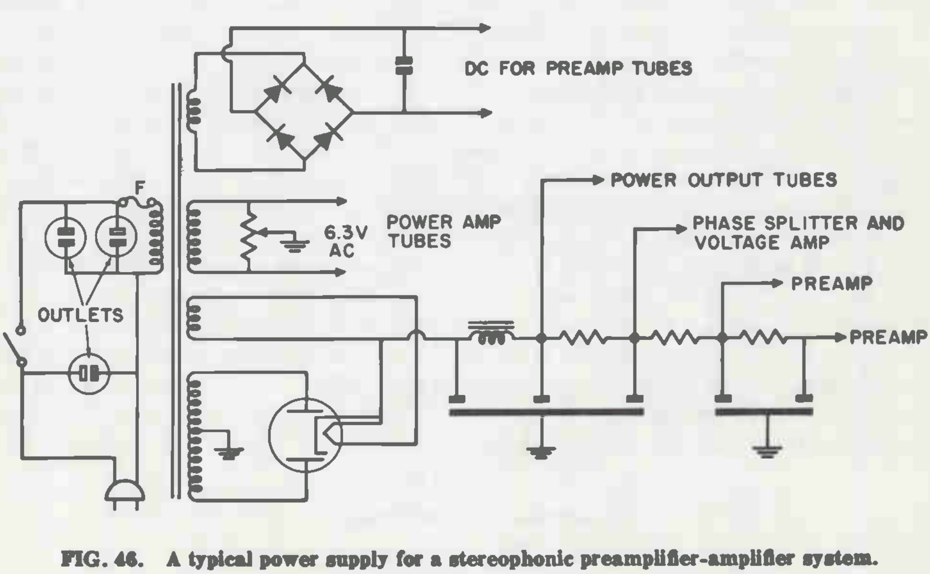


FIG. 46. A typical power supply for a stereophonic preamplifier-amplifier system.

convenient to plug in the phonograph and any tuners that might be used so that when the preamplifier is turned on, power will be applied to all of the units. In addition, the primary is fused.

Of course, the most important characteristic of the power supply is that it produces a pure dc voltage for the plate and screen grids of the tubes. It is just as important that the stages be decoupled from each other to prevent oscillation and promote stability. The choice of capacitors and resistors in the power supply also determines the low-frequency response. In order to achieve stability and sufficient low-frequency response, the impedance of the power supply must be quite low. In order to achieve a low impedance, silicon diode rectifiers are sometimes used in place of the rectifier tube.

There are many other features found in power supplies. For example, the rectifier tube itself, as shown in Fig. 46, often has a cathode-type construction so that it will take as long as or longer to heat than the other tubes in the amplifier. This prevents B+ voltage from being applied to the tubes before they are fully heated, which would shorten their life or cause them to become noisy. Often a resistor that changes value with current drain is used in the primary circuit to limit current surges and thereby protect the tubes and capacitors. In addition, the input capacitor might be of the oil-filled type and of a higher voltage rating than necessary to promote long life and trouble-free performance.

Courtesy Dynaco

FIG. 47. A power supply designed to be used with a preamplifier.

As you learned previously, many high-quality systems have a preamplifier on one chassis and the power amplifier on the other chassis. In such cases the preamplifier may contain its own power supply or it may depend upon the power amplifier for power. If this type of preamplifier, without a power supply, is used with another power amplifier, it would be necessary either to couple it into the other power amplifier, if it is capable of supplying the extra power, or to use a separate power supply. Such a power supply designed when the accompanying power amplifier is not used is shown in Fig. 47. Since the preamplifier consumes little power, the power supply is quite small. Most of the power consumed in the preamplifier is for the heaters.

Loudspeaker Systems

The loudspeaker is the final link in the reproducing chain of a high-fidelity system. It converts the amplified and modified electrical signal to sound so that we can hear it. It is a transducer, like the phonograph cartridge, and as such is less perfect than the other components in the reproducing system.

In addition to measurable characteristics such as frequency response and distortion, loudspeakers have other characteristics that cannot be measured, but that make them sound

Courtesy James B. Lansing Sound, Inc.
FIG. 48. A single full-range speaker.

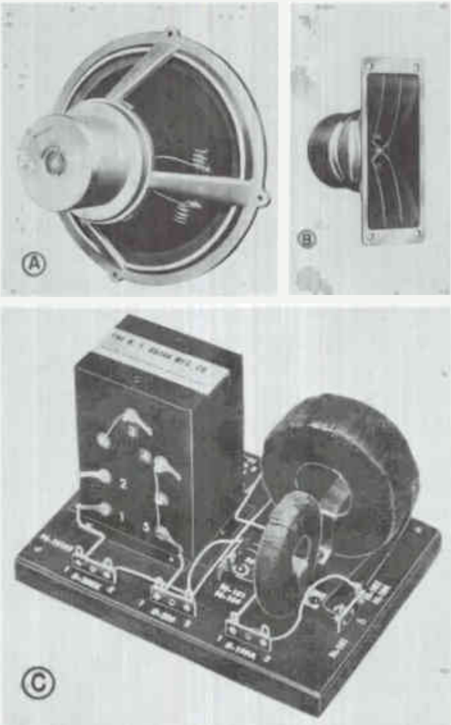
different from each other. This is like the difference between musical instruments of the same type. For example, a Steinway piano does not sound exactly the same as a Baldwin piano of the same size and price although both may be in perfect condition and properly tuned. Moreover, some musicians prefer a Steinway while others prefer a Baldwin. This difference between pianos is definite, though unmeasurable. It is the same with loudspeaker systems; one may "measure" the same as another and yet sound different.

Each loudspeaker has a different tonal character, often called its "texture." This difference in texture is not a difference in quality. Obviously, if one speaker system has poor frequency response with excessive distortion, it will not sound the same as one characterized by wide-frequency response and low distortion; this is a difference in quality. The "sound" of a loudspeaker will depend not only upon its quality, but also on its texture.

Since we discussed loudspeakers completely in an earlier lesson, we will not be concerned with how they are constructed or how they work in this lesson. We will confine our discussion to applications in high-fidelity systems.

Probably the most obvious difference between a speaker system used for high-fidelity reproduction and one used in an ordinary radio or TV receiver is the frequency response. The ordinary four- or five-inch replacement-type speaker used in a radio or TV receiver generally has a frequency response between 100 and 5000 cycles, whereas a high-fidelity speaker system may have a response extending from 30 or 40 cycles to beyond 20,000 cycles. This frequency-response extension is accomplished by a number of different methods. Let's look at these methods.

Courtesy Kingdom Products, Ltd.
FIG. 49. A single full-range speaker with two cones.



Courtesy Wharfedale Wireless Works, Electro-Voice, Inc., and Bozak Mfg. Co.

FIG. 50. A low-frequency speaker, or "woofer" is shown at A; a high-frequency speaker, or "tweeter," is shown at B; and a cross-over network is shown at C.

EXTENDING FREQUENCY RESPONSE

The frequency response of a speaker system may be extended by using a single carefully designed full-range speaker, by using separate low- and high-frequency speakers, or by using coaxial speakers. Let's see the advantages and disadvantages of these methods.

Single Speakers. One obvious method of extending the range of a speaker system is to design a single loudspeaker so carefully that it will reproduce both low- and high-frequency sounds. Such a reproducer is shown in Fig. 48. This 15-inch speaker is able to produce low frequencies because of its low resonance and large cone area. Its high-frequency response is extended by a very thin aluminum dome attached directly to the top edge of the voice-coil form. When very high frequencies are fed to the speaker, the voice coil and aluminum dome vibrate and produce the sound, while the larger, heavier cone is unable to move rapidly enough.

Another method of extending the high-frequency response of the speaker is to use a speaker with two cones. Such a unit is shown in Fig. 49. The small inner cone is attached to the voice coil form, and is intended to vibrate with the voice coil and reproduce the high frequencies, where the larger cone is too heavy.

Multi-Speaker Systems. Although such full-range speakers are capable of remarkable reproduction, most high-quality speaker systems use two or three speakers to reproduce the entire audible spectrum. Each speaker is designed to reproduce a certain section of the spectrum instead of the entire spectrum. A low-frequency loudspeaker, or "woofer," such as shown in Fig. 50A, is combined with a high-frequency loudspeaker, or "tweeter," such as shown in Fig. 50B, to reproduce both high and low frequencies. The sound fed to the speakers is first passed through a cross-over network such as shown in Fig. 50C, which separates the signal by frequency, and feeds the lows to the woofer and the highs to the tweeter.

The woofer, shown in Fig. 50A, is typical of high-quality units. Notice that the chassis or basket of the speaker is very ruggedly constructed. It is made of die-cast aluminum. The magnet assembly is extremely large. The outer edge of the cone of this particular woofer is composed of a special plastic to reduce the resonance to approximately 30 cps.

The tweeter shown in Fig. 50B is a horn-type unit designed to reproduce

Courtesy Kingdom Products, Ltd.
FIG. 51. A tweeter with enclosed back and a screen for high-frequency dispersion.

frequencies from above 3500 cycles to beyond 19,000 cycles. It too contains a large magnet assembly to insure low distortion and good transient response. The throat of the horn contains a phasing plug to reduce any possibility of phase distortion and to insure maximum dispersion.

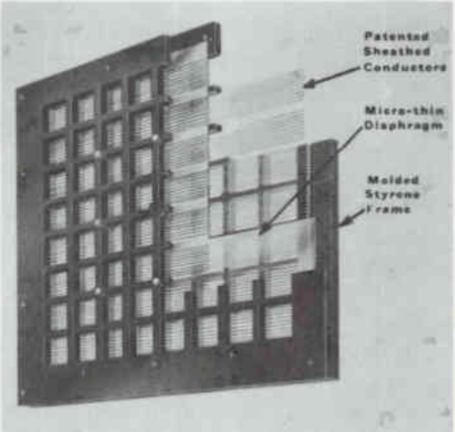
The cross-over network shown in Fig. 50C contains two coils and a capacitor bank.

Sometimes it is desirable to separate the sound into three sections and use a mid-range speaker, sometimes called a "squawker," to reproduce the mid-frequencies. When this is done, the cross-over network must contain an extra section for this third separation of sound. We will discuss cross-over networks later.

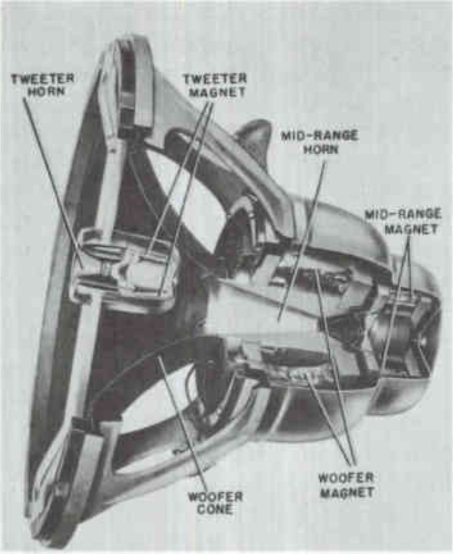
Instead of the horn-type tweeter shown in this illustration, some manufacturers utilize cone-type tweeters. This type of tweeter may resemble an ordinary loudspeaker, but differs in that the cone is generally very hard and designed to resonate at a high frequency. Sometimes the cone is covered with a screen or mesh such as that shown in Fig. 51. This mesh not only protects the cone, but also helps to disperse the high frequencies.

As can be seen by the illustration in Fig. 50B, a high-frequency horn tweeter is completely enclosed except for the natural horn opening. A cone-type speaker such as the low-frequency one in Fig. 50A is ordinarily open in the back. However, when a cone-type tweeter is used, it is necessary to enclose it, to prevent the sound waves from the woofer from reaching the back of the tweeter cone, which could modulate the cone. That is, the sound waves would make the cone move according to the low frequencies produced by the woofer. To prevent this, the cone-type tweeter shown in Fig. 51 is totally enclosed. This will not cause trouble from air compression because the movements of the cone are short at high frequencies.

Mid-range speakers must also be protected from modulation by the woofer and are either fitted with an enclosed chassis or basket, or are mounted in a separate compartment in the loudspeaker enclosure, or even in a separate compartment on top of the enclosure holding the woofer.



Courtesy Neshaminy Electronic Corp.
FIG. 52. Cut-away view of Jans-Zen electrostatic speaker.



Courtesy Jensen Mfg. Co.

FIG. 53. A triaxial speaker.

In addition to the cone and horn-type tweeters, electrostatic speakers are also used for high-frequency reproduction. Since we discussed this type of speaker in a previous lesson, we will not give a detailed explanation of its operation here. One problem in using them is that they generally have low efficiency, so trouble is often encountered in matching them to woofer and mid-range speakers of normal efficiency. This problem has been solved in a number of different ways by manufacturers of high-quality electrostatic speakers.

One solution is shown in Fig. 52. This is what is called a "push-pull" type. It is the basic electrostatic element used in the Jans-Zen electrostatic loudspeakers. Here there are conductors on both sides of the plastic diaphragm. It is usually necessary to use more than one of the elements shown in Fig. 52 in a speaker system. From two to four such elements are most often used.

Besides the push-pull arrangement, step-up transformers are also generally used to increase the signal, and the bias supply for such high-fidelity electrostatic speakers generally supplies a minimum of 1000 volts.

By using a high-bias supply, push-pull arrangement, and more than one element, it is possible to match the efficiency of most woofers, smoothly.

Although most electrostatic loudspeakers are designed only for high-frequency reproduction, some are also designed for operation in the mid-frequency band down to 500 or 600 cycles per second. In addition, there is at least one electrostatic speaker which the manufacturer claims will reproduce the entire audible frequency band, including low frequencies.

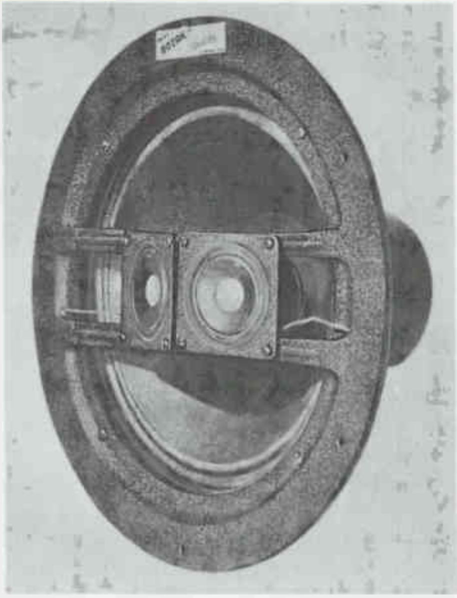
Coaxial and Triaxial Speakers. Instead of using a single full-range speaker system or separate speakers as just discussed, it is possible to combine two or three speakers in one assembly. Such a speaker is shown in Fig. 53. Notice that this single speaker actually contains three separate speakers each with a separate magnet-voice coil assembly. A more common version is that containing just a tweeter and woofer in one assembly.

Another type of coaxial speaker is shown in Fig. 54. Notice here that two small tweeters are attached to a bracket, which in turn is attached to the woofer basket. Such speakers are generally available with or without the tweeter assembly, which can, if desired, be added later.

CROSS-OVER NETWORKS

As explained previously, a cross-over network is designed to separate frequencies in a high-fidelity system so that specific bands of frequencies can be fed to speakers designed to reproduce those frequencies.

Besides this obvious purpose of a cross-over network, it serves another useful function in that it protects the lighter, more delicate, tweeter voice



Courtesy Bozak

FIG. 54. A coaxial speaker with two tweeters.

coil from the high-power, low-frequency signals. Such protection of the tweeter is always necessary.

The tweeter in a two- or three-way system can be protected by connecting a capacitor in series with it as shown in Fig. 55. The capacitor serves to block the low frequencies from the delicate tweeter voice coil. As the frequency is increased, the reactance of the capacitor decreases, and more and more energy is fed to the tweeter. The high frequencies are fed to the woofer at all times. The high-frequency output of the system will then be a combination of the tweeter output and the woofer output. Very often woofers are specifically designed so that they do not produce high frequencies, or the set-up shown in Fig. 55 could be used with a full-range speaker as the woofer and then the tweeter would simply reinforce the very high end where the full-range speaker would tend to fall off.

The capacity of the cross-over capacitor in Fig. 55 would depend on the tweeter and the characteristics of each speaker. The speakers must match each other; that is, if the woofer response tends to fall of at 2000 cycles per second, then the tweeter must be designed to operate as low as 2000 cycles per second. If the woofer falls off at 2000 cycles and the tweeter does not operate below 4000 cycles, there will be a "hole" in the response between 2000 and 4000 cycles. In such a case, either a different woofer or a different tweeter should be used, or a mid-range unit should be added to the system.

Fig. 55 is not a true cross-over network. In a true cross-over network, not only are the low frequencies blocked from the tweeter, but also the high frequencies are blocked from the woofer. This gives a definite advantage. It prevents double-source sound which can cause frequency cancellation at various spots in the listening area. In addition, a full cross-over network can increase the acoustic output of each speaker by about 3 db, since the high frequencies will not be "burned up" in the woofer voice coil in the form of heat. The cross-over will also help prevent woofer cone break-up at high signal levels. This cone break-up problem does not occur in all speakers, since some woofers are specifically designed to be operated without a full cross-over network, and cone break-up is kept to a minimum.

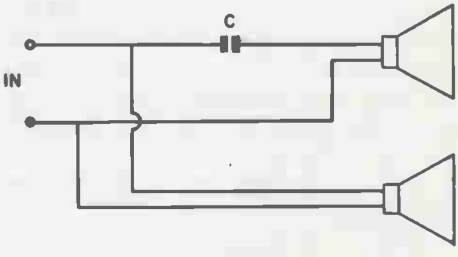
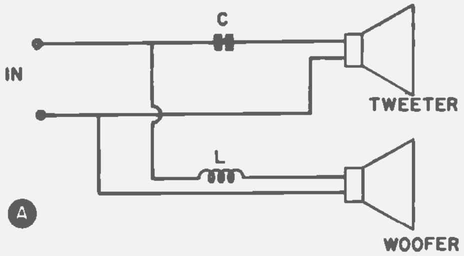


FIG. 55. A cross-over network.



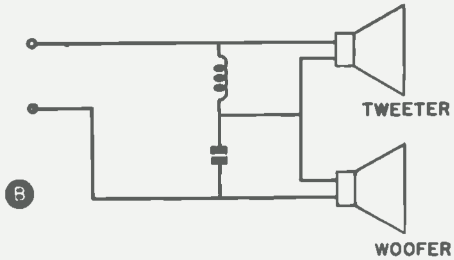


FIG. 56. Two types of cross-over network. A is a parallel quarter section; B is a series quarter section.

There are actually two different types of cross-over networks, but only one is used much in high-fidelity systems. Both types are shown in Fig. 56. Notice that the full cross-over networks shown in this illustration differ from the system in Fig. 55 in that a coil is connected in the circuit. The quarter-section parallel network in Fig. 56A is the most commonly used type. The series-type quarter-section network in Fig. 56B is not very often used. Notice that, as the name implies, the woofer and tweeter are connected in series in this network. The coil and capacitor are connected in parallel with the units. Since they are in parallel, the capacitor is used with the woofer and the coil is used with the tweeter which is opposite to Fig. 55A.

It is also possible to use more coils and capacitors as shown in Fig. 57. The tweeter again has a series capacitor, but also a parallel coil; the woofer again has a series coil, but also a parallel capacitor.

The main difference between the quarter and half-section networks is that the quarter section has an inherent attenuation rate of approximately 6 db per octave, while the half section has an inherent attenuation rate of 12 db. Incidentally, the single capacitor shown in the simple network of Fig. 55 has an attenuation rate of about 3 db per octave.

The networks shown so far are two-way cross-over networks. In other words, they provide for the use of only a woofer and a tweeter. When it is necessary or desirable to use a mid-range speaker, more elements must be added to the cross-over network. Such a cross-over network is shown in Fig. 58. Three speakers are used in this system: a woofer designed to operate below 300 cycles, a mid-range speaker designed to operate between 300 and 3500 cycles, and a tweeter designed to operate above 3500 cycles. The cross-over network is similar to those previously discussed. Notice that a half-section network is used for the tweeter, a half section for the mid range, and a quarter section for the woofer. By carefully choosing the components in the networks, proper cross-over points are obtained.

The coils used in cross-over networks must be composed of very large wire and carefully wound to keep the Q very high. For example, with a 4-ohm speaker voice coil, the resistance of the cross-over coil must be kept to a

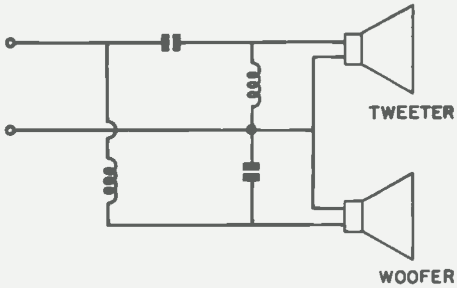


FIG. 57. A half-section cross-over network.

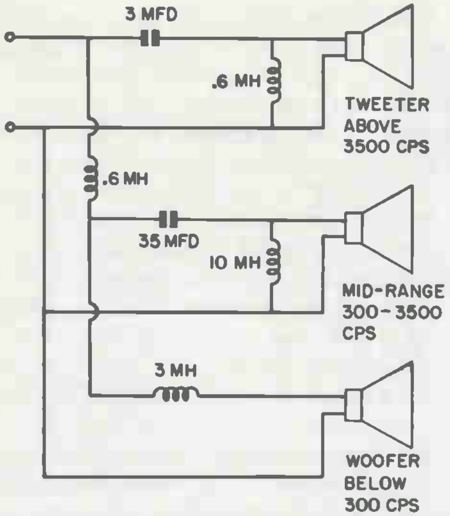


FIG. 58. Cross-over network for three speakers.

small fraction of 4 ohms so that the power will not be dissipated across the cross-over coil instead of being fed to the speaker voice coil.

The capacitors are generally of the oil-filled or paper variety. It is not considered desirable to use electrolytic capacitors in a cross-over network although they are sometimes used with success; in such a case, there should be two for each capacity, and they should be wired "back to back" as shown in Fig. 59.

Sometimes a cross-over network is used to separate the low and high frequencies between the preamplifier and the power amplifier instead of between the amplifiers and the speakers. When this is done, simple R-C networks are used, and a separate power amplifier is required for each speaker. Naturally, such a system is expensive, because of the separate power amplifiers. Because of the expense, such systems are rarely used, particularly in stereophonic systems where even a two-way speaker system for each channel would require a minimum of four power amplifiers.

REPRODUCING HIGH FREQUENCIES

As explained previously, some speaker manufacturers utilize full-range speakers to reproduce the entire audible spectrum. However, although such speakers are capable of excellent low-frequency reproduction, they very often fall down on the high end. The companies that produce full-range speakers also usually produce separate tweeters and cross-over networks designed to be used with the full-range speakers to extend the high end.

It is not particularly difficult to design a tweeter to reproduce frequencies up to 15,000 cycles with sufficient intensity. It is quite difficult to reproduce frequencies above 15,000 cycles, and is extremely difficult to reproduce all frequencies above 10,000 cycles with smooth, even response, free from coloration, that is, unnatural texture. The problem, then, is to reproduce frequencies above 10,000 cleanly and evenly and to disperse them over wide areas. Let's look at these problems.

Dispersion. High-frequency wavelengths are very short compared to low-frequency wavelengths, and the sound tends to spread very poorly. The output of the tweeter tends to be directive like a beam of light, so that the area covered by the tweeter is very small.

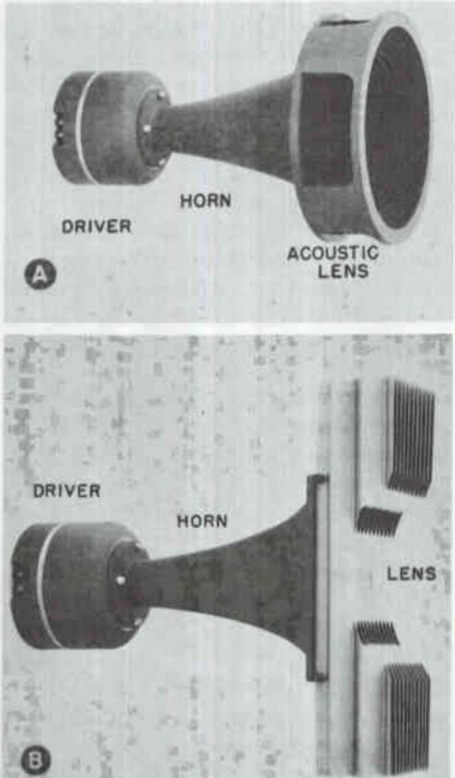
Many methods have been devised to spread or disperse the tweeter sound. Some tweeters have a perforated metal covering as explained previously. More expensive units have some

FIG. 59. Two 10-mfd electrolytics connected "back-to-back" for use as 5 mfd in a cross-over network.

sort of horn or lens assembly. Examples of this are shown in Fig. 60. In these two illustrations the same driver and horn are used with two different assemblies designed to spread the high frequencies. Fig. 60A shows an acoustic lens attached to the horn. This lens actually acts like an optical lens system, but is composed of perforated metal plates of different diameters.

The disperser shown in Fig. 60B is also known as an acoustic lens, but works on a slightly different principle. The metal baffle plates are used to spread the high frequencies over a wide area.

Even Reproduction of Top Octaves. In order to reproduce the top octaves, the tweeter assembly must be precisely manufactured with extremely close tolerances and must be fitted with a highly efficient and large magnet assembly. These characteristics are also required for smooth reproduction. There are a number of inexpensive cone and horn tweeters on the market that are capable of reproduction approaching 20,000 cycles per second, but because of insufficiently large magnet assemblies, or poor quality control, the reproduction is "ragged." That is, the efficiency or output of the tweeter varies with frequency and the output may vary as much as ±10 db between 10 kc and 20 kc. Such reproduction tends to cause the high frequencies to sound harsh.



Courtesy James B. Lansing Sound, Inc.

FIG. 60. Two types of lens assemblies used with the same driver and horn.

There is no distinct advantage of either cone or horn-type tweeters. However, each does have its own characteristics. Generally speaking, horn tweeters are more efficient than cone tweeters, and are capable of much wider dispersion. However, many horn tweeters, particularly those made from metal, have a somewhat harsher "metallic" sound than cone tweeters. Cone speakers, on the other hand, seem to have a "softer" quality to the reproduction. They are, however, characterized by low efficiency and poor dispersion. It is not uncommon to find two or more cone tweeters used in a system, whereas it is rare to find more than one horn tweeter used. Of course, the use of many cone tweeters in a system increases the price considerably.

It is possible by using Bakelite or some other such substance for the horn structure and linen for the diaphragm to reduce the metallic quality of a horn to an insignificant point. By doing this, the efficient dispersion of the horn can be retained, and most of its undesirable characteristics eliminated. Of course, such horns are quite expensive.

Courtesy James B. Lansing Sound, Inc.

FIG. 61. A speaker designed to have a low resonant frequency.

REPRODUCING LOW FREQUENCIES

Low-frequency reproduction probably presents even more problems and more proposed solutions than high-frequency reproduction.

Magnetic Assembly. The magnetic assembly of the high-fidelity loudspeaker is of utmost importance. The reproduction of steep waveforms is probably far more important than extreme frequency response. In order for a speaker to reproduce these waveforms it must be capable of abrupt starting and stopping in its movement. In order to do this, a very strong magnetic field must be used in the voice coil gap. This can only be accomplished by large and efficient magnetic assemblies.

Acoustical Damping. In addition to the electrical damping of the magnetic assembly, the speaker must also be properly damped acoustically.

As you learned previously, the loudspeaker has a certain resonance. That is, the output of the speaker will be fairly constant to its resonant point and then tend to rise sharply, falling off rapidly below the resonant point. It is evident that the low-frequency response of the speaker will depend on its resonance. If the speaker should resonate at 100 cycles there will be little or no output below 100 cycles despite the type of baffling. Of course, with improper or insufficient baffling there could be little output below 200 cps even though resonance occurs much below this point.

It is obvious then that one method of improving the low-frequency response of a speaker is to lower its resonance. There are a number of very low resonant speakers now on the market that offer phenomenal bass response with cabinets of moderate size. For example, the speaker shown in Fig. 61 has a resonance of approximately 19 cycles per second.

It is also necessary to baffle a loudspeaker in order to obtain low-frequency reproduction. If the speaker is not baffled, sound waves coming off the back of the cone will cancel those coming off the front.

Since the necessity of baffles for speakers and the basic types of enclosures were discussed in an earlier lesson, we will not repeat the information here, but we will look at some other baffles that are used strictly for high-fidelity reproduction.

First of all, as you learned previously, one of the best ways to extend the low-frequency response of a speaker and to satisfactorily couple the low-frequency sound to the room is to use a horn such as shown in Fig. 62.

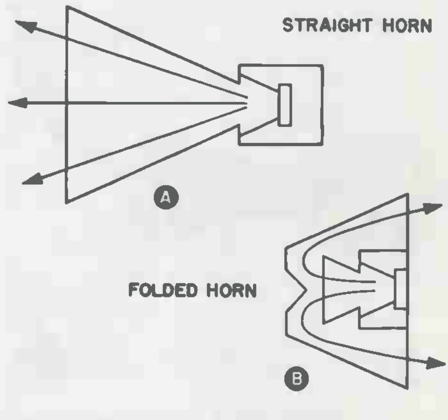
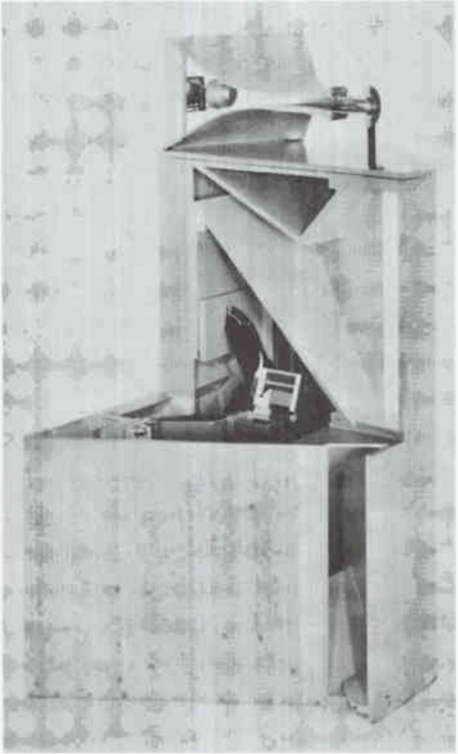


FIG. 62. Horn-type speakers. A, a straight horn; B, a folded horn.

Unfortunately, in order to reproduce the low frequencies necessary for high fidelity, the straight horn shown in Fig. 62A would need to be approximately 30 feet long with a mouth diameter of at least 12 feet. Such a horn would not even fit in a home. Even folded as shown in Fig. 62B, the horn would still have to be extremely large.

Horn systems can be used in the home by varying the horn formula or by utilizing the walls of the room as an extension of the horn mouth. However, even though this is done, a folded horn is still a very large and complicated device.

One of the best known high-quality folded horns is the Klipschorn shown in a cutaway view in Fig. 63. As can be seen, this particular horn is extremely complicated, and is made of heavy wood with many intricate folds and braces. The structure on top of the main enclosure is a special mid-frequency horn, and a high-frequency horn can be seen inside the mid-frequency horn.



Courtesy Klipsch Associates

FIG. 63. A cut-away view of the Klipschorn.

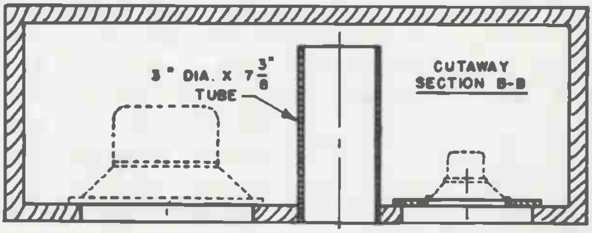
The horn in Fig. 63 is called a front-loaded horn, because the sound from the front of the cone is directed through the horn and eventually into the room. The speaker itself is mounted in a cavity of predetermined size. Another possible method of horn-loading a speaker is to mount the unit so that the front of the speaker faces the room and the back works into the horn structure. This latter method is quite common since it is then possible to use the output from the front of the cone for mid-frequency reproduction and the output from the back for low-frequency reproduction. Suitable acoustic filters in the horn can prevent mid-frequency reproduction through the horn. It is necessary to keep mid- and high-frequency sounds out of the horn, because the wavelengths at these frequencies are too short for the horn length, and standing waves would be set up in the horn.

Folded horns that do not work directly into the room generally utilize cross-over networks designed to crossover below 400 cycles. Either horns or cones can be used with them for the mid- and high-frequency reproduction. Since the low-frequency horn is a highly efficient device, it is generally desirable to use horns for both mid and high frequencies in order to match efficiencies.

In addition to the horns which we have discussed, many other types of enclosures are used to extend low-frequency response. Probably the most popular type of enclosure is the bass reflex which was discussed in an earlier lesson. As you learned previously, this type of enclosure is designed so that its natural resonance is the same as the resonance of the speaker. The sound is fed out from it through a port. This sound is in phase with the sound from the front of the speaker. At the resonant frequency, the air in the enclosure highly damps the speaker cone, cancelling the rising response of the speaker at its resonant frequency, resulting in smoother, extended low-frequency response.

Generally speaking, the lower the resonance of the speaker, and therefore, the cabinet, the larger the cabinet must be in physical size. Since the present trend is for very low-resonance speakers, the enclosures would be of unusually large size.

Infinite baffles, which are simply large enclosed boxes, have largely been neglected by most manufacturers of speaker systems, even though they are quite simple to build. Tbe reason for this is that although the infinite baffle does effectively prevent the sound from the back of the speaker cone from cancelling the output from the front of the cone, the cabinet has the undesirable characteristic of raising the resonance of the speaker because of the acoustic capacity effect of the enclosed air. Since low-frequency response falls off rapidly below the resonance of the speaker, and, until recently, it was rare to find a



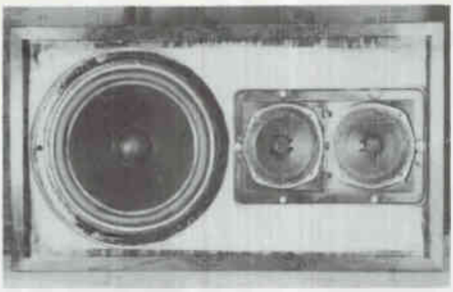
Courtesy Jensen Mfg. Co

FIG. 64. A speaker enclosure with a vent tube.

This can be quite inconvenient, particularly in stereo when two such enclosures are necessary. In order to reduce the size of the cabinet and still tune it properly, the use of ducts or tubes in the cabinet has become quite popular. Such a vented system is shown in Fig. 64. The enclosure around the port can be either in the form of a tube or a rectangular duct, whichever is more convenient to the manufacturer. The use of the duct or tube effectively increases the size of the cabinet as far as its resonance is concerned. Of course, just as the size of the port is critical in an ordinary bass reflex cabinet, the size of the tube or duct is critical in this type of cabinet, not only its diameter, but its length as well.

loudspeaker with a very low resonance, any cabinet raising the resonant point was undesirable. However, because of the recent development of very low-resonance speakers, it is now possible to use a small infinite baffle and still retain satisfactory low-frequency response. For example, if an infinite baffle raises the resonance of the speaker to 10 cycles, a speaker with a resonance of 30 cycles would still have a satisfactory low-frequency response down to 35 or 40 cycles.

Acoustic Suspension Systems. The forerunner of today's very low-resonance speakers is the original acoustic suspension speaker developed by engineer Edgar M. Villchur. As you know, the spider and outer edge of a



Courtesy Acoustic Research, Inc.

FIG. 65. An acoustic-suspension speaker system.

speaker cone act as a spring system to keep the voice coil in the magnetic gap. Any signal applied to the speaker voice coil will move the cone either out or in, depending on its polarity, and the spider-cone edge acts as a spring system, pulling the cone back to its original position. The resonance of the speaker, and thus its low-frequency response, depends largely on the compliance (elasticity) of this spider-cone-edge suspension. In the acoustic-suspension speaker an extremely compliant spider is used, which by itself could not control the cone action. The outer ring usually used is replaced with a very light, thin, rubber-like suspension system. When a signal is applied to the speaker and the cone moves away from its normal position, the spider-edge system will not pull it back. This restoring force is instead supplied by the air in the cabinet in which the speaker is mounted. The cabinet is of relatively small size and is completely shielded and then filled with fiber-glass packing. This provides a very tight air load in the back of the speaker, which acts as a spring system.

A complete speaker system of this type is shown in Fig. 65. The woofer is shown at the left. Notice the thick edge of the speaker. The two smaller speakers at the right provide mid- and high-frequency reproduction.

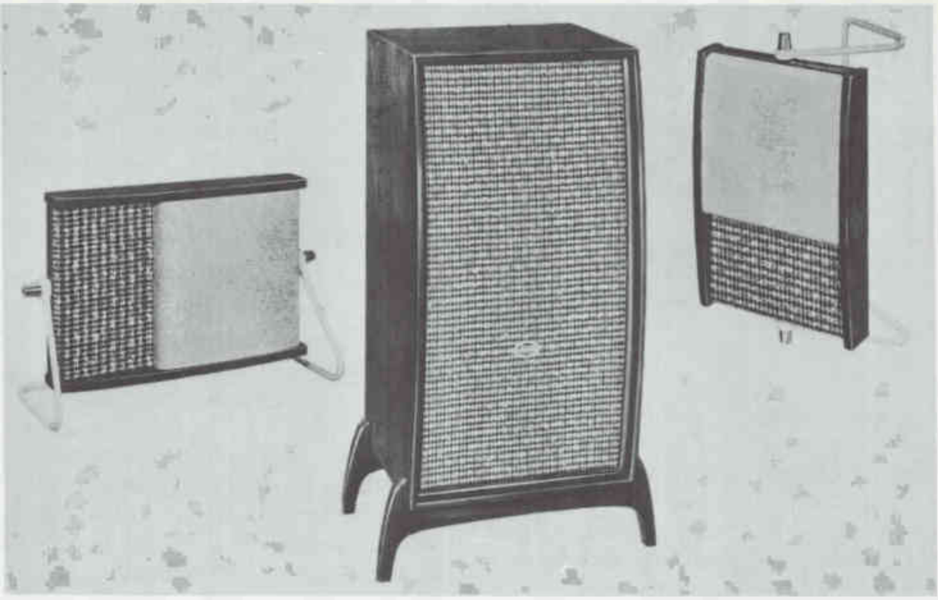
Despite the relatively small size of the speaker and cabinet, this particular unit is capable of low-frequency response approaching 30 cycles per second. Such response was unheard of just a few years ago with ordinary speakers and enclosures.

STEREO SPEAKERS

Most of the recent developments in speaker systems have resulted in physically small systems. This is largely due to the introduction of stereophonic reproduction, since it is extremely difficult, if at all possible, to find place in the average listening or living room for two very large speaker systems. Several means have been tried to combat the space problem. Fig. 66 shows a complete stereo system in one cabinet. This particular speaker system is unusual in that only one woofer is used to reproduce the low frequencies of both stereo chan-

Courtesy University

FIG. 66. A speaker system with one bass speaker and two high-frequency speakers in one cabinet.



Courtesy Jensen Mfg. Co.

FIG. 67. A speaker with one bass speaker and two high-frequency speakers in three cabinets.

nels. This is based on the theory that there is little directional perception below 300 or 400 cps. This woofer uses two separate voice coils on the same coil form, and the low frequencies of both channels are fed to the same woofer by means of cross-over networks. The mid- and high-frequency speakers are mounted in the sides of the cabinet, and thus face towards opposite sides of the room. With the doors open, as shown in Fig. 66A, the mid and high frequencies can be directed off the doors as desired by the user. By placing the doors in different positions, the user can vary the sound reflection according to the shape of the room. Since the low-frequency woofer faces the back of the cabinet, the doors can be closed for monophonic reproduction so that the sound is not quite as separated as for stereo reproduction.

Another stereo speaker system with only one low-frequency speaker is shown in Fig. 67A. This system uses a slightly different approach; it has three separate speaker cabinets. The large center unit is for bass reproduction of both channels, and the smaller units shown to the right and left of the larger unit are used for high-frequency reproduction, one for each channel. The bass response of both channels comes only from the center unit.

Many very large and excellent full-range monophonic speaker systems were purchased before the introduction of stereo. Manufacturers have brought out separate "out-rigger" units to be used with these speaker systems. For example, one particular small system has mid- and high-frequency speakers but not a low-frequency unit. Instead, a special control filter is used to feed the bass of both stereo channels to the original large speaker system. Thus, the system operates on the same principle as the ones shown in Figs. 66 and 67.

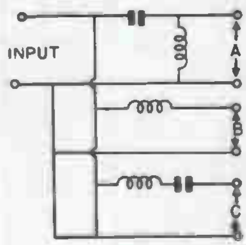
Lesson Questions

Be sure to number your Answer Sheet 30B-2.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. Name the three types of equipment used to play records.
2. What does the term rumble mean as applied to record players?
3. What is the difference between wow and flutter?
4. Name two advantages of using a synchronous motor in a record player.
5. Name three methods of reducing hum in a preamplifier.
6. What is the purpose of a stereo-adapter unit?
7. What is amplifier damping?
8. Why do some cone-type mid-range speakers and tweeters use a closed basket?



9. In the crossover network diagram at the right, which terminals would be used to feed the woofer? What would be the approximate rate of attenuation per octave of the signal fed to the tweeter?
10. The low-frequency response of a properly baffled woofer is primarily determined by which of its electrical specifications?

VARIED INTERESTS

Don't go stale! Keep a fresh, active interest in everything you do. When you work or when you play—work hard, play hard. When you study, concentrate on study. When you stop working, or playing, or studying—let go. Forget about it. The best vacation is merely a complete change from what you have been doing. Loafing is not a vacation—it is merely boredom.

There is nothing better for an office worker after hours than a brisk walk, a swim or a round of tennis. There is nothing better for an outdoor worker than a quiet hour with a book or a good newspaper. But don't do the same things all the time. Vary your life as much as you can. Cultivate a keen interest in the world of which you are a part.

Keeping alert keeps you young. Keeping interested keeps up your energy. Together these things will make you able to learn more in a given period of time. Finally, the more you learn, the more easily you learn.

J. E. Smith