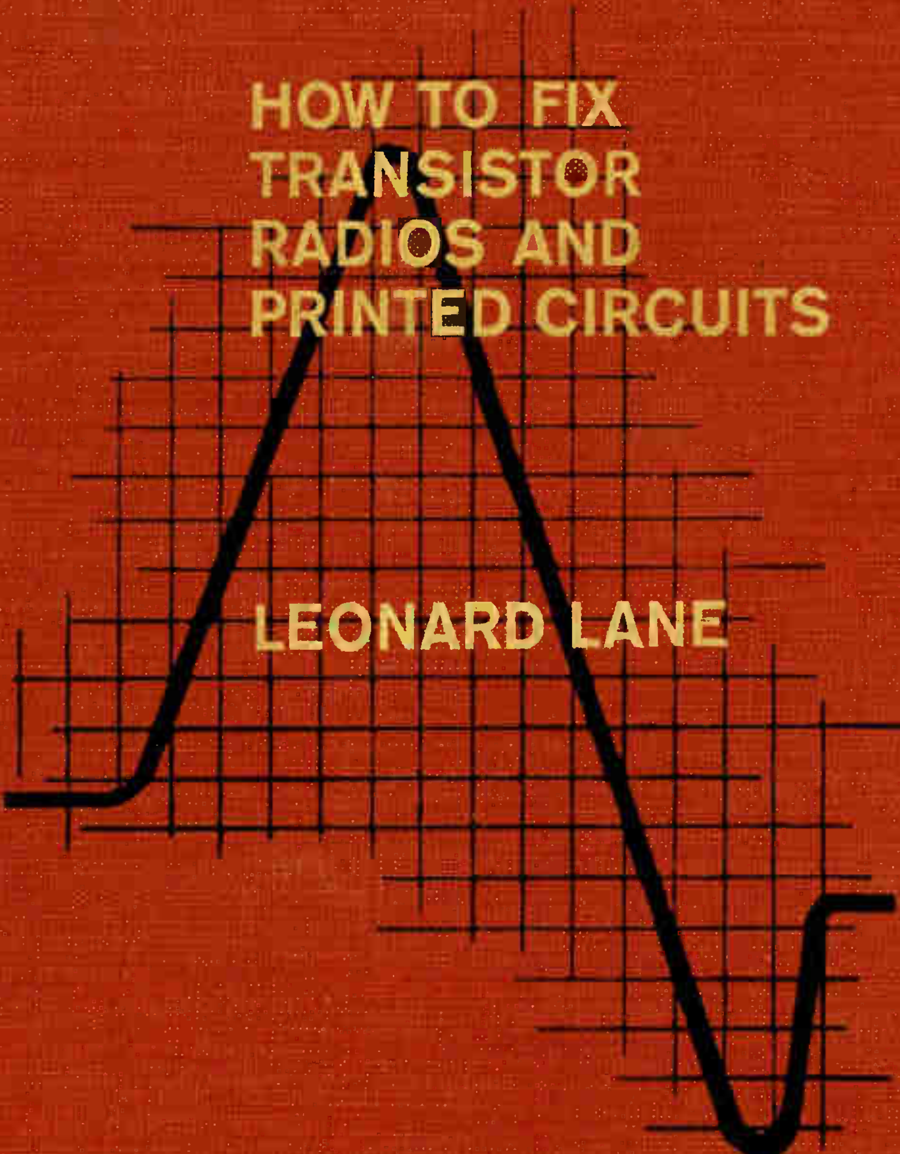
HOW TO FIX TRANSISTOR RADIOS AND PRINTED CIRCUITS

LEONARD LANE



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HOW TO FIX TRANSISTOR RADIOS & PRINTED CIRCUITS

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Volume 1

contents

To Arlene, Stewart

and Clifford

introduction

THIS book, a revised version of a Transistor Radio Repair Course offered by a leading manufacturer in cooperation with Radio Television Training of America, aims to give the service technician a better-than-average working knowledge of transistors, their components and associated circuitry. Semiconductor materials are the foundations from which the building blocks of basic transistor circuitry are developed. Stage by stage the electronic structure of the complete transistor receiver is assembled and analyzed.

Mathematics has been avoided for easier reading. But this does not mean that any technician can entirely ignore such basic calculations as Ohm's law constantly forces upon him in his daily work.

The new concepts of semiconductor applications in the entertainment field have not been oversimplified, but the text does try to allay any fears of delving into a strange, new world of low voltages and high capacitances not encountered in the more familiar vacuum-tube circuits.

The text is written in a friendly manner to help the technician feel at home in this wonderland of semiconductors that promise to increase the electronics field tenfold. Not only has the portable radio given new life to the broadcast entertainment field, but already pocket-size, transistor-operated two-way communicators are available to save steps and time. This book teaches you their principles; they are a stepping stone to the myriad uses of semiconductors in commerce and industry.

Sooner than you might expect, the production techniques used by manufacturers to bring music and news to you anywhere at the turn of a knob will also allow you to keep in touch with, not only business associates, but your family and friends as well. Microscopic in comparison with today's computers, handy calculators will replace the engineer's slide rule and even the accountant's adding machines and more complex calculators. Movies will be recorded, with sound, on magnetic film and viewed through television sets, without any additional processing. These and many more marvels will be produced using the same basic theories that made possible the transistor portable radio.

The material learned here will, when properly applied, be an additional source of revenue for the practicing electronic technician. Time saved by improved techniques means more jobs can be handled in a normal workday, and work that previously had to be passed on to others can now be handled — and both mean added income.

In any course of study, review of the basic points is a constant necessity; therefore, none of the repetitions have been deleted. Some facts and techniques are common to many circuits and may be included in the text at all of these points as reminders as well as reviews. Some techniques are injected into the theory where appropriate, and again presented to emphasize a practical application of a principle in servicing in the second volume.

LEONARD LANE

chapter 1

semiconductor fundamentals

THE transistor is a comparatively new device (it was invented in 1948 and developed since that time) yet its ancestry is almost as old as that of the vacuum tube. Radio receivers and radio broadcasting became popular immediately after the ending of the first World War. In those days, vacuum tubes were so expensive that a handy little substitute was preferred. This vacuum-tube substitute, the crystal detector (Fig. 101), had a variety of names.

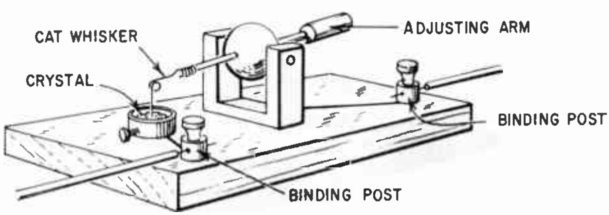


Fig. 101. *The crystal detector has a long history. The drawing shows a detector that was popular many years ago.*

It was known as iron pyrites, galena or carborundum. These minerals, for that is what they are, were used as detectors or signal rectifiers. They formed the heart of the crystal set, a very popular receiver noted for the fact that it required no outside power source, did not need an on–off switch and could be left on indefinitely. The receiver had the advantage of being foolproof and shockproof and could be constructed by practically anyone.

At the height of its popularity the crystal set was probably as widely used as television receivers are today. The crystal set, however, had a very serious disadvantage. The crystal detector could rectify the signal but could not amplify it and so, hand in hand with the crystal set, came a pair of earphones. Earphone reception, though, is a very tiresome affair, and it was not long before the crystal set was superseded by the vacuum-tube receiver – despite the fact that vacuum tubes were expensive.

For a number of years the crystal set and its crystal detector were banished to the attic. With the growth of the television industry, however, the crystal, now completely enclosed and having a fixed contact, was put back into service but it still performed its old function – that of a detector (Fig. 102). It did this job very well

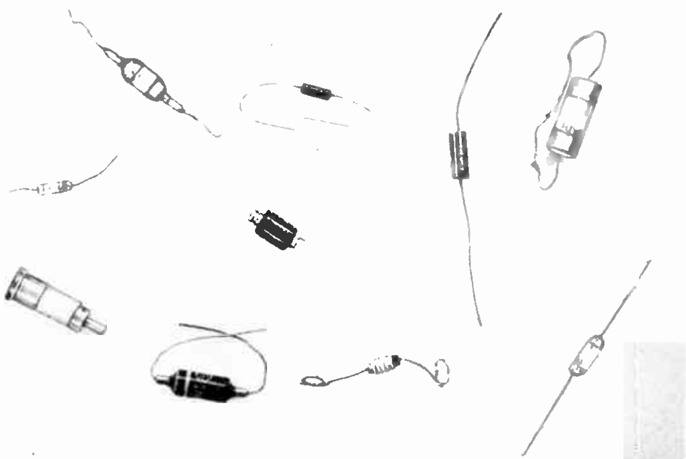


Fig. 102. *Crystal diodes are manufactured in a variety of shapes.*

and quite efficiently since it still required no external source of power. However, engineers and scientists were toying with the idea that the crystal might be made into an amplifier. During the 1920's a number of predictions were made that the crystal would be made into an amplifier, but it took a long time to achieve this objective. Today the amplifying crystal is more familiarly known as the transistor.

Conductors and insulators

In working with radio and television receivers, we can generally classify all materials as conductors or insulators.

Conductors and insulators represent extremes. At one limit, we have the conductor, and at the opposite end we have the insulator. But in between are a host of materials which have some of the properties of conductors and also of insulators. Such materials are known as semiconductors. These semiconductors have a crystal-like structure.

Crystalline substances are much more familiar to you than you may possibly realize. The salt you use on your food is a crystalline material. Certain forms of sulphur, such as copper sulphide and lead sulphide, are crystalline. Quartz is a crystal. Small slices of quartz are used to control the frequency of operation of transmitters. There are many other forms of semiconductors but the particular one in which we are primarily interested is known as germanium. Germanium, which we will discuss in considerable detail, is exactly the same type of germanium that you already know as a diode in radio and television receivers.

The movement of electrons

It is not our purpose to teach you atomic physics or chemistry and yet, if you are to service transistor radios and transistor television receivers, then you should know something about the nature

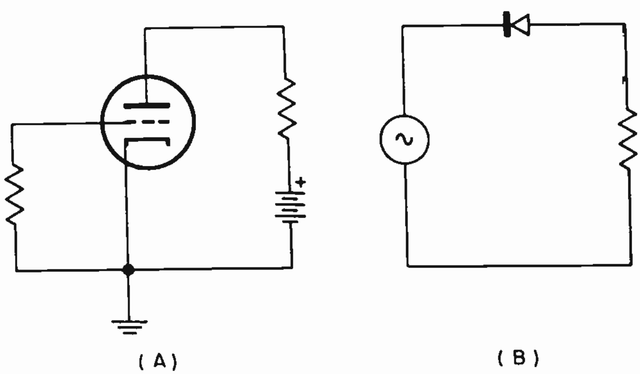


Fig. 103. *Electrons can move through a vacuum (A). They can also be made to move through a solid (B).*

of the movement of electrons. From your work with radio and television sets, you already know a bit about the nature of an electric current.

You know, for example, that electrons can be boiled out of a hot cathode and attracted to a positive plate (Fig. 103). This is another way of saying that electrons carry a negative charge and will be attracted to a positive point or area.

The movement of electrons in a vacuum (as in a vacuum tube) is somewhat different from the movement of electrons in a solid material. In a vacuum tube (aside from a few widely spaced grids), the electrons meet no interference. In a solid substance, such as a wire, electrons find their passage blocked by the atoms of which the copper wire is made. Electrons do not move through a copper wire with the speed of light. As a matter of fact, electrons in a copper wire move along rather leisurely. To get an idea of this motion, picture a small boy who wants to cross a stream. No bridge or boat is available. However, imbedded in the stream are a series of flat rocks and so our young adventurer is capable of crossing from one bank to the other by skipping from one rock to the next. The movement of electrons in a solid conductor proceeds in a

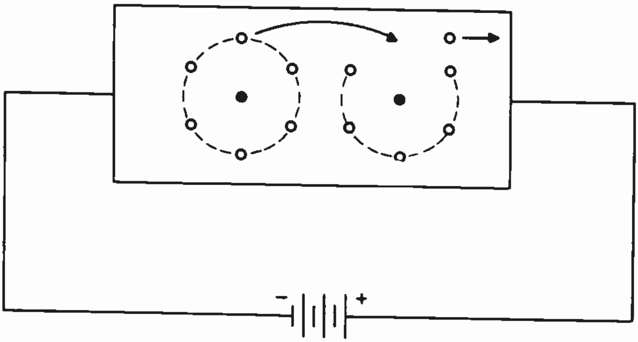


Fig. 104. *Electrons move from one atom to the next.*

similar manner. The electrons move from one atom to the next, ultimately arriving at their destination (Fig. 104).

This movement of electrons is exactly the same in a conductor as in an insulator — it is the same whether we are discussing a length of copper wire or a piece of plastic. The difference between a conductor and an insulator is not in the way the electrons move but in the amount of force needed to get them going. Electrons move fairly readily through a conductor, but it takes a lot of electrical force (or voltage) to persuade electrons in an insulator that they should be on their way.

Based upon what we have said so far, you might imagine that germanium is a rather good conductor since it is used as a diode detector in radio and TV sets. Strangely enough, completely pure germanium is an insulator and it is only when we add some impurities to it that we change its nature. Actually, by "doping" the germanium with impurities, we don't make it into the same type of conductor as a piece of copper wire, for example, but neither does it remain an insulator. Since we put it into a region somewhere between conductors and insulators, we now call the germanium to which the impurity has been added, a semiconductor.

Electrons in the bank

Germanium, like all other materials, is made up of atoms and each of these atoms consists of a cluster or rings of electrons encircling a nucleus.

In Fig. 105 we have a drawing of an atom of germanium. Essentially, it consists of a nucleus (or central portion) around which

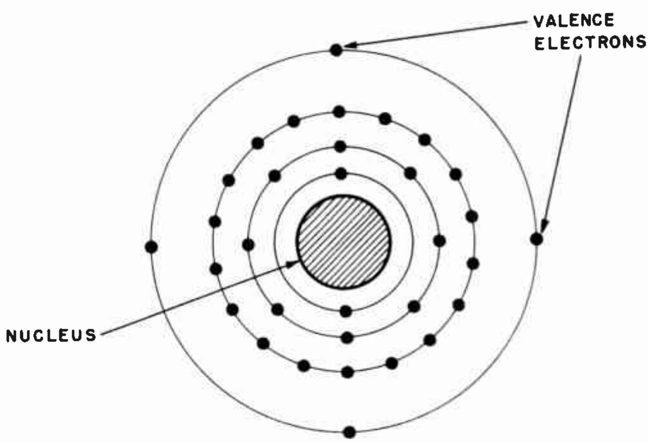


Fig. 105. *The germanium atom. The four valence electrons are the ones we are interested in.*

we have rings of electrons. The innermost ring contains 2 electrons; the second ring, 8; the third ring, 18, and the outermost ring, 4 electrons. These 4 electrons are known as valence electrons and are the only electrons in which we are interested.

The nucleus of the germanium atom has quite an attraction for all the electrons that revolve around it and it certainly isn't going to let them go without a struggle. However, of all the electrons shown in Fig. 105, the outermost or valence electrons are farthest from "home" (the nucleus) and so these are the ones we are going to maneuver into working for us.

In pure germanium, the electrons — all of them — are held fairly tightly by the nucleus. But suppose we add a substance to the germanium and let us also suppose that this substance contains electrons that are free to move. Although they are not actually such, we can consider electrons that are free to move as surplus electrons. Because of this condition, we can regard the germanium now as being "electron-rich" and it certainly has many more electrons than when we first started this business.

N-type germanium

Since all electrons carry a negative charge, what we have done in effect, by adding this impurity to the germanium, is to make it "negative-rich." An easy way of saying this is to abbreviate the word negative just by using the letter "n." And so, by adding an impurity to the germanium, we can make it into n-type. Remember, however, that we can't add just any substance. The impurity that is added to the germanium or is mixed with it must have electrons that are free to move.

Let us investigate this matter just a bit further and consider a substance such as antimony. The atoms in this material have five

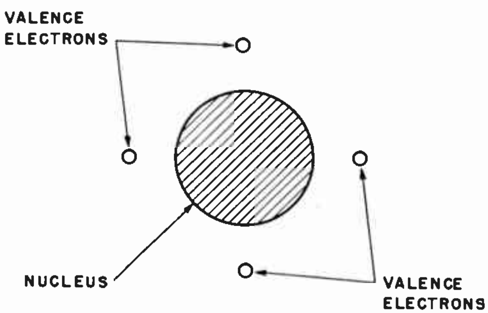


Fig. 106. *Simplified version of the germanium atom. The valence electrons are the ones that will work for us.*

valence electrons. By now, you must suspect what we are up to. If we add a small bit of antimony to the germanium, we are going to make the germanium "electron-rich." That is, it will have more electrons than germanium that is not so treated. Since the antimony gives or donates electrons to the germanium, we call it a donor material.

In Fig. 106 we have another picture of a germanium atom. Naturally, we have simplified this to a considerable extent so that we can get a clear overall view of what is happening. The large circle in the center represents the nucleus or central portion of the atom. There are many electrons surrounding this nucleus but they are not shown since we are not interested in them. Note that the nucleus is surrounded by the four valence electrons. The group of germanium atoms shown in Fig. 106 represents a condition of stability, since the electrons are firmly attached or attracted to their central nucleus.

If, as shown in Fig. 107, we add a donor material such as antimony, we no longer have a condition of stability. The antimony atom can join the crowd of germanium atoms but it is slightly embarrassed since it has one electron more than is really needed.

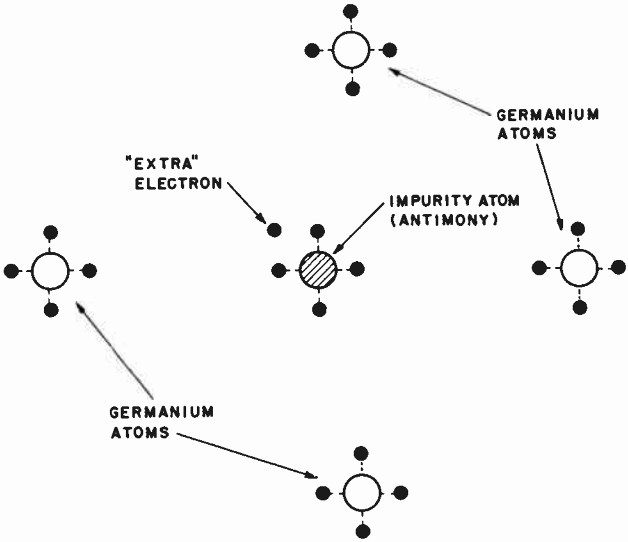


Fig. 107. *N-type germanium is formed by adding an "impurity" that contains excess electrons.*

As far as the antimony atom is concerned, this excess electron has its permission to go wandering off and not return. Now, if you will multiply this condition by the millions upon millions of excess electrons donated by the antimony, you will see that we have a very beautiful arrangement indeed. We have a large number of electrons at our disposal and we need do but two things: (1) put these electrons into motion and (2) control them in some way.

Now if you will think back to the way a vacuum tube behaves, you will see that we are sort of sneaking up on an operation that is already familiar to you. After all, a vacuum tube is simply a device for (1) supplying a large number of electrons and (2) giving us some technique for controlling the movement of those electrons. And so, you can easily see that we are planning to use the same techniques with which you are already familiar. The only difference is that we are going to try to work with a solid material instead of elements in a vacuum.

Electron bankruptcy

Since we have managed to deceive the germanium into believing that it too can be a conductor, let's see what will happen if we add another kind of impurity to the germanium. This time, though, let us add a material that has fewer valence electrons than the germanium. If you suspect that this is another case of being visited by poor relatives, you will be absolutely right.

A substance such as boron or aluminum has only three valence electrons — that is, one less than germanium. In Fig. 108 we show

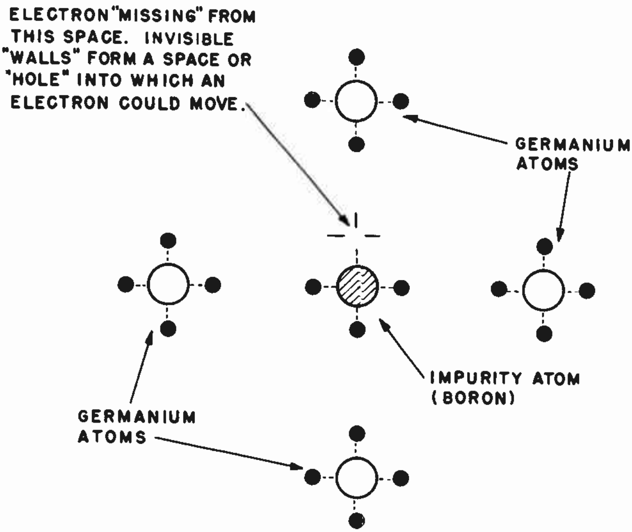


Fig. 108. *P-type germanium is formed by adding an "impurity" that has a shortage of electrons.*

this atom of boron in company with a number of germanium atoms. Everything appears to be fine except that there is a vacant space that should be occupied by an electron. Now it may very well seem to you that the radio and television industry has come quite a way if it has become interested in discussing "vacant spaces," but that is precisely what we are going to do.

Before we get started on it, however, consider a boarding house. A boarding house is of no value unless it has roomers. If the boarding house has 15 rooms and each of them is occupied, then we have a very good situation. But, what if one of the rooms is vacant?

What does it represent? Isn't it really a space into which a boarder could possibly move? It is true that the room is enclosed by four walls, a ceiling and a floor, but the boarder isn't going to live on the walls. He is going to occupy the space (if he rents the room).

In between the boron atom and the germanium atom, we have a "room." This room in our electronic boarding house is for rent. It is a space into which an electron could conceivably move. We give this space the very undignified name of "hole." If this idea of a hole seems fantastic, (and it is), remember that each of the valence electrons around an atom occupies a certain position. If we should remove one of the electrons from its position, it would leave a space into which we could put another electron. Now it

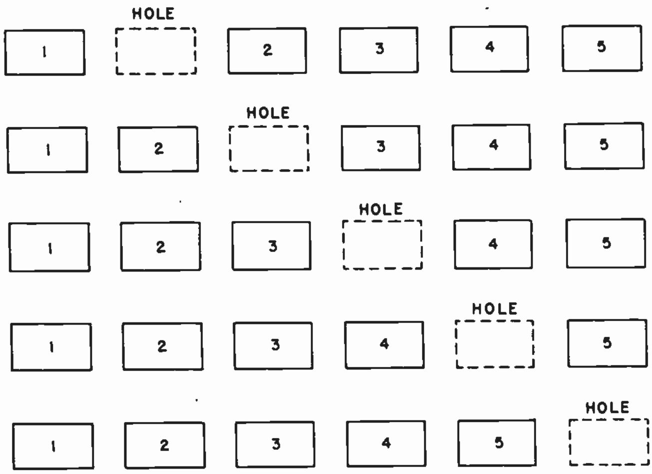


Fig. 109. *Each block represents a freight car. The vacant space or "hole" can be made to move back by changing the positions of the cars.*

may seem to you that space is space and that is all there is to it, but remember that these electrons are held in position by forces which keep them in a certain position with respect to the nucleus.

To make this a little clearer, let us imagine that you have a set of toy trains and that these are arranged on a circular track. You stand at the center and are therefore the nucleus. The set of trains goes around and around as long as power is applied. Let us assume that this train set consists of a locomotive pulling 10 empty freight cars. If you were to disengage the last car, you could substitute another car for it. In other words, the new car would take the place of the old one. That is, it would be inserted in the space occupied by the old one. Note that this isn't just any old space but a particular space. If you were to remove one of the cars somewhere in the center, you would leave a "hole" into which you could put some other freight car.

Movement of holes

Because it will be useful to us, let's continue playing with our set of freight trains. Let us imagine that we can remove any car we wish. Let us also imagine that the cars are all held together by side strips so that, if we do remove any one car, the train will continue in motion just as shown in Fig. 109. All that will happen is that we have a vacant space or hole where our particular freight car used to be. For example, we can have one possible arrangement of a freight train. Behind the locomotive is a big space into which we could put a freight car but which for the moment is empty. The side slats couple the locomotive to the remainder of the freight cars and so the cars are pulled along behind this vacant space. Let us call this vacant space a "hole." In this hole would normally appear freight car 1. We have, however, removed car 1, as you know. Now let us put car 2 in the space formerly occupied by car 1. We now have a hole between cars 2 and 3. Continue a step further and put car 3 into hole 2, just as shown in Fig. 109. A hole now appears where car 3 used to be. Without carrying this analogy much further, you can readily see that, with a bit of imagination, we can move a hole from the locomotive right on back to the caboose or we can go in the other direction if we wish. Once again we call your attention to the fact that we are not moving just any old "space" but rather a space that is reserved for a particular car.

What we have done with a set of freight trains we can do with atoms. Just as we can pass along an electron from one atom to the next, so too can we pass along a hole from one atom to the next.

A material such as aluminum or boron which has less or fewer valence electrons than germanium is known as an acceptor impurity since it is capable of accepting or taking electrons from the germanium.

That business of polarity

An electron has more in common with a freight car than you might imagine. A freight car has substance and so has an electron. A freight car has weight and so has an electron. The difference is one of size. In addition, however, an electron carries a negative charge. If, for some reason, we can force an electron to move away from its atom, it leaves a space that can be filled by some other electron, but, when an electron moves away, it takes its negative charge with it. When an electron moves from the space it occupies, this space or "hole" is said to be positive.

Don't let this terminology confuse you. It's really quite practical. As an example, if you had 50¢ in your pocket as represented by two 25¢ pieces, you might consider your financial condition quite sound. If you should spend one of the 25¢ pieces, you could represent your condition as "minus 25¢." This concept isn't any different from similar radio and television theory you have studied before. If you can force electrons to leave the top plate of a capacitor and migrate to the bottom plate, you simply say that the top plate is positive (it has lost electrons) and the bottom plate is negative (it has gained electrons). We now apply the same sort of thinking to the space or hole vacated by a departing electron.

P-type germanium

Let us now consider a substance such as boron. Instead of four valence electrons, it will have only three electrons and a hole into which we can squeeze a spare electron (if we can get our hands on one). Since we don't have an electron available at the moment, the hole will have to be represented by a positive charge. Of course, if we mix this material with germanium, we will in effect be adding a tremendous number of positive charges to the germanium. For this reason, when donating an impurity that is deficient in electrons to germanium, we create a new sort of semiconductor to which we give the name "p-type" (Fig. 108). The letter "p," of course, is an abbreviation for the word *positive*. Now that we have two types of germanium, n-type and p-type, we are ready to go into the business of manufacturing transistors.

The semiconductor diode

As a first step in the manufacture of transistors, let us make ourselves a germanium sandwich. This sandwich will consist of two slices of germanium — p-type and n-type. One of these slabs, the p-type, is rich in positive charges and the other, the n-type, is characterized by an excess of negative charges. And, since we are not satisfied to let well enough alone, let us put our germanium sandwich across a source of voltage such as that supplied by a battery. This is shown in Fig. 110.

You probably know exactly what will happen but we cannot restrain ourselves from telling you. The electrons, shown as solid black dots, will try to move through the germanium toward the

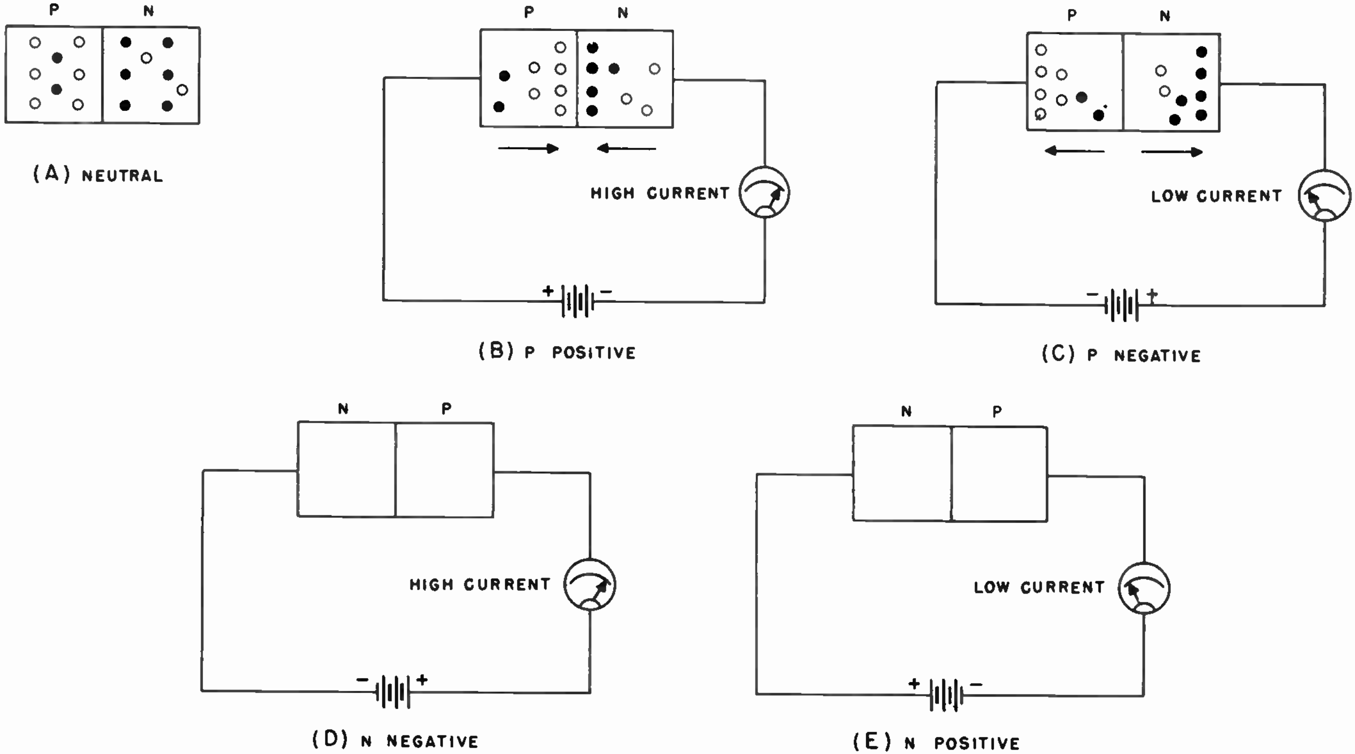


Fig. 110. *When the p-n diode is properly biased, a "high" current flows.*

positive side of the battery. And what about the little circles that represent the holes? As you can see in the illustration, they will migrate toward the negative side of the battery. This is quite natural since the negative terminal represents a source that is rich in electrons. Of course, if we turn the battery around, the situation will be complete reversed. Note the meter reading in both these illustrations. In the first instance, the meter indicates a rather large flow of current and in the second drawing, the meter is either zero or is very close to it.

A new kind of thinking

Your background and your training have been such that you are accustomed to thinking only of the movement of electrons. All of your radio theory and experience – especially in vacuum tubes and circuits – emphasizes electron flow. It will be much easier for you if you can now conceive of the idea of "hole" flow. After all, a hole is a "positive" charge and it really is no more unusual for a positive charge to move than for a negative charge. This doesn't mean that our study of transistors proves that everything we studied about vacuum tubes is wrong. On the contrary, our knowledge is moving along and growing and as a result we need to think about current in a new way.

We have one suggestion to make that you may find helpful. Instead of thinking of "electrons" and "holes" as two separate items, group them in your mind as a single unit and call them current carriers.

Now let's get back to our germanium sandwich. The flow of current carriers is due to the movement of electrons and holes. But, when we speak of current carriers, we know that both electrons and holes are involved. It's interesting to know which of these two items makes the greater contribution. The answer is quite easy. We've got n-type and p-type germanium placed close together. It would be somewhat unusual if the n-type germanium had exactly as many electrons as the p-type had holes. That is, if the n-type has 1,000,000 electrons, the odds are very much against the p-type having 1,000,000 holes. Either we have more holes or more electrons.

And what about our current flow (since that's what we're really interested in)? If our n-type germanium is rich in electrons and the p-type germanium is on the poor side and doesn't have many holes, then our "current flow" will consist mostly of electrons. If the opposite is true, then our "current flow" will consist mostly of

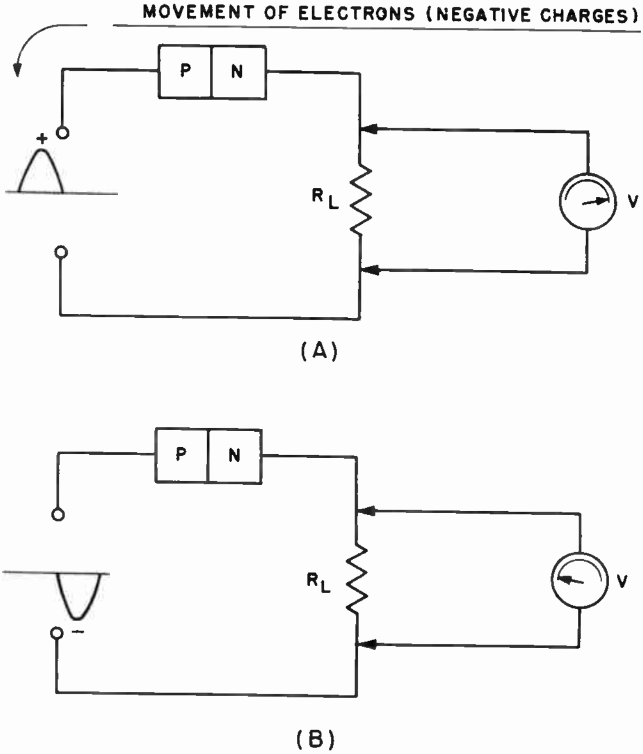


Fig. 111. *A p-n diode acts as a rectifier for an ac voltage.*

holes. From a practical point of view, we don't care too much since we are going to start thinking of current carriers — and that viewpoint covers both electrons and holes.

Transistor language

It is about time that we began to learn some of the very special phrases that are used in transistor work. The voltage that we apply to our transistor sandwich is known as a bias voltage. A bias voltage is a steady dc potential and, instead of referring to the transistor as a sandwich, let us call it a junction. We know that when we apply a bias voltage to our junction diode, we will get a large current in one instance; if we reverse the battery leads, we will get a very low current. The state of affairs under which we had a large current is known as a condition of low resistance. Low resistance and high current are similar — two ways of saying the same thing.

Since we will get a large current flow, we say that the junction diode is biased in the forward direction. When the junction diode is biased in the reverse direction (battery transposed), we have a condition of very low current or very high resistance.

Now this sort of behavior is not new to you. It is exactly the same way in which a germanium diode performs when acting as a detector in a television set. As you know, such a diode permits current to flow much more readily in one direction than in the other. While it might seem to you that we are right back where we started, we are now actually only one short step away from converting our diode into a triode amplifier.

Instead of biasing our diode, we can apply an ac voltage as shown in Fig. 111. Here we have a p-n diode connected to a source of ac. In series with the diode we have placed a load resistor, R_L. To learn if current will flow through our resistor, we have a voltmeter placed across it. In Fig. 111-A, we see that the positive half of the input cycle is being applied. This is the same as a condition of forward bias – that is, we are putting a positive voltage on the p-region. A large current will flow through the load resistor. When the input cycle changes its polarity, as shown in Fig. 111-B, the voltage applied to the p-region will be negative. This is the same as a condition of reverse bias, and so very little current flows through the diode load.

We could, of course, reverse the direction of current flow through the diode load simply by transposing the p-n diode. This behavior is exactly similar to the crystal diodes used as detectors or demodulators in radio and TV sets.

Making the sandwich

In calling a p-n unit a sandwich, we have probably given you the completely mistaken idea that a manufacturer simply slaps two pieces of germanium together. Making p-n units (and transistors) is a tough job and the manufacturing plant looks more like a big laboratory than a factory. There are many elaborate techniques for making transistors. We need not study them but we should know something about the fundamental types.

In Fig. 112-A we have a point-contact type of p-n unit. It consists of a large section of n-germanium and a very small area of p-germanium. Contacting the p-region is a fine pointed wire known as a catwhisker. Those of you who are old-timers will recall that crystal receivers in the early 1920's also used a catwhisker on the crystal. The idea is the same. The point-contact type is considered obsolete – but you can never tell. It has many unique possibilities and some day may be popular again. However, you will not find it used in any of the transistor receivers you will encounter.

In Fig. 112-B, we have what is known as a grown type of junction. This type of unit is made by adding the proper impurities to the crystal during its manufacture. Fig. 112-B is a highly simplified illustration and may give you the idea that we have two

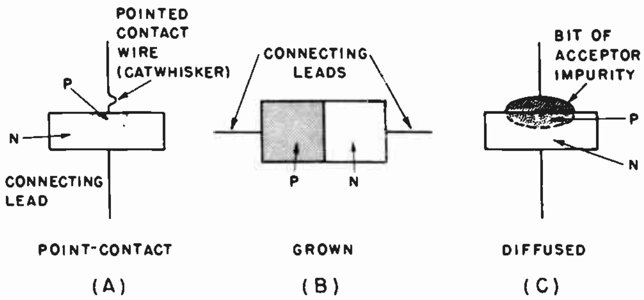


Fig. 112. *The p-n "sandwich" can be made in many ways. The point-contact type, is practically obsolete.*

separate and distinct blocks of germanium. The structure of the grown p-n unit is fairly complex, but for our purposes the illustration of Fig. 112-B will serve.

In the third illustration (Fig. 112-C) we show a diffused p-n unit. Here the impurity is placed on a bit of n-type germanium. With the application of heat, part of the p-type germanium diffuses into the n-type germanium – hence the name applied to this type of structure.

Fig. 113 is a photo of some of the semiconductor power rectifiers that have been popular. We have included some selenium types along with the silicon and germanium rectifiers for size comparison only. Such rectifiers have been used quite extensively in both radio and television transformerless receivers. Many have been superseded by more efficient units.

The full-wave rectifier in the upper right-hand corner of the photo may be found in small low-voltage battery eliminators. Similar rectifiers may well find an application in transistor radios that will operate from the power line, as some transistor hi-fi am-

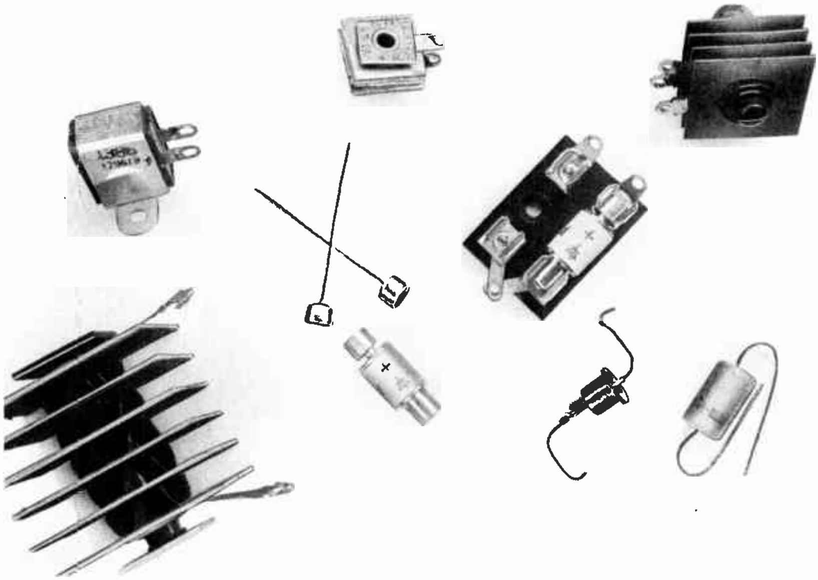


Fig. 113. *Semiconductor rectifiers used to supply dc for radio and television receivers.*

plifiers and preamplifiers are now powered. For ordinary use, batteries are still less expensive, and bothersome line cords are not needed.

The new, more efficient batteries, and those with a rechargeable feature, offer advantages that will keep the semiconductor power supply for transistor radios from becoming popular rapidly. It will probably keep its status as a plug-in accessory for quite some time. The power rectifiers shown vary in capacity from the small pig-tail type of 20-milliamperes to the 500-milliampere silicon cartridge that clips into a holder and is as easily replaced as a fuse. Used with adapters it converts to a pig-tailed rectifier that can be used to replace other types.

Plug-in power rectifiers are also designed to replace tubes. These direct replacements need no filament current as do the 6X4, 12X4 and 6X5 vacuum rectifiers used in some auto radios as well as the more powerful types (5U4 and 5AU4) used in ac-powered equipment. These units cost more than 10 times the vacuum tubes they replace but power supplies designed for these rectifiers are only two-thirds the size and weigh only a sixteenth

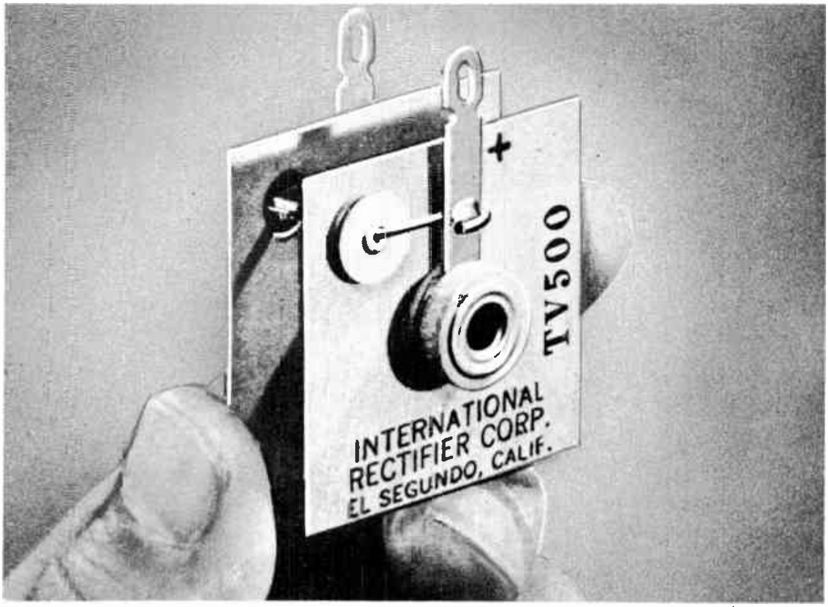


Fig. 114. *Silicon rectifier designed to replace 500-ma selenium rectifier stack. Fins help to dissipate heat.* (International Rectifier Corp.)

as much. Power consumption and heat generation may be reduced as much as 25 watts.

Let us never consider semiconductors as limited to low-current applications. The fins in Fig. 114 help dissipate the heat

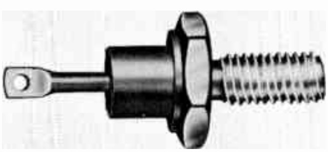


Fig. 115. *Both silicon rectifiers and Zener diodes are mounted in this type of case.* (International Rectifier Corp.)

generated while rectifying 750 ma. The eyelet type construction and the heat-exchanger fins give this silicon unit a remarkable resemblance to the selenium rectifiers it was designed to replace. This type of construction allows the original mounting holes to

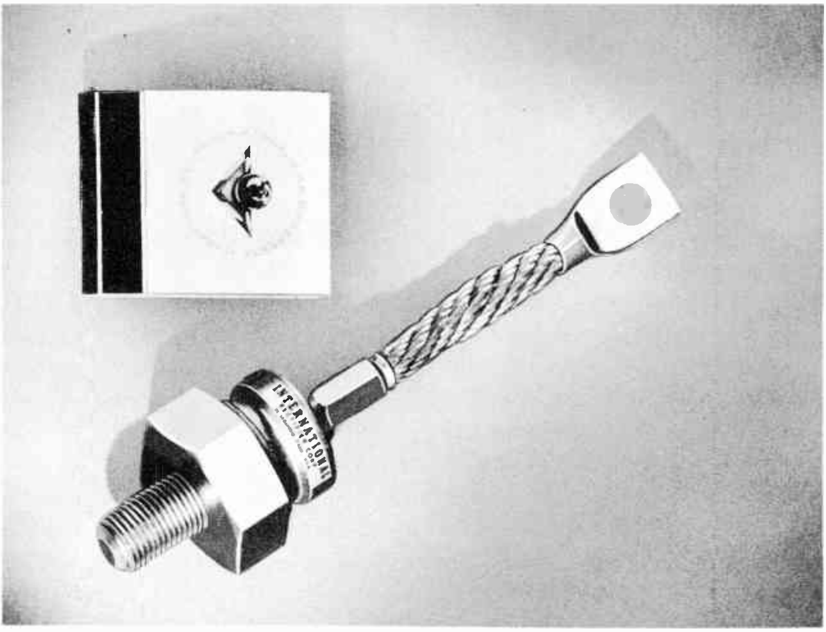


Fig. 116. *This silicon rectifier is a variety than can handle 70 to 250 amperes at 50 to 500 piv.* (International Rectifier Corp.)

be utilized without resorting to conversion kits or drilling new holes.

A semiconductor package like that in Fig. 115 could contain a voltage-regulating semiconductor call a *Zener diode.* Although

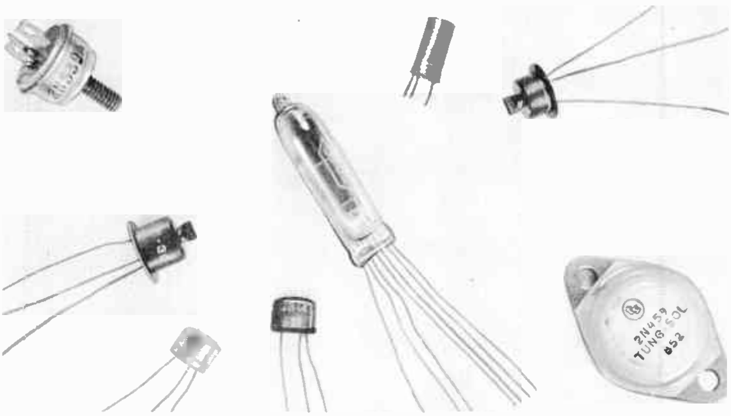


Fig. 117. *Compared to subminiature tubes, transistors still look small.*

it will not be found in small transistor radios, it might be found in a battery eliminator of sufficiently good design to incorporate a voltage-regulating circuit.

The basic circuit is quite like the one used with gas-filled voltage-regulator tubes. A resistor is utilized as a varying voltage drop; by varying the current drawn through it, the regulating device keeps the voltage across itself constant. The Zener diode is used extensively in industrial equipment either as the regulating device or as a reference-voltage source.

Industrial applications of semiconductors are quite different from entertainment uses. Silicon rectifiers are made that exceed the capabilities of the seemingly monster-size 250-*ampere* rectifier of Fig. 116, which dwarfs the book of matches beside it. These units might be found in a heavy-duty battery charger of the quick-charge type used by many automotive ignition service stations. Semiconductor diodes and transistors are by no means limited to the portable radio field, and these heavy-current units have been included only to emphasize the vastness of the semiconductor field and will not be discussed further in this book.

Size

Radio parts, and radio and television receivers, are all getting smaller. The transistor has given miniaturization a big push. Just as an example, compare the transistors shown in Fig. 117 with the vacuum tubes. As far as size is concerned, the tube takes up very little space. Compared to the transistor, though, the tube is a giant.

Other components (Fig. 118) shrink to keep up with the diminishing size of transistors. Variable potentiometers are smaller than a stack of several coins — complete with switch and knob. The coupling capacitors are of seemingly large values, made necessary by the inherently low impedance characteristics of the transistor circuitry.

Capacitors using an electrolyte of tantalum oxide are now manufactured with capacitances that once would have been remarkable in a unit of pencil-eraser size. Some variable capacitors utilize thin plastic insulators between their plates, not only to take advantage of the increase in dielectric constant, but to provide a comparatively short-free unit. Loudspeakers are as small as earphone assemblies. Transformers for both audio and rf are only a shadow of their former selves. Jacks, plugs and other connectors are shrinking rapidly to maintain their proportions to

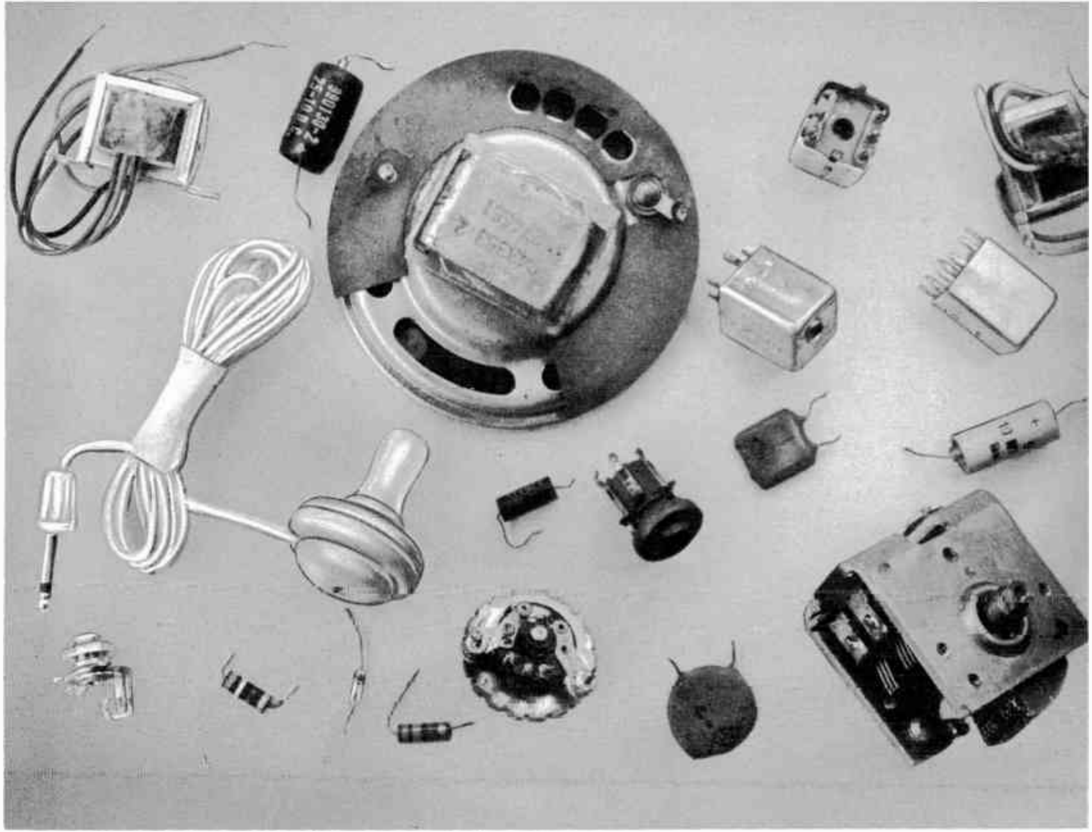


Fig. 118. *A 2½ inch speaker is shown with many of the major components of a transistor receiver.*

the daintiness of the other components, all redesigned to make easier connection to printed-circuit assemblies.

Microminiaturization is another swing around the industrial spiral. Whole circuits are formed on postage-stamp-size wafers, complete with input, output and power terminals. Stacked into a marshmallow-size cube, a complete subassembly is formed. An entire instrument may be no larger than a single if transformer once was. You will become better acquainted with the electrical characteristics of transistor components in the chapters on servicing.

chapter 2

how transistors work

You probably recall that, when you first started studying about vacuum tubes, you began with a diode. This makes sense for many reasons. A diode is easy to understand since all it does and all it can do is to let current flow in one direction. It acts like a valve and nothing could be less mysterious. That is why, in our first chapter, we started with p-n units.

We are now ready to go a step further and we can begin by looking at Fig. 201. Here we have a p-n diode which we have connected to a bias battery. The only difference between this and

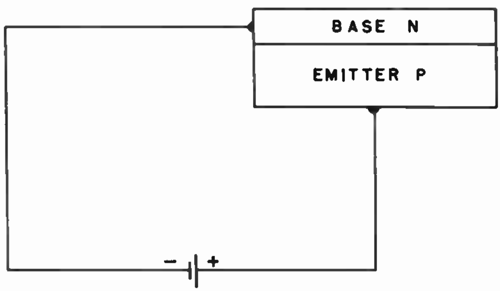


Fig. 201. *The emitter injects current carriers (holes) into the base.*

the units we studied in Chapter 1 is that we have started to name the elements of the diode instead of referring to them by that very "inelegant" word, sandwich. Let's see what we have. We have a single bias cell connected to a p-unit which we call the emitter. Our slab of n-type germanium, connected to the negative terminal of the cell, is called the base.

There are a few more facts we can learn from Fig. 201. Because of the way the battery is connected, the diode is forward-biased. The emitter (p-type germanium) will release current carriers, and these current carriers will flow into the base (n-type germanium). And what are these current carriers? In Fig. 201, the current carriers are holes or positive charges. Because of the flow of current carriers, we can regard the resistance of this forward-biased diode as being low. Note also that the size of the base is small compared to the emitter.

Here comes the transistor!

To arrive (finally) at the transistor, we have to take just one small step, as shown in Fig. 202. Note what we have done. We

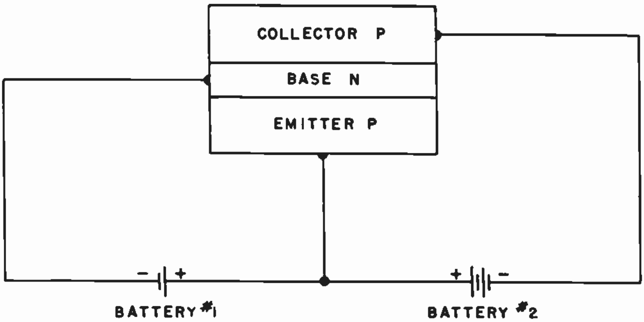


Fig. 202. *The transistor consists of an emitter, base and collector.*

have added a slice of p-type germanium to the diode of Fig. 201. And just to make the circuit complete, we have added another bias battery. But, before we go any further, please note the name of the new element we have introduced. It is called the collector. The collector, like the emitter (in this instance), is made of p-type germanium.

The arrangement we have shown in Fig. 202 really consists of a pair of diodes, back to back. The emitter and base form one of the diodes, and the collector and the base form the second diode (Fig. 203). Note also that the collector (Fig. 202) is connected to the negative terminal of a bias battery.

Now let's see how this setup works. Holes (or positive charges) move out of the emitter into the base. When the positive charges get into the base region, they must come to a decision. They are

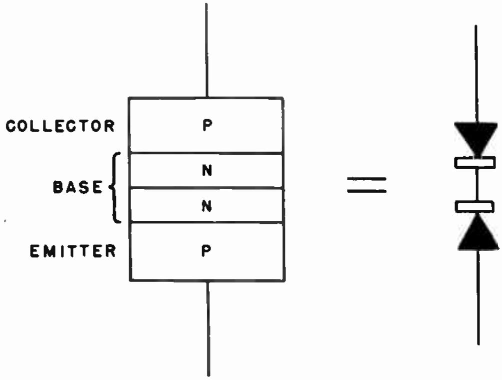


Fig. 203. *If the n-region of the transistor is sliced in half (theoretically), it will form two diodes placed back to back.*

really pulled in two different directions. They are attracted by the negative terminal of battery 1. And they are also attracted by the negative terminal of battery 2. If both batteries were of equal strength, you could very well get an equal division of charges.

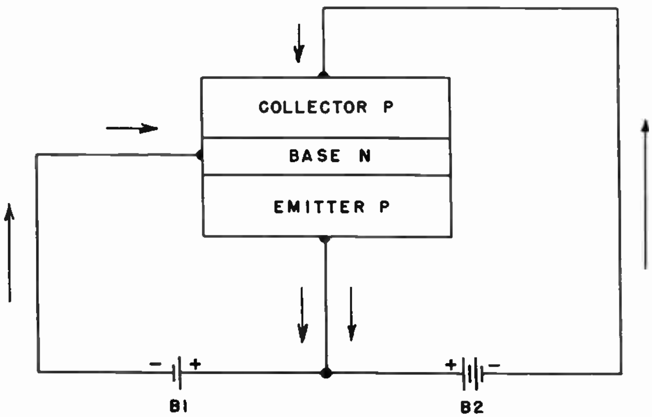


Fig. 204. *Most of the carriers (holes) go to the collector and form the collector current. A few of the carriers flow in the base-emitter circuit. The arrows indicate electron movement external to the transistor.*

But suppose that we make battery 2 much stronger than battery 1. Those positive charges aren't going to be sidetracked by battery 1 but are going to hustle right on over to battery 2.

Hole movement in a p-n-p unit

Let's see what happens in our p-n-p transistor. First, consider the forward-biased diode made up of the emitter and the base. The action is similar to that shown in the left-hand drawing of Fig. 110 in Chapter 1. The base is made extremely thin and so some of the holes diffuse over into it.

Note that the action here isn't a passive one. We didn't sit back and just wait and hope that something would happen. The construction of the diode and the connection of the battery are such that we didn't give the holes in the emitter much choice. For this reason it is perfectly proper for us to say that positive charges are injected by the emitter into the base. Most of these charges or "holes" are attracted to the collector because the collector has a strong negative voltage on it. Some of the positive charges remain in the base area because of the presence of battery 1. For those of you who like figures, we estimate that about 95% of the positive charges will go to the collector and about 5% (the remainder) of the positive charges will be sidetracked and just stay in the base. In Fig. 204, we have a drawing showing just what is going on.

Keep one fact in mind. *We get both electron and hole movement* in the transistor because of its crystalline structure. But the current movement in any circuit *external to the transistor* will consist only of electrons. Let us say that we have a single positive charge at the collector. It will attract a negative electron from the battery. This is a current flow from the battery to the collector. But another way of saying the same thing is to consider the hole as a positive charge that could move (inside the transistor) toward the battery.

What's so difficult about that?

If you feel that you are learning something that's terribly new, disillusion yourself by looking at Fig. 205. Here we have a triode with a cathode (emitter), control grid (base) and a plate (collector). Please don't feel horrified by the fact that we have put a positive voltage on the control grid. This positive voltage is extremely small and might be equal to the peak positive voltage of an incoming signal. Electrons (negative charges) leave the cathode and move over to the control grid. Some of the negative charges are attracted by the very small positive charge on the control grid and so, not knowing any better, they waste their time meandering through the grid–cathode circuit. But the great majority of the electrons move over to the plate which has a nice fat juicy positive charge on it — just the kind that electrons like.

Now what is the big difference between what's going on in Fig. 204 and the events taking place in Fig. 205? Actually, very little. In the case of the transistor we have a movement of positive charges (holes) and in the other case we have a movement of

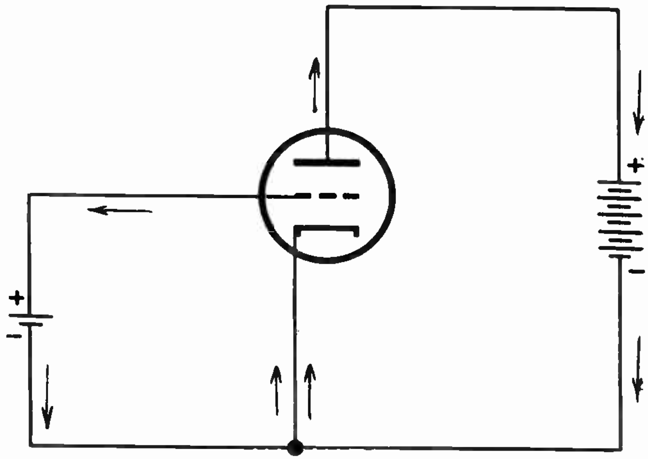


Fig. 205. *The triode transistor can be compared to a triode vacuum tube. Arrows show paths of electron flow.*

negative charges (electrons). In the case of the tube, not all of the electrons get over to the plate and, in the case of the transistor, not all of the holes get over to the collector.

The n-p-n transistor

We can arrange our p-n germanium diodes so that they look like Fig. 206. The very first thing we want you to do is to compare Fig. 206 with Fig. 202. At first glance the two will seem alike but, if we look carefully enough, we will note some differences. We still have the three elements of a transistor — an emitter, a base and a collector. But now the emitter is n-type germanium, the base is p-type germanium and the collector is n-type.

Now examine the bias batteries, B1 and B2. The batteries seem to be in the same position as those shown in Fig. 202, but observe that the batteries have been turned around.

Electron movement in the n-p-n transistor

When we studied the p-n-p unit of Fig. 202, we learned that the current carriers were holes. In the n-p-n transistor, however, the current carriers are electrons. The emitter (made of n-type germanium) injects electrons into the extremely thin base region.

Here the electrons are attracted by two positive forces – the positive voltage of B1 and the positive voltage of B2. Most of the electrons are attracted to the collector but some electrons do travel from the base, through B1 and so back to the emitter.

Since the motion of holes takes place only inside the transistor, what good is it? We might ask the same question about the cathode in a vacuum tube. We need the cathode because we need a device

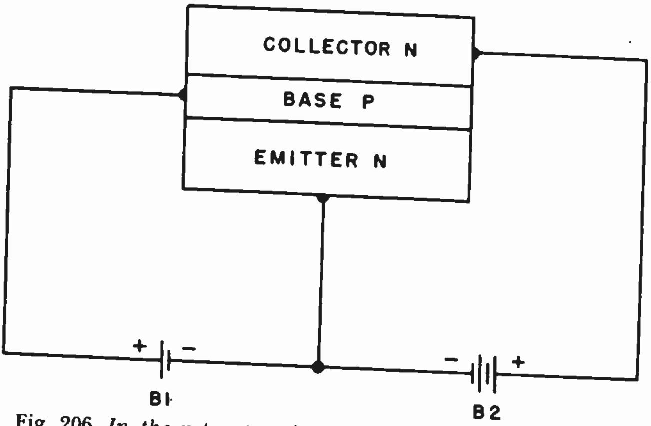


Fig. 206. *In the n-p-n transistor, the negative terminal of bias battery, B1, is connected to the emitter.*

that will, somehow, start the "electron ball" rolling. We don't have a cathode in the transistor, but through the use of positive charges or holes we manage to stir electrons out of their lethargy.

Hole movement and electron movement in a transistor are opposites – always moving in opposite directions. In Fig. 204 we show electron current in the external circuit.

At this point, we begin to realize the convenience of thinking of current carriers instead of holes and electrons. If we just talk about current carriers, then there is really no great difference between the p-n-p and the n-p-n types.

In Fig. 207, we show the flow of electrons in an n-p-n circuit. Compare this with Fig. 204. In the n-p-n transistor, the direction of current flow (as shown in Fig. 207) is similar to that of a triode vacuum tube. In the p-n-p transistor (as shown in Fig. 204) current flow is exactly opposite that of the tube. While the end result is the same for both types, most transistor radios use p-n-p units. And so, when measuring voltages, when considering polarity and when replacing electrolytics, you must be careful and not let habit get the better of you.

Current-carrier injection and cathode emission

The fundamental idea in either a transistor or a vacuum tube is to produce a current and then to obtain complete control over that current. In a vacuum tube, we obtain a current by brute force. We coat a cathode with an electron-rich material and then literally boil the electrons off through the application of intense heat. This method works — as any vacuum tube will bear witness — but it is definitely inefficient. Heating a filament or cathode requires a lot of watts and represents a large percentage of the power that must be poured into a radio or television receiver.

No heat is used in the transistor to get a movement of current carriers. As a matter of fact, the transistor is quite comfortable

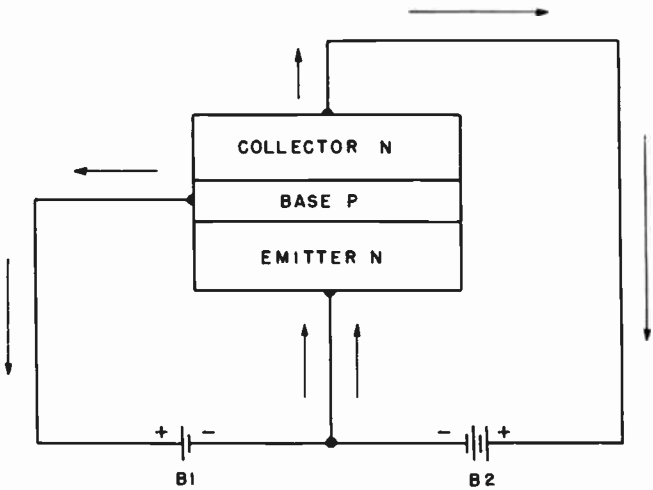


Fig. 207. *Electron flow in the n-p-n transistor circuit.*

without the application of heat. In the transistor, current carriers are *injected* into the base by the emitter. We've mentioned the word — *injected* — briefly a little earlier but it is information-packed and requires more than just a word of explanation.

Let us, just for a moment, go back to Fig. 201. The emitter is p-type material. This means that it has an excess of positive charges. The nearby base region is n-type germanium, and, of course, has an excess of negative charges. The base region is physically tiny compared to the emitter. There are several factors that cause a movement of positive charges into the base region. The negative terminal of the battery is connected to the base. This is an attractive force, encouraging the movement of holes from the emitter into the base. The positive terminal of the battery is connected to the p-region, and here the positive terminal of the battery can be considered as exerting a pushing force on the positive charges in the emitter. As a result of these combined actions, the emitter permits the movement of holes or positive charges into the base. The technical term we use is injection. We say that the emitter injects current carriers into the base.

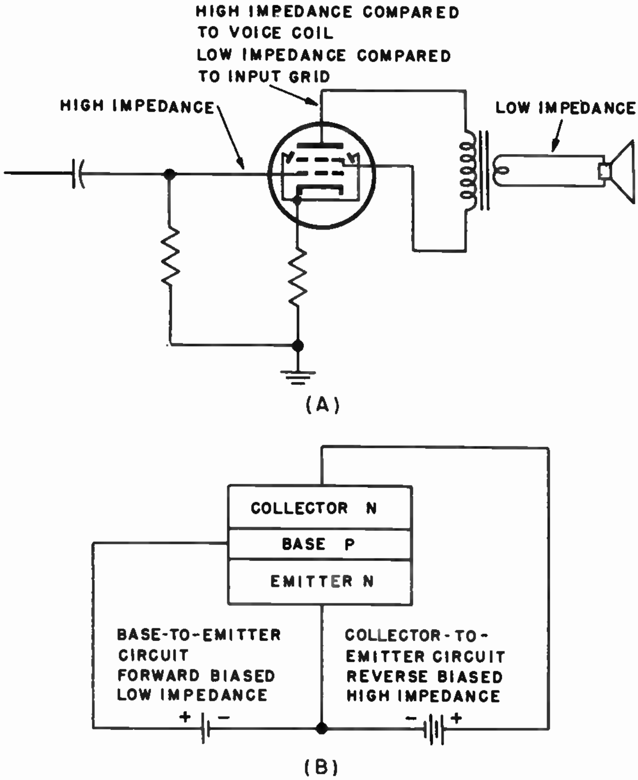


Fig. 208. *Input and output impedances in vacuum-tube and transistor circuits.*

Of course, Fig. 201 shows a simple diode. If we were to set up a transistor, we would then note that the current carriers, injected by the emitter into the base, travel to the collector (for the most part).

The action in an n-p-n transistor is exactly the same with the exception that the current carriers injected into the base are negative charges (electrons).

High and low impedance

These terms are quite commonly used by service technicians but perhaps it is about time that we arrived at some understanding about them. First of all, the terms are relative. What is high impedance in one circuit might be low impedance in another. For example, the input to the control grid of a vacuum tube is considered a high-impedance point, while the plate of that tube, passing a large current, is low-impedance when compared to the control grid of that same tube. (Fig. 208-A). But suppose we are talking of an audio output tube, transformer-coupled to a speaker. The plate of an audio output tube could be regarded as a low-impedance point, from the viewpoint of the control grid of that tube. But the speaker to which the plate is coupled is far lower. The speaker might be 3 ohms, the plate of the tube might be 10,000 ohms and the grid might be in the order of megohms.

In the case of a transistor, if a circuit is biased in the forward direction, it is low-impedance and, if biased in the reverse direction, it is high-impedance. Thus, in the arrangement of Fig. 208-B, the base-to-emitter circuit is low-impedance (it is biased in the forward direction) while the collector-to-emitter circuit is high-impedance (it is biased in the reverse direction).

Transistor symbols

So far, we have been drawing transistors in block-diagram form. However, just as we have electronic symbols for vacuum tubes, so

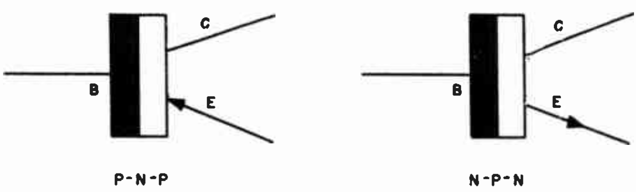


Fig. 209. *Electronic symbols for p-n-p and n-p-n transistors.*

too do we have them for transistors. The two basic transistor symbols are shown in Fig. 209. The letters B, C and E represent base, collector and emitter, respectively. Note also that the symbols for p-n-p and n-p-n units are almost identical. The only difference is in the direction of the arrow connected to the emitter. In the p-n-p unit it points inward, and in the n-p-n it points outward.

These symbols are for three-element transistors — that is, transistor triodes. There are other transistors — such as transistor tetrodes (described in Chapter 12) – but we are not as yet concerned with them. The symbols shown in Fig. 209 may be drawn in any convenient position. The letters identifying the electrodes can be omitted, if desired.

The input signal

In vacuum-tube circuits, signal input is often represented by a sine wave enclosed in a circle. We can use the same symbol in transistor circuits. In Fig. 210, we have one way in which the input

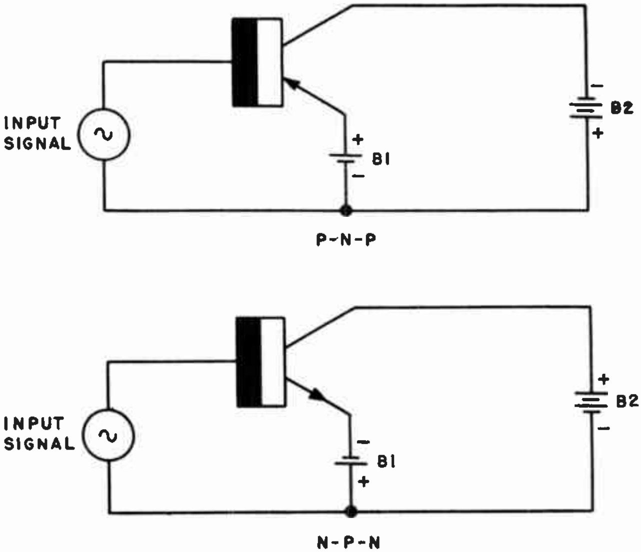


Fig. 210. *The input can be a radio signal or the output of a generator.*

voltage can be connected to the transistor. In this circuit, the base behaves in a manner similar to the control grid of the vacuum tube. The emitter is equivalent to the cathode and the collector represents the plate.

The emitter is biased by battery B1. As long as B1 and B2 are not changed, a small but steady current flows in the collector circuit. The input signal is in series with battery B1. The base-to-emitter circuit now consists of the base, the input signal voltage, battery B1 and the emitter. Because the input signal voltage is ac, it adds to or subtracts from battery voltage B1. This has the effect of changing the biasing in the emitter circuit. As a result, the movement of current carriers is similarly affected. This, in turn, modifies the amount of current carriers reaching the collector. In this way, the collector current is a replica of the signal voltage.

The circuit in Fig. 210-A is for a p-n-p unit while that in Fig. 210-B is for an n-p-n unit. It is important to note the difference in battery connections.

In identifying a transistor, we refer to it as an n-p-n or p-n-p type. The first letter refers to the emitter, the second to the base and the third to the collector. Thus, an n-p-n transistor has n-type germanium for the emitter, p-type for the base and n-type germanium for the collector. This bit of information is always helpful in remembering how to connect batteries correctly. Always start with the emitter. If it is p-type (positive), the positive terminal of the bias battery is connected to it, either directly or through a resistor.

Adding the load resistor

In vacuum-tube circuits, the load is the component across which the output signal is developed. The load can be a resistor, such as the load for a diode detector. It can also be a speaker or a relay.

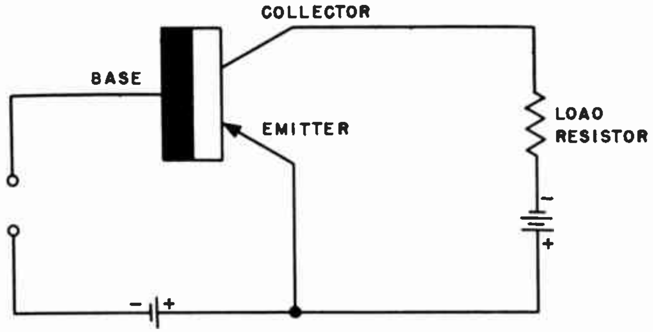


Fig. 211. *Technique for connecting the load resistor to the transistor.*

In Fig. 211, we have a p-n-p transistor circuit. You can see that we have two terminals so we can connect a signal to the input circuit consisting of emitter and base. Because our signal source is not connected, we can consider the input circuit as being open. However, the output circuit is now closed through our use of the load resistor and so we get a small amount of collector current. Please remember that the collector circuit is reverse-biased and that its resistance is very high.

Now let us close the input circuit by putting a shorting wire across the signal input terminal. As a result, we will get an increased movement of current carriers — in this case, holes. These will migrate to the base. The strong negative field of the nearby collector attracts them. Hence, a large quantity of electrons will flow from the negative terminal of the battery through the load resistor, through the collector, back to the emitter and the plus terminal of the battery.

The important thing to realize at this time is that we have managed to make an increased current flow through a high value of resistance. It is because we are able to do this that the transistor performs as it does.

The amplifying transistor

Before we get down to the very serious business of learning just how it is that we get amplification out of a transistor, let us consider the input and output resistances of a typical transistor circuit. Let us suppose that the input resistance is 100 ohms and let us further suppose that the output resistance is 10,000 ohms. The ratio of these two resistances — that is, the output divided by the input — is equal to 10,000 divided by 100. In other words, the output resistance is 100 times the input resistance.

Let us go one step further. Let us suppose that we have 1 milliampere of current flowing in the input circuit. Since our input resistance is 100 ohms, 1 ma (.001 ampere) will give us a total of $\frac{1}{10}$ volt in the input circuit. This is obtained by using Ohm's law and multiplying the input current by the input resistance.

Of course, not all of this current will reach the collector but, just to make our arithmetic easier, let us imagine that it does. This means that we will have 1 ma of current flowing in the output circuit. This 1 ma (.001 ampere), when multiplied by the output resistance of 10,000 ohms, will give us an output voltage of 10. In other words, we now have a voltage gain of 100 since voltage gain is the ratio of the output voltage to the input voltage.

Current gain-alpha

Using the n-p-n transistor as an example, not all of the current flowing in the emitter circuit reaches the collector circuit. Most of it does, but not all. In many transistors the amount of current reaching the collector ranges between 95% and 99% of the emitter current. The ratio of these two currents — that is, the ratio of collector current to emitter current — is known as alpha. Since collector current is less than emitter current, alpha is less than 1. Hence it is often expressed as a decimal or a percentage. Thus, if the emitter current is 10 ma but the collector current is only 9 ma, then the current gain equals 9 divided by 10. This equals 0.9 or 90%.

Voltage gain

To determine the voltage gain of a transistor circuit, divide the output resistance by the input resistance and, when you get

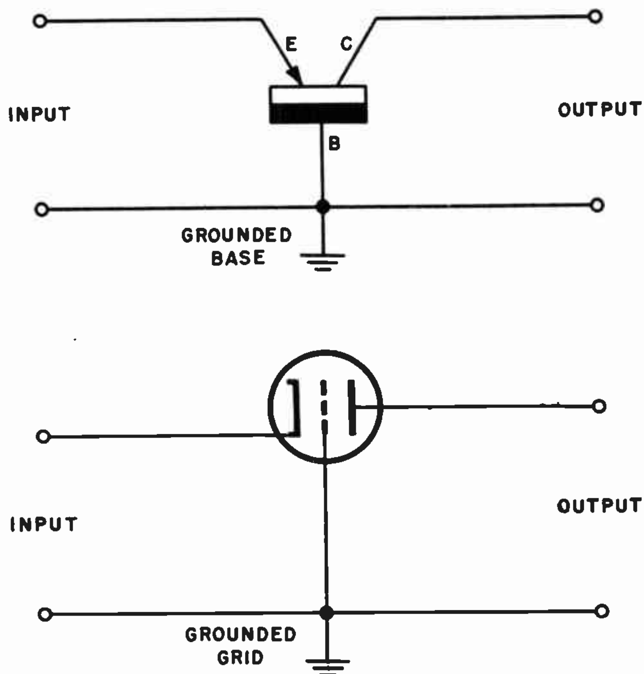


Fig. 212. *Circuit of the grounded-base transistor and its counterpart, the grounded-grid vacuum-tube amplifier.*

this value, multiply it by alpha. In the example you were given a little while ago, the output resistance was designated as 10,000 ohms and the input resistance as 100 ohms. Dividing these two, we get the ratio of the two resistances as 100. If the alpha of a particular circuit is 0.97, we then get 0.97 times 100, or 97. This is the voltage gain of the particular circuit.

From what we have learned so far, you can see that if you want to get a great deal of gain out of a transistor circuit, the output resistance should be made as high as possible, the input resistance as low as possible and alpha as high as possible.

Basic amplifier circuits

Transistor amplifiers can be arranged in three ways: One of the "electrodes" is generally grounded or grounded through a resistor,

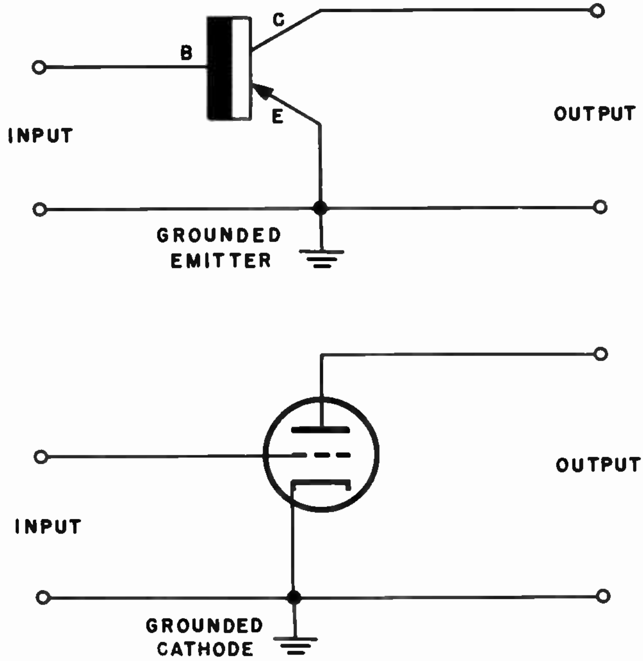
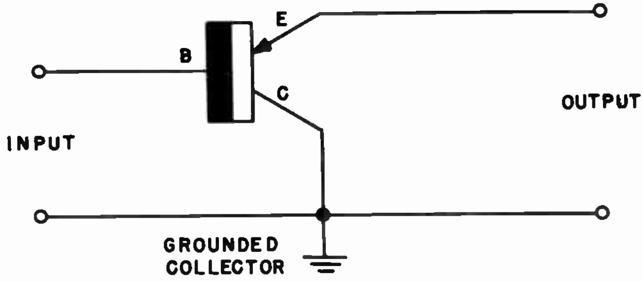
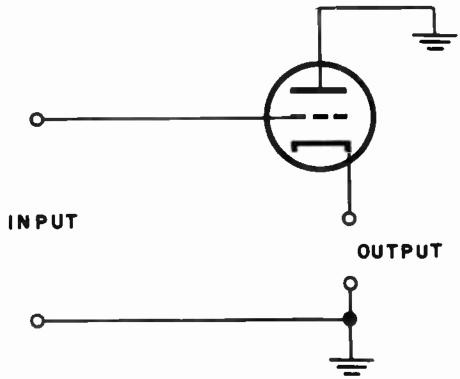


Fig. 213. *The grounded-emitter transistor amplifier is similar to the grounded-cathode vacuum-tube circuit.*

and the amplifier is named for the grounded unit. Thus, when the base is grounded, the circuit is referred to as a grounded-base amplifier (Fig. 212). Similarly, if the emitter is grounded (Fig. 213), it is termed a grounded-emitter amplifier, and, finally, if the collector is grounded (Fig. 214), we have a grounded-collector amplifier.

Both the grounded-base and grounded-emitter amplifiers have very low input impedances. As a general rule, you can consider the input impedance as less than 1,000 ohms. The output impedance is high. For the grounded-base, the output impedance is usually several hundred thousand ohms. The output impedance of the grounded-emitter is generally less than 50,000 ohms.





CATHODE FOLLOWER

Fig. 214. *The grounded-collector has characteristics similar to those of the cathode follower.*

The grounded-collector, so similar to the cathode follower, has a very high input impedance and a very low output impedance. For example, the input of the grounded-collector transistor amplifier ranges from 100,000 to as high as 300,000 ohms. The output impedance is just a few thousand ohms.

Phase inversion

In nearly all radio and television circuits, the signal on the output or plate side of a vacuum tube is out of phase with the signal at the input. All that this means is that the output signal becomes more positive when the input signal becomes more negative, and vice versa.

There are certain vacuum-tube circuits in which we get no phase reversal of the input signal. For example, there is no phase reversal in a cathode follower. In the grounded-collector transistor

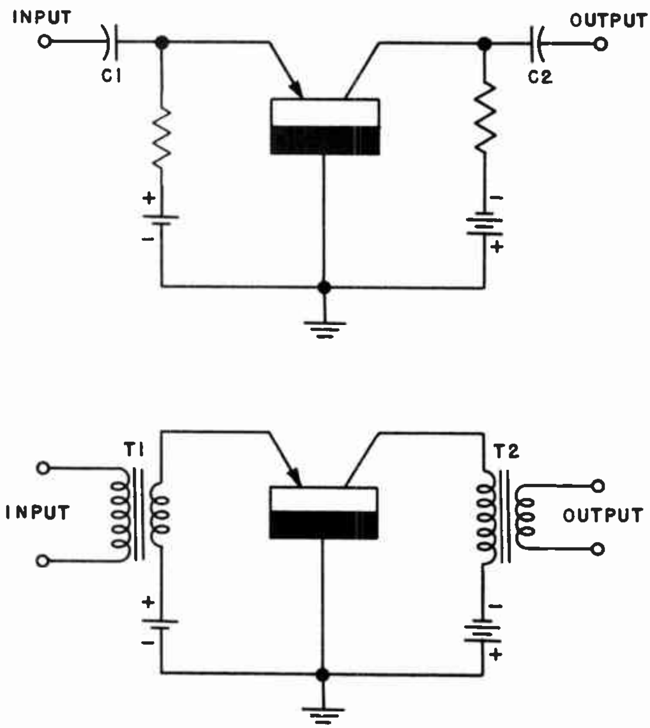


Fig. 215. *Resistance- and transformer-coupled grounded-base amplifiers.*

amplifier, there is also no phase reversal. (Remember, we have compared the grounded collector to the cathode follower.) If there is no phase reversal, it simply means that, when the incoming signal becomes more positive, so does the signal voltage on the output side of the transistor. Whether or not phase reversal is important depends entirely on the circuit and what you expect from it.

The only transistor circuit in which phase reversal is obtained is the grounded-emitter. This is similar to the grounded-cathode vacuum-tube amplifier. The grounded emitter arrangement is the one that is most widely used in transistor receivers.

In Fig. 215, we have circuit diagrams of two typical grounded-base single-stage amplifiers. The one at the top is a resistance – capacitance-coupled unit while the one at the bottom is a transformer-coupled unit.

The input resistance (or impedance) is low and its output resistance is high. Therefore, the two transformers shown in the circuit diagram are both stepdown units. That is, the secondary of T1 is

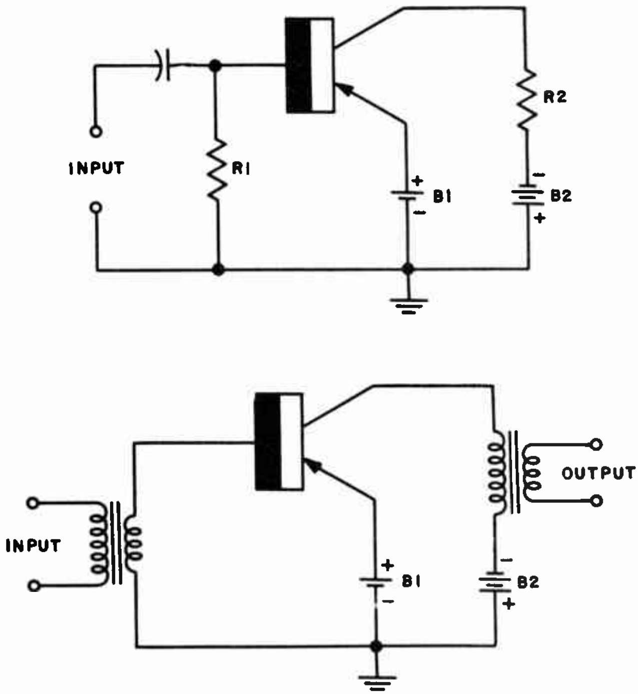


Fig. 216. *Resistance- and transformer-coupled grounded-emitter amplifiers.*

low-resistance (or low-impedance) to match the input resistance of the emitter circuit, while the output transformer has a high-resistance (high-impedance) primary to match the high impedance of the collector. In this type of circuit, you can logically expect the impedance in the output circuit to be at least 50 times as much as the input impedance. Remember – this circuit does not give phase reversal of the signal, which means that if, at any moment, the input signal is positive-going, so is the output signal.

In Fig. 215, we have added two new components, C1 and C2. These work as coupling and dc blocking units, just as they do in vacuum-tube circuits.

Grounded-emitter amplifier

In Fig. 216, we have two circuits of the grounded-emitter amplifier. One of these is a typical resistance-coupled stage while the other is a transformer-coupled stage. Although bias battery B1 is connected between emitter and ground, the emitter is effectively grounded through this component. Also note the inclusion of resistor R1 in the resistance-coupled stage. The input signal is developed across this resistor.

In the transformer-coupled stage, we once again have stepdown transformers in the input and output sides of the transistor. The input is low-impedance, hence we connect it to the low-impedance secondary of the input transformer. The primary of the output transformer is high-impedance to match the high impedance of the collector circuit.

Grounded-collector amplifier

Fig. 217 shows two circuits of grounded-collector stages. Once more we have used resistance- and transformer-coupled units as our examples. It is essential to remember that the grounded-collector is quite different from the other two amplifier types we have just described. In the grounded-collector circuit, the input impedance is much higher than the output impedance. You will have no trouble in remembering this if you keep comparing it to the cathode follower.

In the circuits of Figs. 215, 216 and 217, we have shown only p-n-p transistors. We could have used n-p-n units if we had so desired. The only change to be made in the circuit would have been to transpose both emitter and collector bias battery polarities. Failure to do this could readily result in damage to the transistor.

Transistor components

The transistor is small, hence it lends itself very well to portable receiver operation. The use of the transistor has accelerated the trend toward miniaturization of components. In the transistor receiver you will find parts such as audio transformers whose maximum dimensions are less than 1 inch. Miniature penlight or mercury cells are often used. We will have a further discussion of the parts in transistor receivers when we reach the chapters on servicing. You will also find that transistor receivers make extensive use of printed-circuit boards. These will also form an important part of this book.

Voltage and current

Transistors have a wide operating range of voltages and currents. It is always helpful to know the approximate ranges of voltages and currents which we can expect. Please remember, however, that the figures to be given here do not cover all transistors.

Thus, one of the values in which we are interested is collector current. This corresponds to the plate current of the vacuum tube.

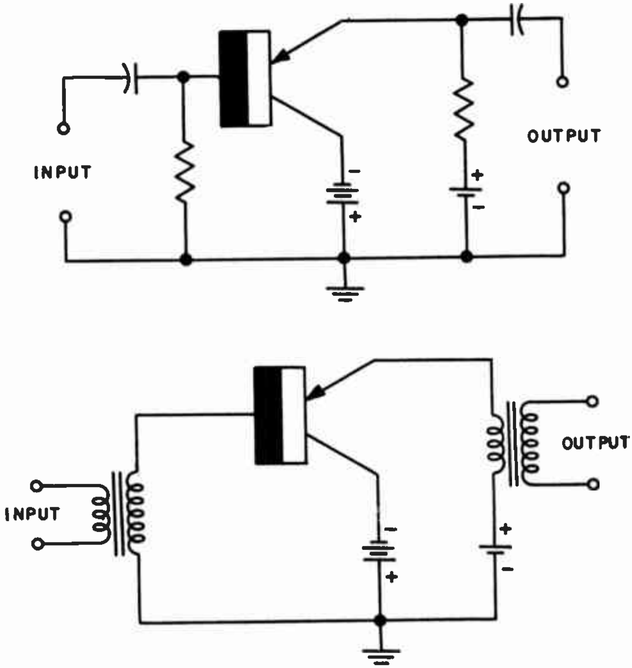


Fig. 217. *Resistance- and transformer-coupled grounded-collector amplifiers.*

For many transistors, the collector current will have a minimum value of several milliamperes (2 to 3) with a maximum in the order of 20 to 25 ma. A dc milliammeter lends itself very nicely to the measurement of collector current. The bias supply for the collector can range from a few volts to as much as 40 volts.

As the voltage on the collector is increased, the amount of collector current will also increase. Of course, when we refer to collector voltage, we mean the voltage between collector and emitter. Compare this to a similar situation in vacuum tube circuits in which plate voltage really means the voltage existing between plate and cathode.

Control of current carriers

It takes a lot of energy to move a car, especially from a standing position, yet all you have to do is to turn a key or press a foot pedal. Simply stated, a little effort on your part controls a tremendous release of power. Now all this means is that you are to your car what the control grid of a vacuum tube is to the power supply. All the control grid needs is just a tiny bit of signal voltage and a power supply starts delivering.

Transistor control element

We have a control element in the transistor also. In practically all transistor radios, the base has this job. The movement of current carriers in the transistor is determined by what we tell the base to do. First, let's consider a p-n-p transistor. When we apply a negative voltage to the base of a p-n-p unit, we increase the flow of current carriers. And if we do exactly the opposite – that is, if we put a positive voltage on the base – we can decrease or stop the flow of current carriers. Now we cannot just say positive or negative and let it go at that. By themselves, positive and negative are meaningless. When we say the base is negative, we intend it to be negative with respect to the emitter (just as in a vacuum tube a grid is nearly always negative with respect to the cathode).

Positive and negative

Now that we have this information, let's see what good it will do us. First of all, if a receiver uses p-n-p transistors, the voltage on the base will always be negative (except in the case of oscillators) with respect to the emitter. It is important to know this because not all manufacturers put down voltage markings in the same way. For example, on a schematic, a p-n-p transistor could have 3.8 v marked next to the emitter. But what is this? Is it plus or is it minus? If you will look at the base, it will be marked 3.6 v. But both of these are positive voltages and since the emitter has the higher voltage, it is more positive than the base.

Polarity on n-p-n types

In an n-p-n transistor, we have just the opposite state of affairs. When the base is made positive, current carriers will flow. When the base is made negative, current carriers will decrease or stop.

Now this is a very interesting situation and quite different from vacuum-tube receivers. In practically every circuit, the control grid (if it is biased at all) is biased negatively. In a transistor radio, the bias (dc voltage between base and emitter) is so arranged that current carriers flow.

If you think that this is a bit too much to remember, think of what we mean by p-n-p and n-p-n – n means negative, p means positive.

This might seem a little confusing since we just got through with an example in which we talked about p-n-p transistor which had positive voltages on both base and emitter. However, it is perfectly correct. If the base is more negative than the emitter, it is exactly the same thing as saying that the emitter is more positive than the base. You have been using the same technique with vacuum tubes but perhaps it just hasn't impressed itself on you. Consider a triode vacuum tube with a cathode and a plate. The plate is positive, usually by several hundred volts. The cathode is also positive, usually by just a few volts. Both elements are positive, but how are they with respect to each other? The plate is positive with respect to the cathode (it has more positive volts than the cathode). But the cathode is negative with respect to the plate (it has far fewer positive volts).

This subject is a tantalizing one, perhaps because so many technicians (and very experienced ones at that) have so much trouble with this idea of something that seems to be positive and negative at the same time. But consider a storage battery. One end is plus. The other end is minus. But what about the metal strap that connects the cells? It's both plus and minus, depending upon your reference point. The connecting strap is positive with respect to the minus terminal of the battery, and negative with respect to the positive terminal of the battery.

Current gain-beta

When we compare the collector current to the emitter current, we find that the collector doesn't do too well by comparison. The collector current (except in point-contact transistors) is always less than emitter current. Somewhat earlier in this chapter we learned that the ratio of these two currents is know as alpha, and, because collector current is always the smaller amount, alpha never reaches 1 but is always less than 1. Thus, if the collector current is 5 ma, the emitter current (for a given value of collector voltage) might be 5.2 ma. The ratio of these two (5 divided by 5.2) is the value of alpha and in this case 5 divided by 5.2 = 0.96.

We can also compare collector current to base current. When we do, we will find that this time the collector has the upper hand. Base current is usually very small in comparison to collector current. This comparison (it really is a ratio) is known as beta. Beta is also known as the base-current amplification factor. But this description we have given of alpha and beta is somewhat simplified. Beta is the ratio of a change in collector current for a change in base current.

Transistor testers

As you have probably suspected, the measurement of *alpha* and *beta* is a good way of testing a transistor. The methods are similar to the emission and transconductance tests performed on vacuum tubes.

Transistors are comparatively simple devices; the testers required are equally simple. Only the switching circuits used, to give maximum testing abilities to a minimum number of components, make the complete tester complex (Fig. 218).

The first switching circuit necessary is the one that changes the polarities of the meter and battery for p-n-p and n-p-n transistors. Without this switch, it would be necessary to have two separate test circuits – one for p-n-p transistors and one for n-p-n.

Since the characteristics of all transistor types are not the same (that is why they have different identifying numbers), it will be necessary to compensate for these differences in the tester. The most economical control is a potentiometer. This could be used in a circuit that would vary the battery voltage applied to the base of the transistor, which, in turn controls the base current.

In the schematic of the transistor tester kit (Fig. 218) a switch is used in the base. The three resistors are selected in turn, and form a voltage divider with the fourth resistor connected from the base-to-emitter terminals of the transistor socket. This has the definite advantage of giving three permanently resetable conditions, eliminating the possibility of getting slightly different readings each time a setting is made for a particular transistor type. Variations are still possible but they will depend mostly on the temperature and the aging of the resistors, and the variations will not be great. When the emitter-collector leakage is measured the base is connected to the emitter through the 51,000-ohm resistor.

The use of three meters – one for the emitter, one for the collector and a more sensitive one for the base – would eliminate some switching. It would still be necessary to reverse the meter polarities for n-p-n and p-n-p tests. When the meters are easily reversible, it is an easy matter to read the reverse currents through the transistor under test. These reverse or *leakage currents* will be covered in the next chapter. Such tests can be equally as important as the alpha and beta tests and correspond to the short and leakage tests in vacuum tubes.

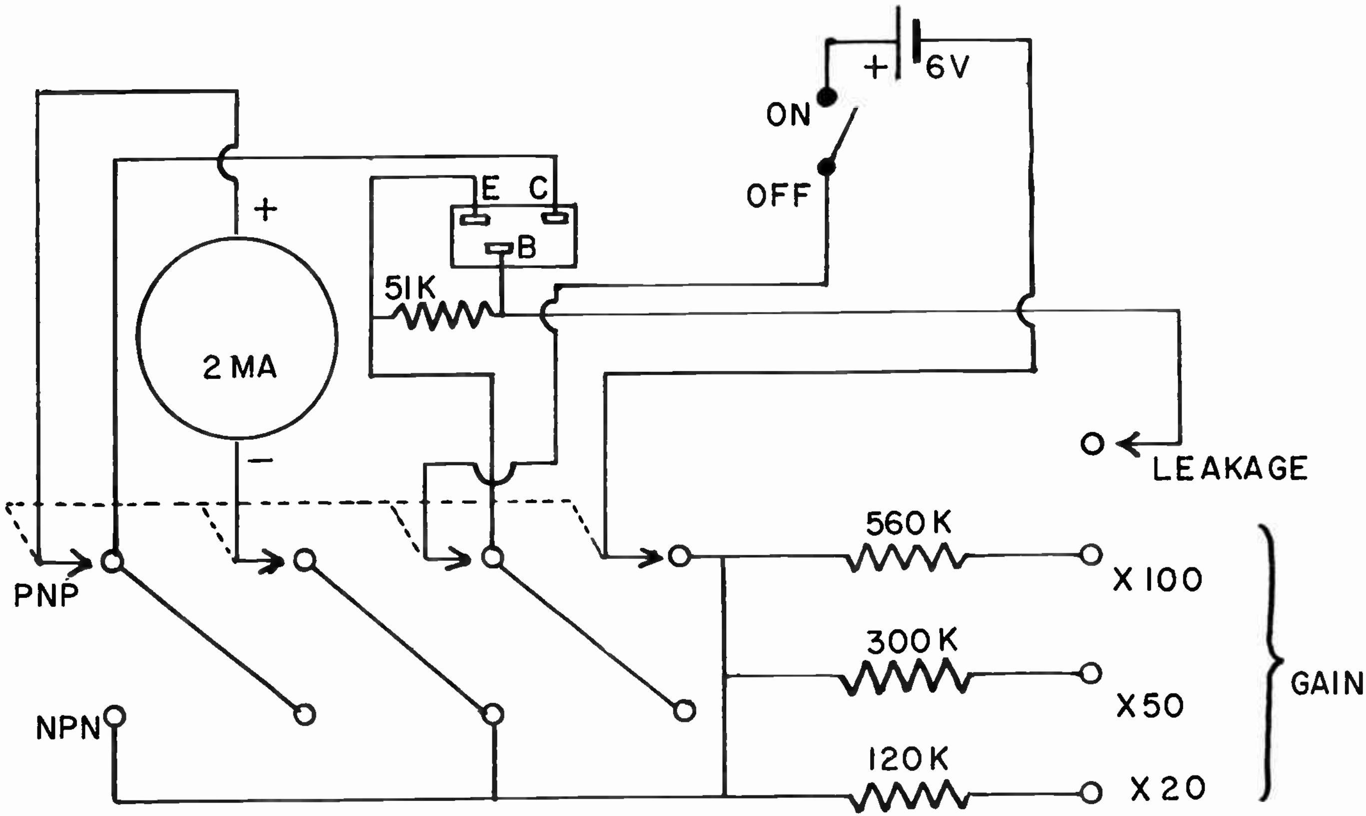


Fig. 218. *Circuit used in a transistor tester kit. A meter, three switches, four resistors, a battery and a socket are all housed in a neat prefinished cabinet.* (Electronic Measurements Corp.)

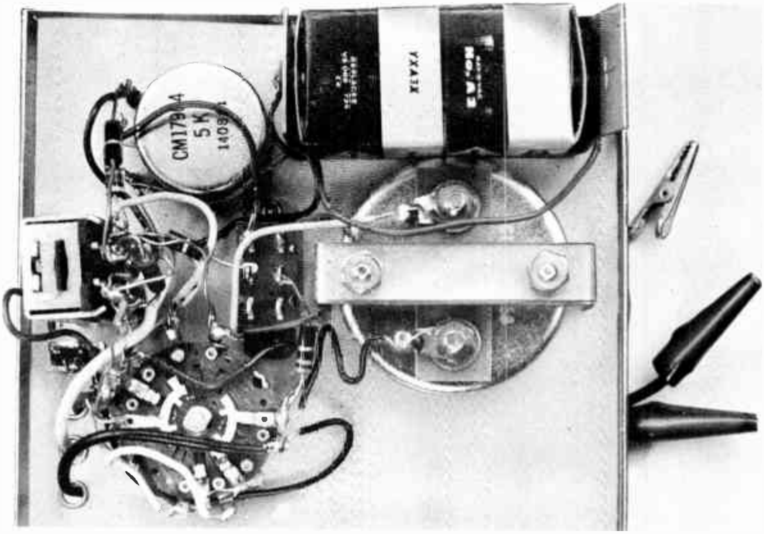


Fig. 219. *Factory-wired transistor tester uses a calibrated potentiometer. Clip leads supplement transistor socket*

The transistor tests performed by service type instruments are satisfactory for repairing transistor circuits found in the average portable. These tests are as complete as those made with tube testers of the same general price range used for servicing radio and television receivers.

This one-meter tester, Fig. 219, while economical, has the disadvantage that it requires a calibrated setting of a potentiometer to apply the proper current bias to the transistor under test. The data for available transistors are furnished with the tester, but additional data must be added when a new transistor comes on the market.

Some testers will test most transistors while they are connected in their circuits. This is an advantage since many, if not most, transistor radios have eliminated sockets in the interests of manufacturing economy.

There are other ways to test transistors using the regular equipment found in the average service bench. Audio and rf signal generators may be used for substitute input circuits, and the signal tracer and oscilloscope can replace the regular output circuits. This is practically the same *signal-injection* and *signal-tracing* technique used in servicing vacuum-tube receivers.

Fig. 220 shows the variety of connections that can be used for the audio generator signal-injection technique in finding a defec-

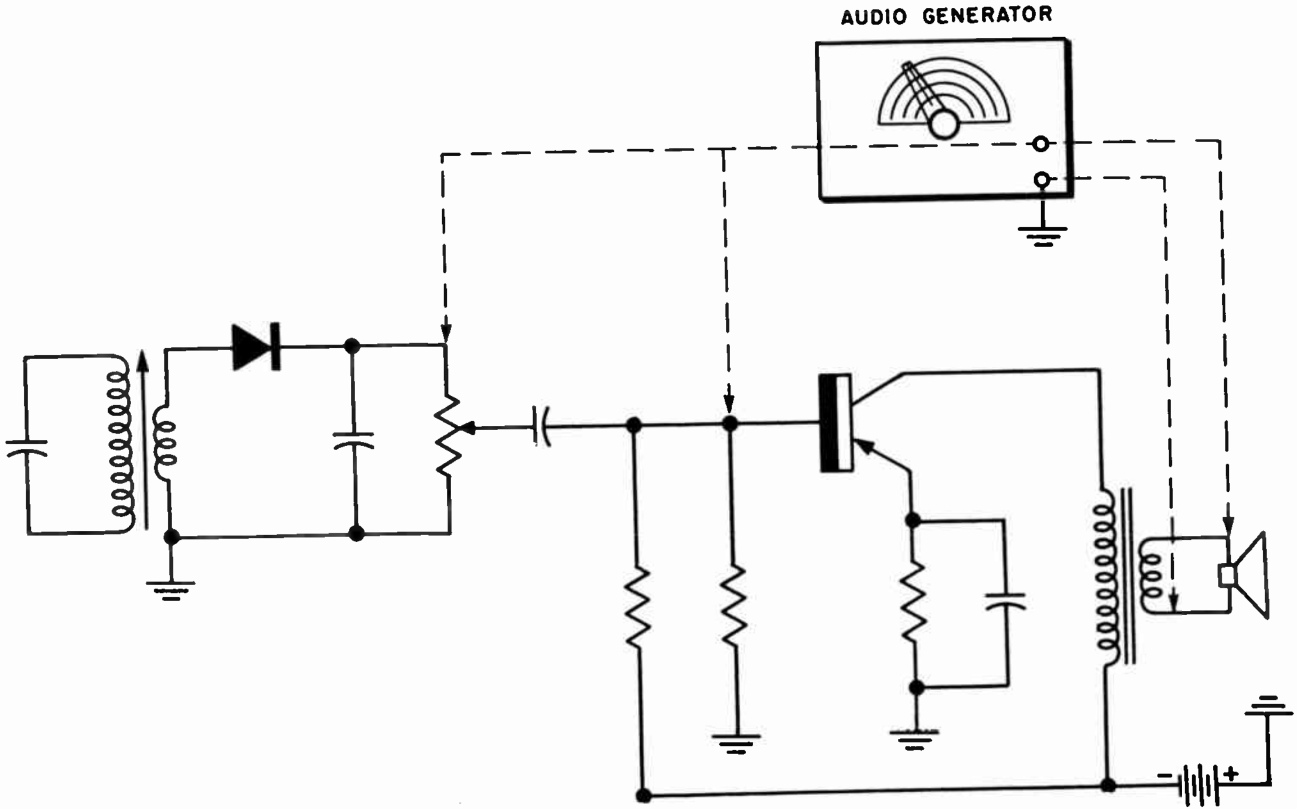


Fig. 220. *There are a variety of connections that can be used for the audio generator signal-injection technique in finding a defective audio transistor. The practical applications of this system will be explained more fully in Chapters 7 and 8 in Vol. II.*

tive audio transistor. The practical applications of this system will be explained more fully in Chapters 7 and 8 in Vol. II.

Another transistor tester has an indicator lamp instead of a meter. This dynamic check uses an oscillator circuit in which the transistor under test has to be of sufficiently good quality to light a neon lamp connected to a stepup output transformer.

All of these tests have their merits. Some transistors may pass some of these tests and not pass others. As with vacuum tubes, they may seem to operate in a satisfactory manner even without passing all tests by a large margin, but, since many transistors are soldered into their circuits, it is not likely that many transistors that work at all will ever be tested.

If an inoperative circuit has a transistor that fails in any one of many possible tests, it is best to replace it. Like a vacuum tube, a transistor may work in one circuit configuration and not in another; that is, it may work well as an audio amplifier or if amplifier and not as an rf amplifier. Some poorly designed circuits may even require the selection of a transistor from a group of the same type. Circuits of this kind are not frequent but they are encountered.

It would be desirable to have a single instrument to test all the semiconductors available, but this is not practical. Many new developments in the semiconductor field have brought strange new devices, and such a tester might be obsolete before it reached the production stage. Unijunction transistors and controlled rectifiers that resemble the thyratron and ignitron are doing familiar jobs, and tests are quite normal. The equipment needed to test tunnel diodes and semiconductor voltage-variable capacitors can start to make a quite bulky package.

A service technician must plan on the obsolescence of his semiconductor test equipment. A few years from now the semiconductors used in the transistor radio of today will probably seem as bulky and crude as the diodes and triodes of the early part of this century do when compared to present-day vacuum tubes.

chapter 3

basic amplifiers

ONE of the very great advantages of the transistor is that it lends itself very nicely to battery operation. It is true that vacuum tubes can also be battery-operated but the power requirements and the physical space occupied by the transistor are considerably in its favor. In transistor receivers, the first thing you will probably notice is the complete elimination of the power transformer, rectifier and filter.

Because a transistor operates at low voltages and currents, servicing is somewhat simplified. The danger of possible damage to test instruments by high voltages in the receiver is eliminated. However, as we will learn later, transistor radios have their own servicing precautions.

Voltage limitations

In a vacuum-tube receiver, the voltages that can be placed on the plate and screen of a tube can generally be varied within rather wide limits. The bias voltage on the control grid is, of course, much more critical but, since this is usually supplied through a cathode resistor, the service technician simply measures the voltage across it as a quick check on tube operation.

A transistor, however, is quite another story. You must keep in mind that the transistor is a tiny device and that the volume of "active" material in a transistor is quite limited. Because of the small volume and area, the ability of the transistor to dissipate heat (without external help) is restricted. The junction of a transistor is capable of heating rather rapidly. Coupling this with

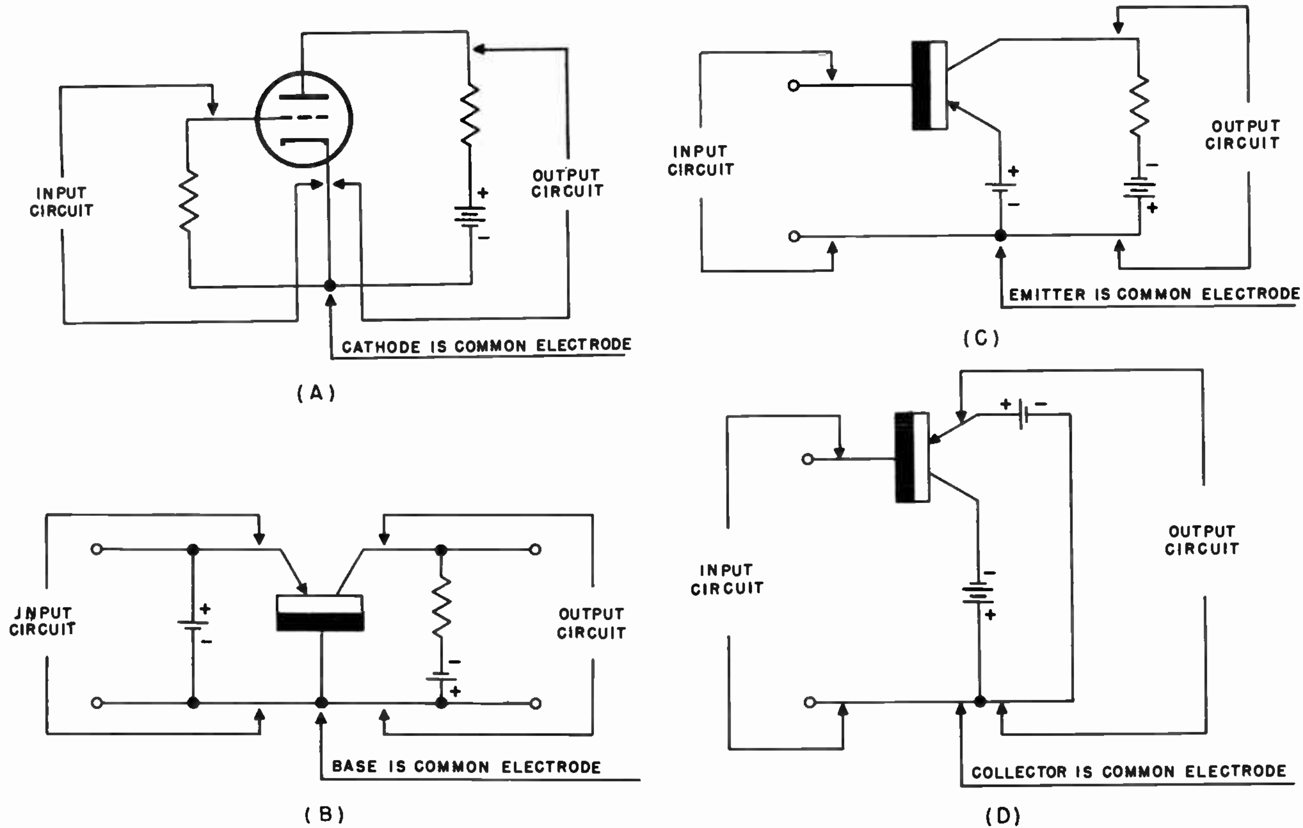


Fig. 301. *Like the vacuum tube, the transistor uses one electrode common to input and output circuits.*

the fact that the junction is temperature-sensitive means that damage can be done easily. The collector voltage should never exceed that specified by the manufacturer. The amount of collector voltage depends upon the particular transistor, the circuit in which it is used and the values of the components associated with the collector.

Naming the amplifier

In the previous chapter, we discussed the three basic types of transistor amplifiers — the grounded-base, grounded-emitter and grounded-collector circuits. But now let's consider these circuits in a new light. These three fundamental circuits are shown in Fig. 301. Instead of referring to them as grounded-base, grounded-emitter etc. let us call them common-base, common-emitter, etc.

Consider, for example, the simple vacuum-tube triode shown in Fig. 301-A. The triode has an input and an output circuit. The input consists of grid and cathode while the output consists of plate and cathode. The cathode is used by both circuits. Hence, it could be called a common-cathode circuit — that is, the cathode is common (is used by) both input (grid) and output (plate) circuits.

Figs. 301-B, -C and -D show common-base, common-emitter and common-collector circuits. In each instance, one of the elements of the transistor — base, emitter or collector — is common to both input and output circuits. Of these three possible arrangements, the common-emitter is the most widely used.

Leakage currents

In a vacuum tube, you can apply a sufficiently negative voltage to the control grid to drive the tube into cutoff — a condition in which no plate current flows. In a transistor, on the other hand, some collector current is always observed even though the emitter current at the moment may be zero.

The leakage current of a transistor exists between collector and emitter, and also between collector and base. These currents will vary from one transistor to the next and will depend upon circuit design, age of the transistor, temperature and voltage.

The leakage current of a p-n-p unit can be checked as shown in Fig. 302-A. The amount of battery voltage should be that which would actually appear on the collector. However, you can presuppose a 15-volt battery and make allowance for the fact that under actual conditions a higher or lower voltage battery would be used.

The test shown in Figs. 302-A and -B are static tests – that is, there is no signal input. The test for a p-n-p unit is shown in Fig. 302-A while that for an n-p-n is in Fig. 302-B. Note the way in which the collector battery is connected in both cases. The meter leads must also be transposed when changing from p-n-p to n-p-n connections.

The leakage current that will be measured is known as collector-to-base leakage and will be very small, generally less than

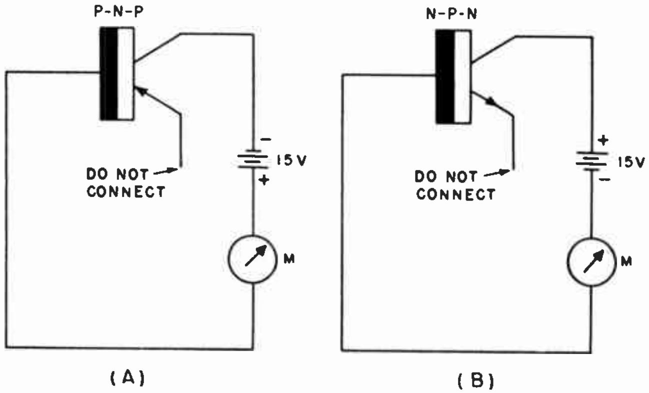


Fig. 302. *Method for checking collector-to-base leakage in p-n-p and n-p-n transistors.*

25 μa. The meter needle should remain steady during this test and should approximate the value specified by the manufacturer for the particular transistor being checked. The transistor is defective if the reading is erratic or if the collector-to-base current is much in excess of the manufacturer's recommended value.

Collector-to-base leakage has a number of names. It may simply be called leakage or collector leakage. Sometimes it is termed collector saturation current or collector cutoff current (even though these last two terms seem to contradict each other). However, there is no such thing as cutoff. There is always some collector-to-base leakage, however small.

Another leakage current that exists is between collector and emitter. The test is very much the same as that described for collector-to-base leakage. However, the leakage current for the test shown in Fig. 303 will be much higher than for the earlier test. Collector-to-emitter leakage may range in excess of 100 μa. Compare the reading you get with that specified by the manufacturer, keeping in mind the fact that you may be using a smaller or higher collector voltage. Once again, if the collector-to-emitter leakage current is excessively high or is unstable (that is, the meter needle fluctuates), the transistor is defective.

The amount of leakage current will depend on how the tran-

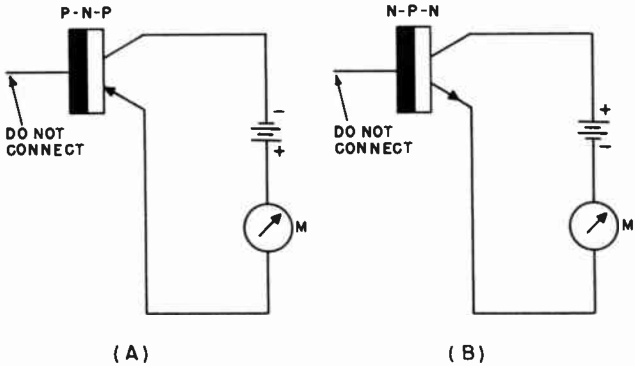


Fig. 303. *Technique for measuring collector-to-emitter leakage in p-n-p and n-p-n transistors.*

sistor is made. Some transistors, made of silicon, have extremely low values of leakage current. If the meter being used in the test has a range of 250 μa dc maximum, it is entirely possible that the meter needle may not move or move so little that no reading can be taken. This is just an indication of extremely small leakage.

Transistor stabilization

The collector-to-base leakage current we have just described is very sensitive to temperature. If, for some reason, this leakage current should increase, the total collector current will also increase. The effect will be to raise the temperature of the junction in the transistor. But with a rise in junction temperature, leakage current and total collector current will continue to grow. This raises the temperature of the transistor still further, resulting in a transistor which will finally become completely defective.

You undoubtedly recall from your study of vacuum tubes that the bias voltage determines the operating point of a tube. You can shift the operating point of a vacuum tube simply by changing the bias. In this way you can have class-A, class-B or class-C amplifiers. The bias voltage in a vacuum-tube circuit is important since incorrect bias results in distortion. In a transmitter, incorrect bias (or loss of bias) can destroy the tube. This usually does not happen with a receiving type tube since the currents are so much smaller.

The dc operating point (or the amount of bias) is just as important in a transistor as it is for any vacuum tube. Since the transistor is temperature-sensitive, and, as we have seen, can have "collector-current runaway," we must devise some means to prevent this possibility.

In a transmitting tube (Fig. 304), plate-current runaway is prevented through the use of the cathode resistor. A separate

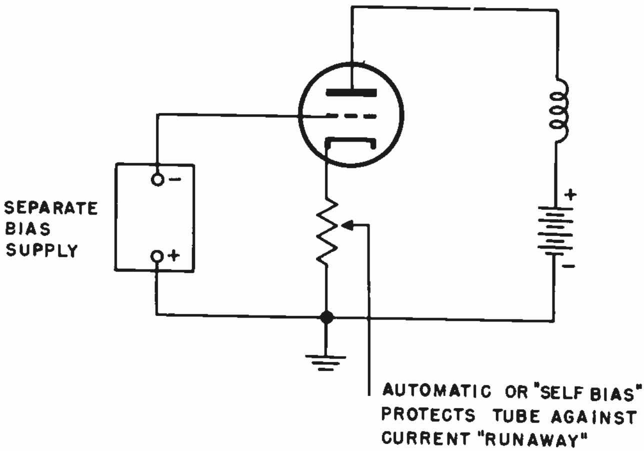


Fig. 304. *The cathode resistor helps keep the plate current within reasonable limits.*

power supply is used for bias. This bias voltage is supplemented by the voltage developed across the cathode resistor. The total bias is the sum of the voltage across the cathode resistor and the dc bias supply. If the plate current should try to increase, the voltage across the cathode resistor increases. This raises the total bias on the tube and, as a result, the plate current is forced to decrease.

The same technique or basic idea can be used with transistors. Keep in mind that the class of operation of a transistor amplifier (whether class-A, -B, etc.) is determined by the bias applied to the input circuit. The only difference between a vacuum tube and a transistor is that the vacuum tube uses *voltage* as a bias whereas in the transistor it is the amount of bias *current* that determines the class of operation.

All of this gives us a clue on how to stabilize a transistor so that the collector current stays within limits. All we have to do is to set up a circuit so that an increase in collector current results in a change in input-circuit bias current that opposes the collector-

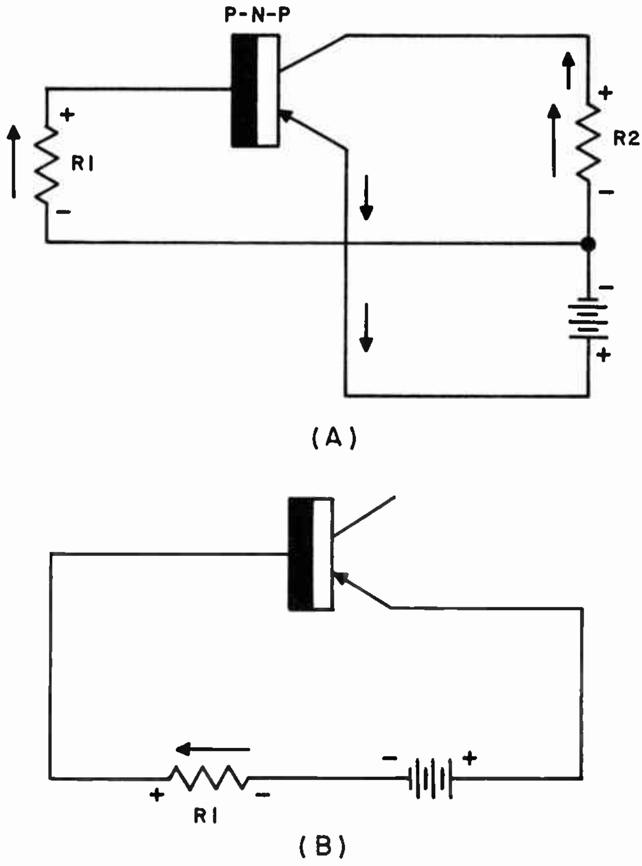


Fig. 305. *Electrons move into the transistor through the collector, return via the base and emitter in the p-n-p transistor.*

current increase. This technique will have a number of advantages. It makes the circuit less dependent on the transistor — that is, you can replace one transistor with another unit of identical type and not be too concerned with differences in transistor characteristics. It also will make the transistor somewhat more independent of temperature changes.

The amount of collector current depends upon the amount of bias current in the input circuit. If bias current in the input increases, collector current in the output also increases. Therefore, to stabilize a transistor, we would want the opposite effect to take place — an increase in collector current resulting in a decrease in input-circuit bias current.

To continue this line of investigation, let us take a look at Fig. 305.

In Fig. 305, we are using a single battery for collector voltage. R2 represents the collector load resistor, and it is across this

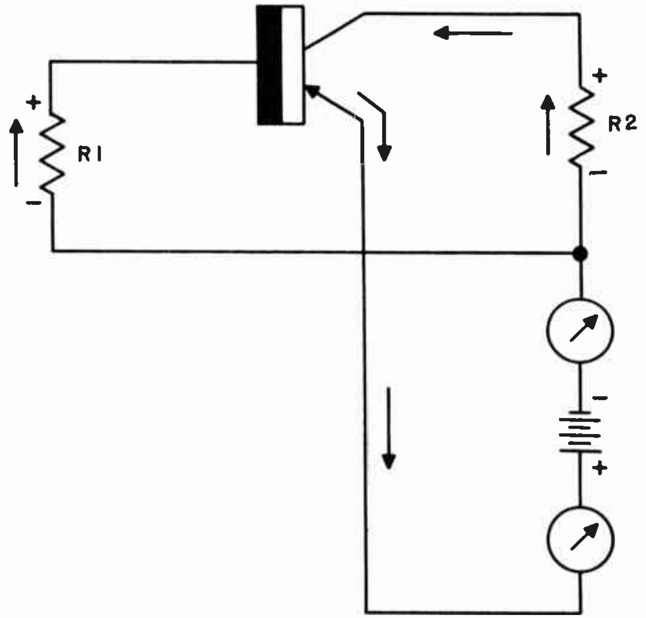


Fig. 306. *The electron flow out of the battery is identical to the electron flow into the battery.*

resistor that we are going to develop our output signal voltage. We know from what we have learned earlier that the current carriers inside the transistor consist of positive charges. But, in the external circuits, in the input and output circuits consisting of resistors, wires and a battery, all we get is a movement of electrons. Consider the electrons as starting from the negative terminal of the battery. Note that there are two paths — through load resistor R2 and also through resistor R1. But for every electron that leaves the battery, an electron must return. In other words, if we were to insert a dc milliammeter at the negative terminal of the battery and an identical meter at the positive terminal of the same battery (Fig. 306), both meters would read exactly alike. Although there are two outgoing paths from the battery, there is but a single return path. The sum of the currents flowing through R1 and R2 must be equal to the current flowing through the emitter.

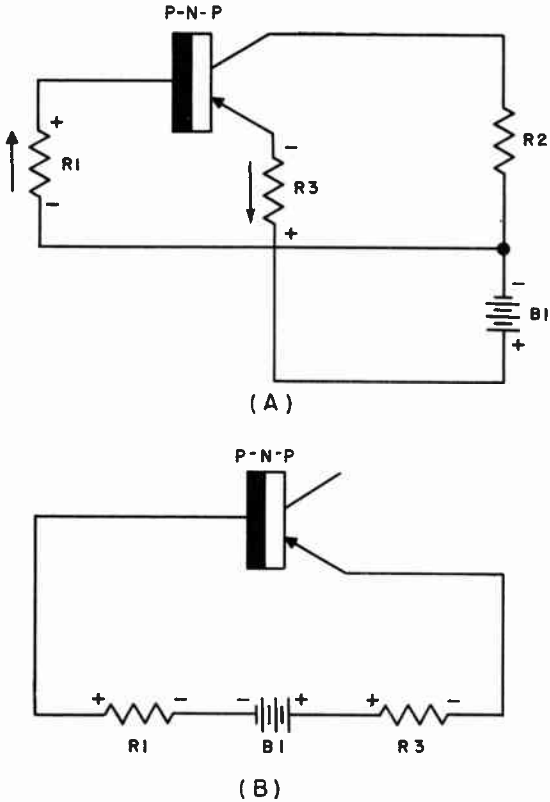


Fig. 307. *The voltage across R1 supplies fixed bias. This bias remains fairly constant. The voltage across R3 supplies self-bias. The value of self-bias depends primarily upon the amount of collector current.*

Whenever a current flows through a resistor, it produces a voltage drop across it. The arrows in Figs. 305 and 306 show the direction of current and also the polarity of the voltage across R1. The voltage produced across R1 has a polarity that is opposite to that of the collector battery.

In Fig. 305-B, we have a simplified version of the circuit in Fig. 305-A. R1 helps to complete the input circuit and at the same time allows us to use a single battery for both output (collector) and input bias. This type of input bias is called *fixed bias*. This isn't a very satisfactory arrangement since R1 would have to be adjusted for each individual transistor – and there is still nothing to prevent collector-current runaway.

The circuit in Fig. 307 looks exactly like that in Fig. 306 except that we have added another resistor, R3. Unlike resistor R1, which passes but a small amount of current (usually less than 5% of the total), R3 carries not only the base current but the collector current as well.

Let us suppose that for some reason the collector current increases substantially. This current, flowing through R3, will increase the voltage drop across this resistor. But this voltage has a polarity that opposes the movement of any current in the base-emitter circuit. When the current in the base-emitter circuit decreases, so does the collector current. A reduction in collector current, though, will lower the voltage across R3, permitting the current in emitter-base circuit to rise to normal once again.

The circuit in Fig. 307-B is a simplified version of Fig. 307-A. Note that the polarity of the voltage across R3 is such that it *opposes* the battery voltage. Suppose, just as an example, we were to short resistors R1 and R3 with a piece of wire. The forward bias would be the entire voltage of battery B1. This battery, of course, is properly polarized for base current bias – that is, the plus terminal of the battery is connected to the emitter and the minus terminal to the base. Consequently a very heavy emitter current will flow since the emitter-base portion of the transistor is biased in the forward direction. If we remove the shorting wire from across R1, we will now get a reduction in forward-bias voltage because the voltage across R1 opposes that of B1. The voltage across R1 is not too large since the base current is so small. We can get more effective action by removing our shorting wire from across R3. R3 carries the collector and base currents, but it is primarily the collector current itself which controls the amount of bias in the input circuit.

Both R1 and R3 determine the amount of input circuit bias. R1 supplies fixed bias while R3 supplies self-bias. By now the difference between fixed and self-bias should be apparent. Fixed bias, as the name implies, remains the same regardless of what happens in the output circuit. Self-bias means that the transistor biases itself. Self-bias operates automatically to put the right amount of dc voltage on the input (base and emitter) so that the transistor works at its correct operating point.

Common base and common collector

We have been discussing the common-emitter circuit for the most part since it is more widely used than the common-base or common-collector arrangements. However, the biasing ideas that we have been studying can also be used for these other circuits — and the methods for obtaining biasing are identical.

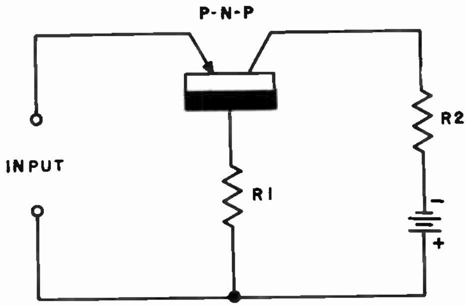


Fig. 308. *Common-base p-n-p arrangement using self-bias.*

The common-base circuit shown in Fig. 308 uses R1 for self-bias. Whether or not the circuit will also use fixed bias depends upon the type of input. If transformer input is used, the secondary winding of the transformer will have a very low resistance and will contribute practically nothing to the overall base-emitter bias. If resistance-capacitance coupling is used, the amount of fixed bias will depend upon the resistor connected across the input terminals.

The common-collector circuit of Fig. 309 follows the same pattern as the earlier circuits. R1 supplies fixed bias for the input circuit.

Voltage divider

Resistors are frequently used to enable us to obtain various voltages from a single source and for this reason are often called voltage dividers. Voltage dividers are not economical from the viewpoint of battery power but they do represent a simple way of getting required voltages. To see how this is done, let us look at Fig. 310. Here we have two series resistors connected across the battery. Current will flow through the two resistors and we will get a voltage drop across them. The arrows show the direction of current (electron) flow and the polarity of the voltages. The center or common connection of the resistors is marked B while the outer terminals are identified by the letters A and C. A is the most negative point while C is the most positive. But what about B? B is negative with respect to C, but positive with respect to A. We can use B as a positive or a negative point, depending upon whether we use A or C as our reference.

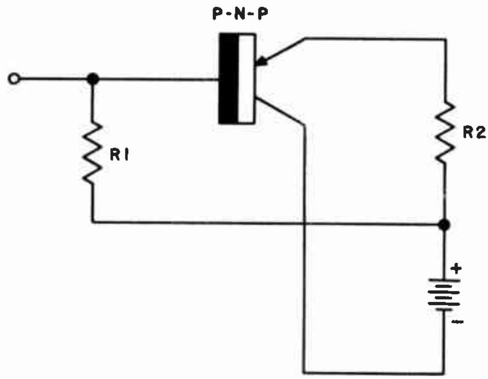


Fig. 309. *Common-collector circuit using fixed bias supplied by the voltage drop across R1.*

We can put the voltage divider to work as shown in Fig. 311. Here we have two resistors R1 and R2 connected in series. If you will trace the circuit, you will see that the battery and the resistors R1 and R2 form the same circuit as shown in Fig. 310.

Current leaves the negative terminal of the battery, flows through R1 (producing a voltage drop), through R2 and then back to the positive terminal of the battery. But what about point B, corresponding to point B in Fig. 310? This point (connected to the base) is negative with respect to point C. In other words, point C (the emitter) has been made positive with respect to point B (the base). The base-emitter circuit is now properly biased in the forward direction.

The amount of bias voltage for the base-emitter circuit will depend upon the values of R1 and R2 and upon the amount of battery voltage. This sort of bias is fixed bias since it is completely independent of the transistor.

Neutralization and feedback

These two terms, neutralization and feedback, have been carried over from vacuum-tube circuits to transistors. Although the two words are sometimes mistakenly used to mean the same thing, there is a very definite distinction between them. Feedback can be either positive or negative. In a circuit, the use of positive feedback results in regeneration and sometimes in oscillation. Positive feedback increases the gain of a circuit. Negative feedback, also known as degenerative or inverse feedback, decreases the gain of the circuit to which it is applied and also produces certain desirable circuit characteristics. Negative feedback and, to a lesser extent, positive feedback are mostly used in audio amplifiers. Neutralization is negative feedback only and is used in radio-frequency amplifiers to keep the amplifiers from oscillating. Neutralization is often found in connection with transmitting rf amplifier triodes and is also associated with the triode rf amplifier in television front ends.

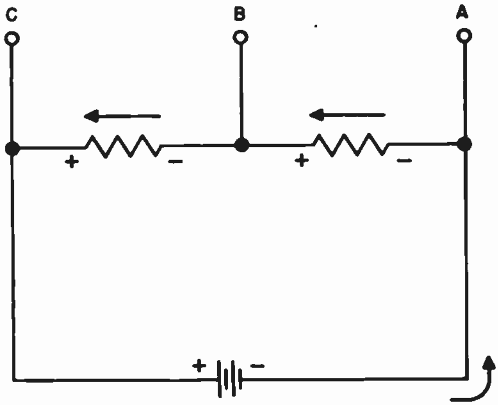


Fig. 310. *Simple voltage-divider action.*

Degenerative feedback

In a vacuum-tube receiver, degenerative feedback is easily obtained by omitting the bypass capacitor shunted across the cathode resistor. In a transistor amplifier, the same technique is followed. This capacitor is normally placed across the emitter resistor in a common-emitter amplifier. Fig. 312 shows a p-n-p circuit with the emitter bypass capacitor in place. For an n-p-n arrangement (Fig. 313), the emitter bypass (if an electrolytic) must be transposed.

There are a number of effects that can be produced by not using the emitter bypass. The circuit becomes more stabilized – that is, there is less opportunity for the operating point of the amplifier to shift, less chance for collector-current runaway. The gain of the stage is reduced, just as it is in vacuum-tube circuits.

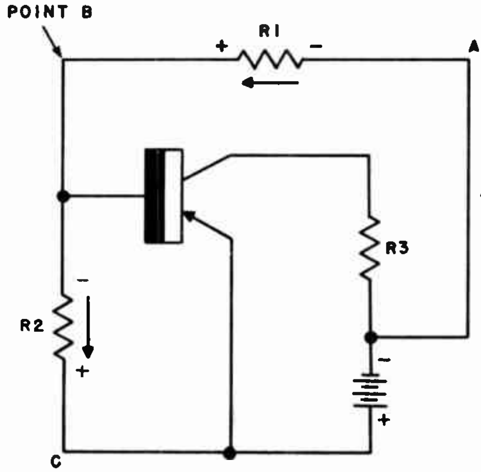


Fig. 311. *R1 and R2 act as a voltage divider across the battery.*

However, the stage becomes more linear in its operation – there is less distortion. The frequency response of the amplifier becomes wider. And, finally, the input impedance increases.

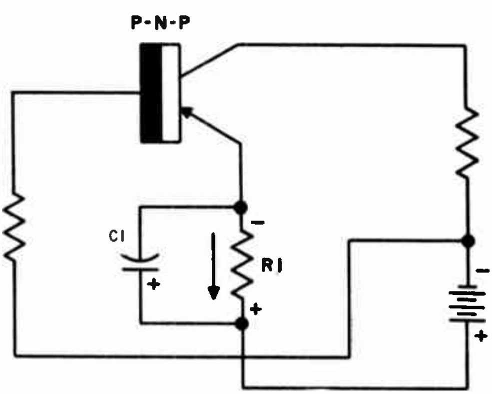


Fig. 312. *The emitter resistor, R1, is bypassed by capacitor C1. If C1 is an electrolytic, its polarity must be the same as that of the emitter resistor.*

The amount of degeneration obtained depends upon the voltage drop across the emitter resistor. Remember — the voltage across the emitter resistor opposes the forward bias of the transistor input circuit. The larger the resistor, the greater this voltage drop will be, hence the amount of degenerative feedback will be greater.

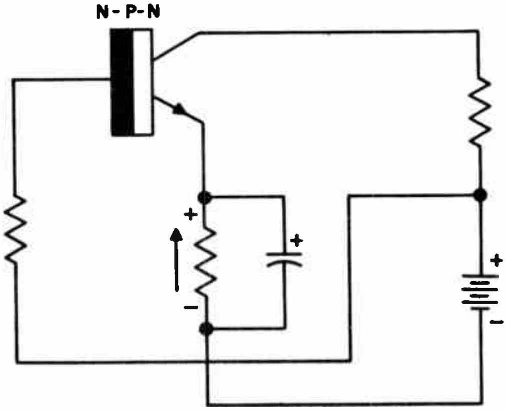


Fig. 313. *When using an n-p-n unit in place of p-n-p, not only must the battery leads be transposed, but the emitter bypass (if an electrolytic) must also have its leads changed.*

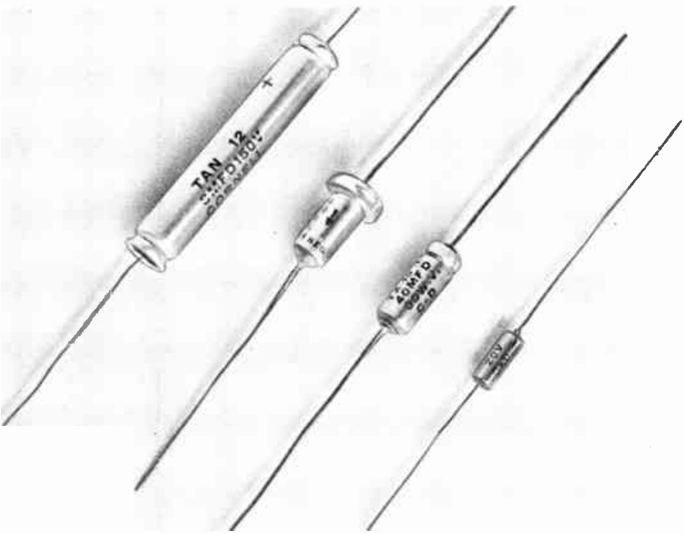


Fig. 314. *The photo shows typical electrolytics used in transistor receivers. These are very small compared to the units you will find in vacuum-tube receivers.*

The value of the emitter bypass capacitor can be 50 μf or higher. When connecting this capacitor, watch polarity carefully. It must agree with the polarity of the voltage developed across the emitter resistor. For p-n-p units, the negative terminal of the capacitor connects to the emitter. For n-p-n transistors, connect the positive end of the capacitor to the emitter.

Electrolytic capacitors used in transistor receivers are small compared to the types you will find in vacuum-tube receivers. The dc working voltage is generally less than 20. Both aluminum and tantalum electrolytics are used. See Fig. 314.

Multiple stages

Coupling of transistor stages follows the same general techniques used in vacuum-tube receivers. Transformer coupling is quite common as is resistance-capacitance coupling. Direct coupling of one stage to the next is also used.

Transformer coupling

A typical transformer-coupled transistor amplifier is shown in Fig. 315. Both of the transistors are p-n-p types and are used as common- (or grounded-) emitter amplifiers. A single battery supplies collector current for both stages. Fixed bias for the first stage is furnished by R1 and fixed bias for the second stage by R2. Capacitors C1 and C2 are used to prevent shorting the dc voltage developed across R1 and R2. Without the capacitors, resistors R1 and R2 would be in shunt across the battery.

Each stage of this circuit is characterized by a low input impedance and a high output impedance to match the characteristics of the grounded-emitter amplifier. Transformers T1, T2 and T3 are audio transformers.

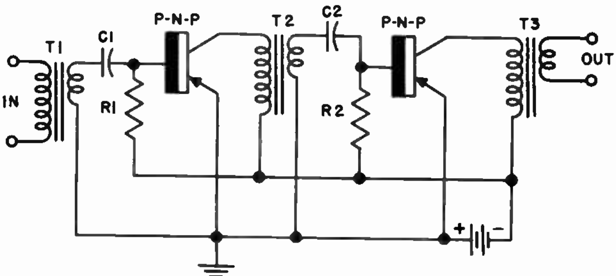


Fig. 315. *Two-stage transformer-coupled amplifier using p-n-p units. A single battery supplies collector bias. Resistors R1 and R2 furnish fixed bias for the base-to-emitter input circuits.*

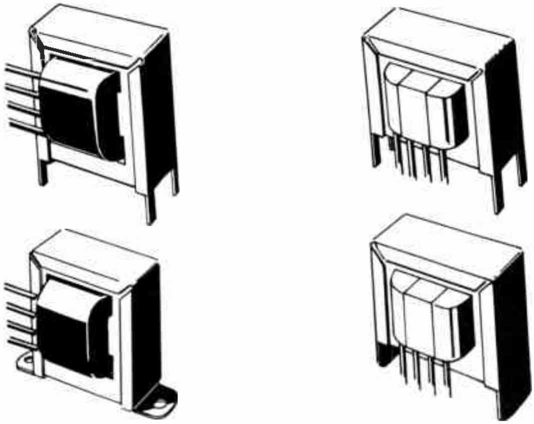


Fig. 316. *Transistor transformers are small compared to those used in vacuum-tube receivers.*

In line with the trend toward small size, the transformers used in transistor radios are quite tiny. Fig. 316 shows pairs of transistor audio transformers whose maximum dimension is less than 1 inch. The transformers in transistor receivers can be input, interstage, driver and output types—just as in vacuum-tube receivers. The ratio of the primary to secondary impedance of the transformers depends upon the application and type of transistor. The chart shown in Fig. 317 will give you some idea of the turns

Application	Turns Ratio Pri. to Sec.	Impedance in Ohms Pri.	Impedance in Ohms Sec.	D.C. Resistance in Ohms Pri.	D.C. Resistance in Ohms Sec.
Input	1.00:45.5	30 C.T.	50,000	14.7	4060
Interstage	3.08:1	100 C.T.	10 C.T.	19	1.27
Output	5.22:1	350 C.T.	4, 12	38	1.45
Output	5.53:1	500 C.T.	4, 8, 16	75.3	3.55
Interstage	3.16:1	500 C.T.	50	59.7	7.9
Output	5.65:1	600 C.T.	4, 8, 16	73.2	3.2
Interstage	10.0:1	500 C.T.	50,000	76.8	5135
Output	6.75:1	825 C.T.	4, 8, 16	74	2.7
Output	9.80:1	1,250	4, 12	132.5	1.4
Interstage	4.08:1	1,200	20,000 C.T.	142	1860
Interstage	1.65:1	1,500	500 C.T.	104	46.5
Output	11.8:1	2,500	4, 16	370	2.3
Interstage	1.00:1.22	5,000 C.T.	7,500 C.T.	650	790
Interstage	1.00:1.41	5,000 C.T.	10,000 C.T.	635	1100
Interstage	1.00:4	5,000 C.T.	80,000 C.T.	573	5740
Output	24.6:1	10,000 C.T.	4, 8, 16	1174	2.6
Interstage	14.0:1	10,000	200 C.T.	1200	33.4
Interstage	2.24:1	10,000	2,000 C.T.	1200	257
Interstage	1.83:1	10,000	3,000 C.T.	1200	385
Output	5.55:1	400 C.T.	11	71.5	1.5
Interstage	3.44:1	500 C.T.	150 C.T.	62	21.2

Fig. 317. *This chart shows typical characteristics of input, interstage and output transformers used in transistor receivers.*

ratio, the primary and secondary impedances and the dc resistances of the primary and the secondary windings of typical transformers.

R-C (resistance-capacitance) coupling

A three-stage R-C amplifier is shown in Fig. 318. The coupling capacitors C1, C2 and C3 and C4 can have values of 1 μf or larger. A typical coupling capacitor would be a unit having a capacitance of 2 μf and a dc working voltage of 18 or less. These capacitors are aluminum or tantalum types. They are quite small in comparison with the units found in vacuum-tube or television receivers. Large values of capacitance are needed for coupling in audio transistor stages since the input impedance of such stages is very low compared to vacuum-tube circuits. Such capacitors can be electrolytics. When using electrolytics as coupling units, watch the polarity of the capacitors. Since, for p-n-p units, the negative terminal of the battery is connected to the collector, the negative terminal of the electrolytic also goes to this point. If the capacitor couples from the collector of one stage to the base of the next, the positive terminal of the capacitor would go to the base

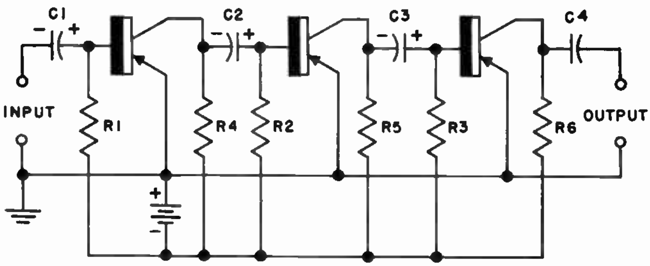


Fig. 318. *R-C-coupled transistor amplifier using p-n-p units. Fixed bias is used throughout. The coupling capacitors can be 2-μf tantalum electrolytics.*

of the following stage. (NOTE: The problems raised by defective components such as capacitors and transformers will be covered in the chapter on servicing.)

Although you will find resistance-capacitance-coupled amplifiers in a few receivers, for the most part transistor receivers use transformer coupling. You will find R-C coupling in some circuits. Very little space is actually saved by R-C parts since transformers in transistor receivers can be extremely small. Usually additional stages are required to replace the possible gain lost by using R-C coupling.

DC (direct-coupled) amplifiers

There are a number of possible arrangements of direct-coupled amplifiers, one of which is shown in Fig. 319. This circuit is unique in that a number of biasing arrangements are used. We can immediately recognize R1 and R2 as the type of voltage divider that we studied earlier in this chapter. R2 supplies fixed bias. In the first stage, R3 forms part of the base-to-emitter bias network but, since R3 is not bypassed, this stage has a certain amount of negative feedback, depending upon the amount of collector current flowing through R3 and its resistance in ohms. Actually, R3 cannot be bypassed since the signal voltage for the second transistor stage is developed across this resistor. One side of R3 is connected directly to the base of the second transistor while a connection is made to the emitter by the bottom end of R3 through the common-ground wiring. R3 not only carries the signal currents but also furnishes a small amount of fixed bias for the second transistor. For the most part, however, bias for the

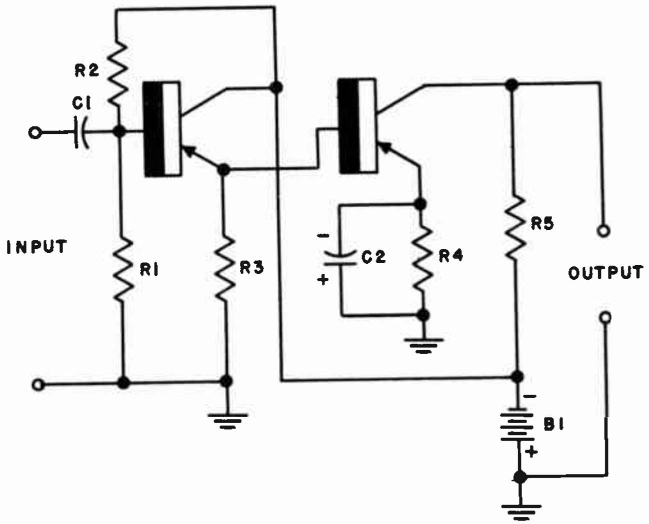


Fig. 319. *Direct-coupled transistor amplifier.*

second stage is supplied by R4 shunted by electrolytic bypass capacitor C2. The presence of C2 increases the gain of the second stage.

Combined negative feedback and self-bias

Components in transistor radios can be made to perform a double job. Resistor R3 in Fig. 319 is a typical example of this.

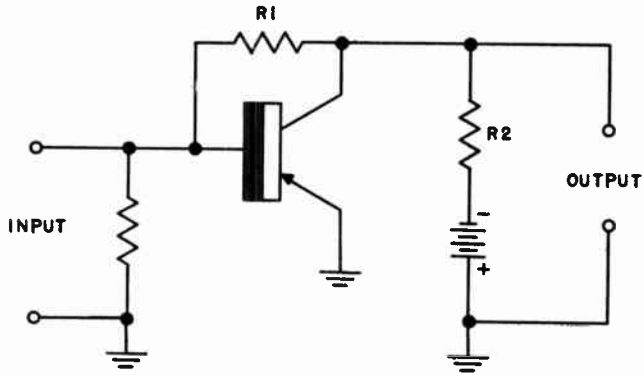


Fig. 320. *R1 has two jobs. It supplies fixed bias and negative feedback.*

We can also return to a circuit that we studied somewhat earlier and now shown in Fig. 320. When we examined the circuit, we learned that R1 was used to supply a certain amount of fixed bias for the p-n-p transistor. In a grounded-emitter circuit, however, the output signal voltage is 180° out of phase with the signal input. The output signal voltage is developed across R2, with the top end of R2 representing the "hot" end of the resistor. But one end of R1 is connected to this very point.

This means that some of the output signal is being fed back

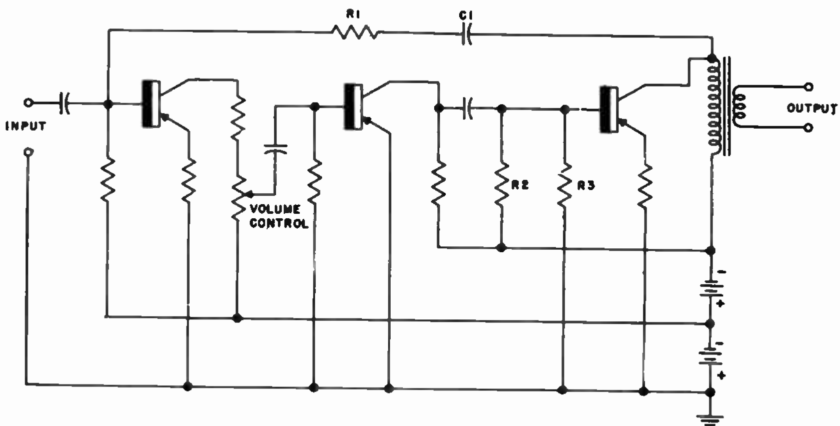


Fig. 321. *R1 and C1 represent the negative feedback circuit. The amount of voltage fed back depends upon the values of R1 and C1 and also upon the output signal voltage. R2 and R3 form a voltage divider across the battery supply and place the correct amount of bias voltage on the input circuit of the last transistor.*

to the input and, furthermore, is out of phase with the input signal. This, then, is a representative case of negative feedback. So, in considering R1, we must regard it as a bias resistor supplying the input circuit with fixed bias, but also with negative feedback. While R1 will help bias the base-to-emitter circuit properly, it also acts to cut down on the gain of the stage.

Under certain circumstances, negative feedback may be desired without accompanying bias voltage. All that is necessary is to put a capacitor in series with the feedback resistor, as illustrated in Fig. 321. Here R1 and C1 form a feedback path from the collector of the output stage to the base of the input stage. C1 prevents R1 from becoming part of the voltage divider but permits the output signal to be fed back to the input transistor. The amount of feedback voltage depends upon the values of R1 and

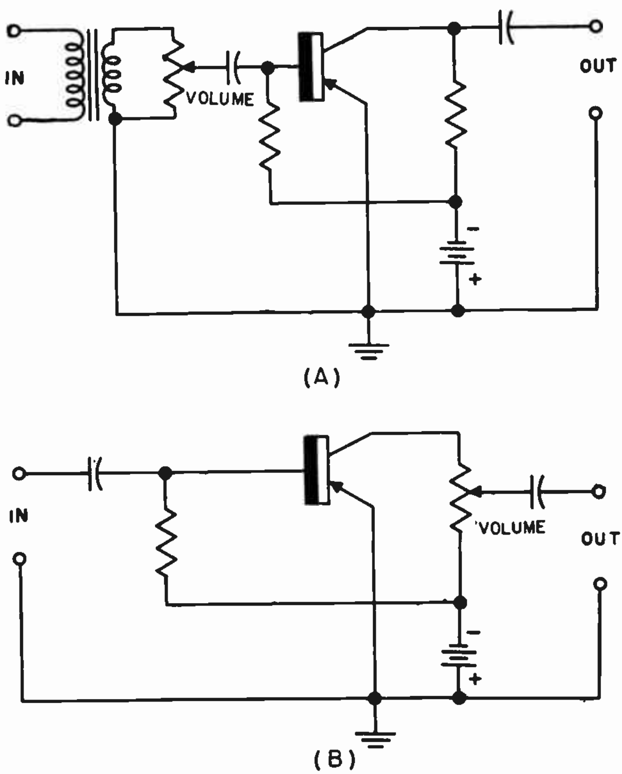


Fig. 322. *Typical placement of the volume control in transistor receivers.*

C1 and also upon the amplitude of output signal voltage available. It is important to see, also, that negative feedback of this type is done over an odd number of stages. The feedback can be from the output to the input of 1, 3 or more stages. In the case of Fig. 321, we have a three-stage transistor amplifier.

Fig. 321 has other interesting points. R2 and R3 may look somewhat strange but, if we were to trace the circuit, we would readily see that they form a voltage divider across the battery and in so doing manage to place the correct amount of bias voltage on the base-to-emitter (input) circuit of the final transistor. A tap is run off from a connection on the batteries for the input of the first stage. Incidentally, this technique could also have been used for the other stages. R2 and R3, while wasteful of battery current, help form a more constant current source for input bias.

The volume control

In most vacuum-tube receivers, the volume control is placed at the input grid of the first audio amplifier. While this is very common, you will still find some old receivers in which the volume control doubles as a cathode bias resistor or is sometimes inserted in the antenna input circuit.

The position of the volume control in a transistor receiver is somewhat fussier since we are always concerned with impedance matching. Having established a correct impedance match between one transistor circuit and the next it would not be desirable to insert a variable resistor that would upset this arrangement. The illustrations, Figs. 322-A and -B, show how the volume control can be connected either in the input or the output circuit of a transistor.

What's next?

In this chapter we have spent quite some time on fundamental transistor amplifiers. This does not mean that we have covered every aspect completely, since we have not as yet touched upon push-pull amplifiers, the various classes of operation, tone controls, rf amplifiers, etc. These operations, and many others, will be described as we go through the book.

In this chapter, we also described a single but extremely important test — the measurement of leakage current. In future chapters, we will describe many other tests, how they are performed and the use of test instruments in connection with transistors.

chapter

4

rf and if stages

In Chapter 3 we covered the operation of the transistor in a rather general way. This was done to give you an overall idea of the sort of behavior you could expect from a transistor. But while such a description was necessary to give you a good basic background, you need to know just how transistors work in actual circuits and just how to repair these circuits when they become defective.

The most commonly used circuit today is the superheterodyne. Many transistor kits are being sold, however, and these also sometimes find their way into the service shops. Some of these kits consist of trf (tuned radio-frequency) receivers, regenerative and reflex receivers. These range in size from very tiny units to moderately sized portables. Because receivers (including the superheterodyne) can be small, many service technicians handle the transistor very gingerly, treating it with a caution it doesn't deserve – or need. The transistor is physically stronger than a vacuum tube. There is no glass and the overall structure is sturdy. The transistor has only three enemies – wrong or excessive bias voltages, excessive current and high temperatures. A little care and common sense can prevent this unholy trio from getting near the transistor.

Tools

Trying to use your existing tools for repairing transistor receivers is like using a monkey wrench for repairing a watch. The tool is too big for the job. You will also need additional tools which you probably do not have at the moment. Some of these are shown in Fig. 401.

Screwdrivers: The very small screwdriver which you use for vacuum-tube receivers is still useful. In addition, you should obtain a set of jeweler's screwdrivers. You will find that these screwdrivers are so designed that you cannot apply excessive rotating

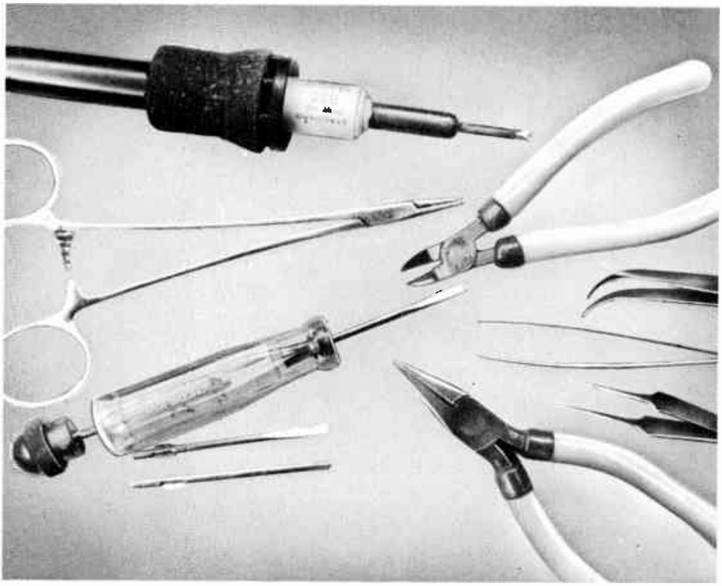


Fig. 401. *Typical tools used in servicing transistor receivers.*

force. Stripping the threads of tiny screws is a nuisance, especially if you do not have a replacement screw available.

Tweezers: You should have at least two types of tweezers – a pair that comes to a sharp point and a pair of duck bills. The duck bills have a large flat surface near the ends. When obtaining tweezers, do not get the short types but get the long tweezers that will enable you to reach into remote parts and still give you ample grip on the tweezer. Many fine tweezers are still being sold as surplus and you can often obtain a good pair for very low cost.

Jeweler's Loupe: You have probably seen the way in which your local jeweler examines the interior of a watch assembly. He does this with a magnifying glass which is held in place near the eye by the muscles of the face. This has the advantage that the hands are free to work. If you prefer, you can obtain a lens mounted on a stand. Some of these come equipped with electric light bulbs so the part to be examined can be put into strong light. As a start, you could get a hand-held magnifying glass but you will probably find it somewhat inconvenient. Various types are shown in Fig. 402.

Fig. 402. *Magnifying lenses are useful in working with transistors.*

Soldering Irons: Your most useful tool will probably be an iron rated somewhere between 25 and 32 watts. An iron having interchangeable tips is best. However, this does not mean that your regular 100-watt iron is of no value. It all depends on your own skill. A 32-watt iron held on transistor leads for 10 seconds can do more damage that a 100-watt iron used for 1 second. The whole purpose in soldering — or unsoldering — transistors is to use the least amount of heat that will do the job properly. But heat can accumulate — and so the use of a 32-watt iron is no guarantee that the transistor will not be damaged. Do not use a soldering gun. Its heat is extremely high. Further, the intense magnetic field surrounding the soldering gun can induce voltages which could damage the transistor.

You will find most transistors soldered into place, but some do use sockets. If a socket is used, take advantage of it by removing the transistor before making any soldered connections to the terminals. Some technicians, noting that a few transistors come equipped with long leads, try to avoid unsoldering by cutting them. Avoid this practice if at all possible. In some sets, leads are welded. Here the only alternative is to cut the leads.

There are a number of techniques you can use to protect the transistor from the heat of a soldering iron. The easiest method is to use a heat sink. As shown in Fig. 403, this consists of a pair of long-nose pliers placed between the transistor and the ends of the leads. The heat of the soldering iron, instead of going into

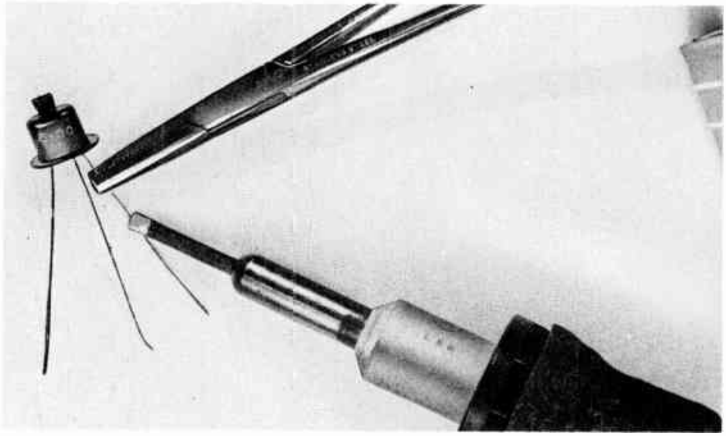


Fig. 403. *Pliers used as heat sink when soldering transistor leads.*

the transistor, is shunted away by the large amount of metal of the pliers. Put a rubber band around one end to hold the pliers in place. Be sure to keep the pliers attached for at least several seconds after the iron has been removed.

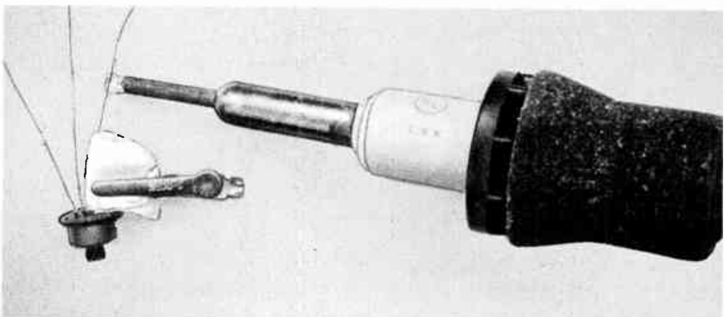


Fig. 404. *A bit of damp cloth held in place with an alligator clip can serve as a heat sink.*

You can use a piece of damp cloth, cotton or felt as a heat sink. Dip the cloth in water and then squeeze gently until the cloth is saturated but not dripping. Attach the wet cloth to the transistor lead with an alligator clip as shown in Fig. 404.

Special soldering iron tiplets are manufactured to make desoldering the components of printed-circuit boards considerably easier. Shaped to make contact with tube-socket terminals, the three cup-shaped tiplets make socket replacement simpler. The slotted tiplet will make it easier to straighten tabs on sockets, controls and transformers while keeping the solder in a liquid state. The bar tiplet mounted in the iron is convenient for soldering the multiple in-line terminals of the printed networks that reduce the number of connections required between stages.

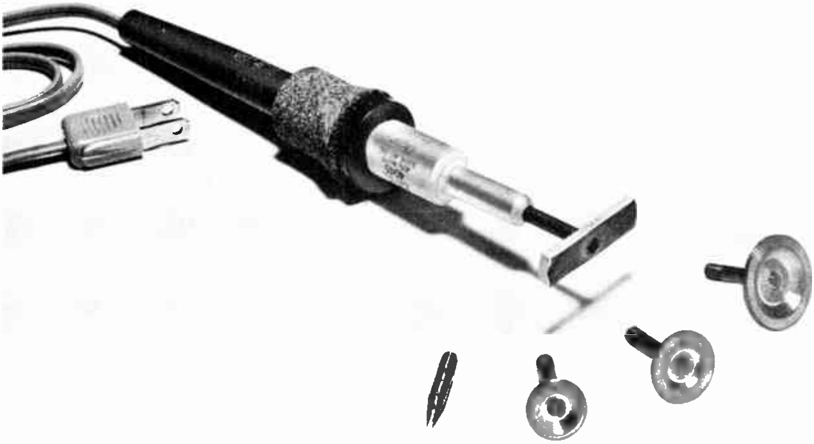


Fig. 405. *Interchangeable tips are designed for unsoldering components from printed-circuit boards.* (Ungar Electric Tools)

Not all solder has the same melting point. If you use a high-melting-point solder, you will probably damage the transistor long before the solder has melted. As a precaution, use 60-40 rosin-core solder. The same arguments that are used against acid-core solder in vacuum-tube receivers apply here. However, acid-core solder does permit very fast and easy soldering. If you do use such solder, be certain to clean thoroughly with alcohol after the connection has been made. Incidentally, do not replace a transistor unless you are definitely sure that it is the transistor that needs to be replaced. Most service technicians are conditioned

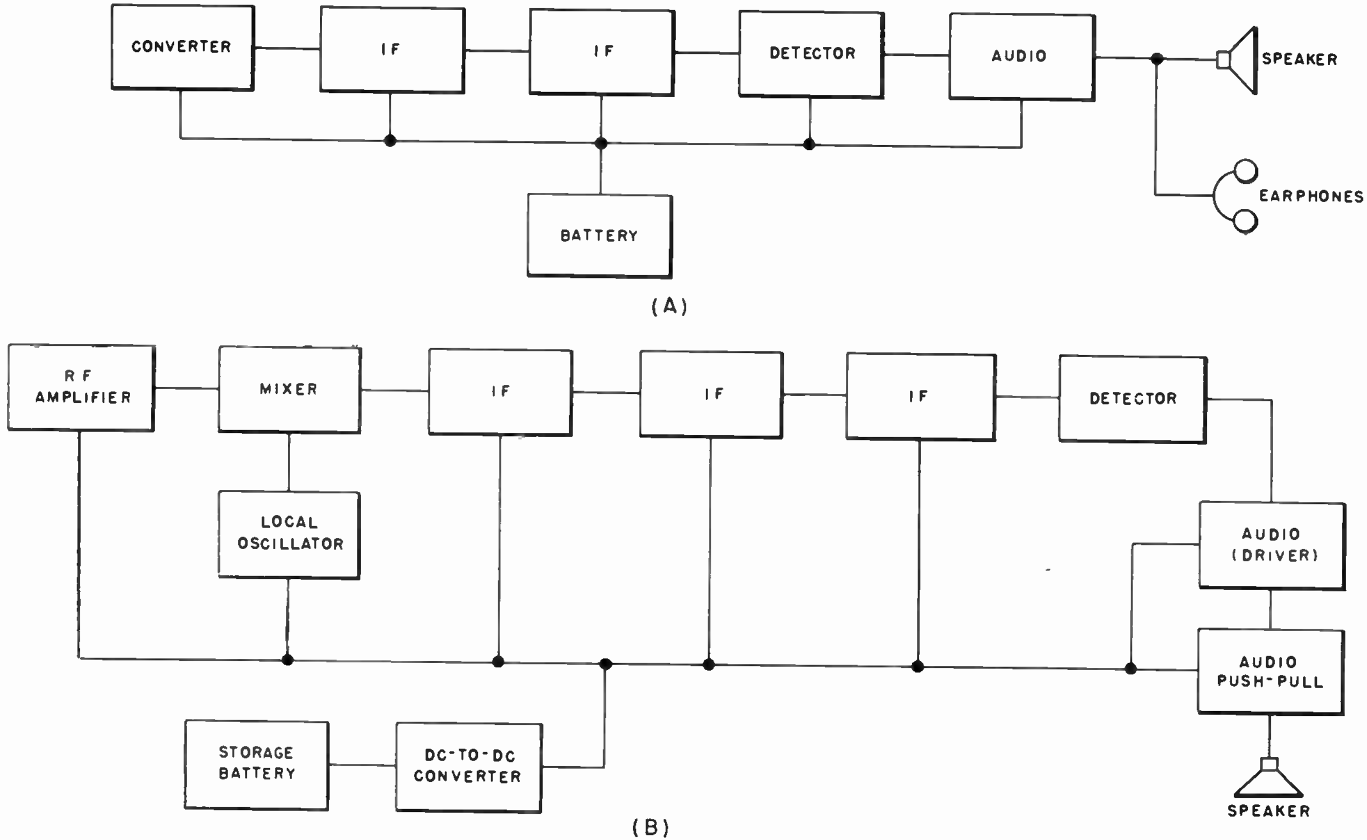


Fig. 406. *Block diagram of a portable or home receiver (A) and a diagram of an auto radio (B). The automobile receiver is more complicated.*

to the fact that troubles in radio and TV sets are mostly tube troubles. It does not follow, though, that most troubles in transistor receivers are caused by the transistors. On the contrary. As we proceed you will learn that the transistor is a fairly sturdy component that seldom needs replacement.

The superheterodyne receiver

The transistor superheterodyne receiver works in exactly the same way as a vacuum-tube set. The incoming radio-frequency signal is mixed with a voltage generated by a local oscillator. The difference frequency (or intermediate frequency) is fed into several if amplifiers and then into a diode detector. The detected audio signal is amplified and is used to operate a speaker. Fig. 406 shows the block diagrams of typical transistor superheterodynes. The diagram of Fig. 406-A is for a portable. The one shown in Fig. 406-B is for an automobile radio. Note the difference between Figs. 406-A and 406-B. The auto radio has an rf amplifier stage and may use a dc-to-dc converter. Some auto radios are hybrid types — that is, there may be a combination of transistor and vacuum tube circuits.

The schematic of a portable superheterodyne receiver is shown in Fig. 407. The receiver, like others of its type, covers the AM broadcast band. The set consists of a converter (mixer-oscillator), two intermediate-frequency amplifier stages, an audio driver stage and push-pull output. The intermediate frequency (in most sets) is the same as that used in vacuum-tube receivers — 455 kc.

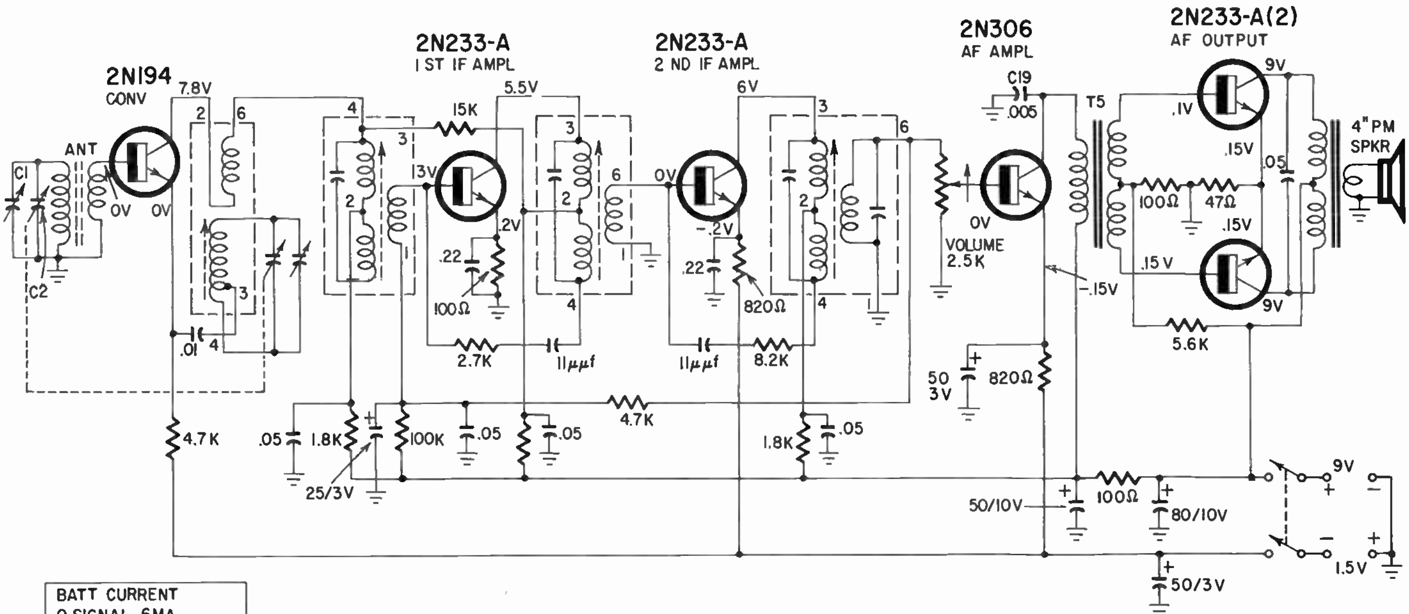
The "power-supply" consists of seven 1.5-volt size-C batteries. One of these cells supplies the 1.5 volts of bias required for the base-emitter circuits of the transistors. The remaining six batteries form a total of 9 volts for the collector supply.

The circuit of the transistor receiver shown in Fig. 407 uses n-p-n transistors. However, as we told you in an earlier chapter, the trend in transistor sets is toward the use of p-n-p's. In receivers using n-p-n transistors the direction of flow of current is similar to that of a vacuum tube set.

Transistor receivers use printed-circuit boards extensively. In later chapters we will study the printed-circuit board quite thoroughly. You will learn why transistors and printed circuits go together so naturally.

How we will proceed

Going through a complete transistor radio is quite a big mouth-



BATT CURRENT
O SIGNAL 6MA
50 MW OUTPUT 28 MA

Fig. 407. *Complete schematic of a portable transistor receiver.*

ful of information to swallow. Instead, we are going to analyze each circuit, from the front end to the speaker. A variety of circuits in addition to Fig. 407 will be covered, so you will be ready for any type of receiver.

Radio-frequency (rf) amplifier

With very few exceptions, portable and home receivers using transistors do not have an rf amplifier stage. In this respect, they follow the long-established practice of ac-dc vacuum-tube receivers. The matter is not one of economy on the part of the

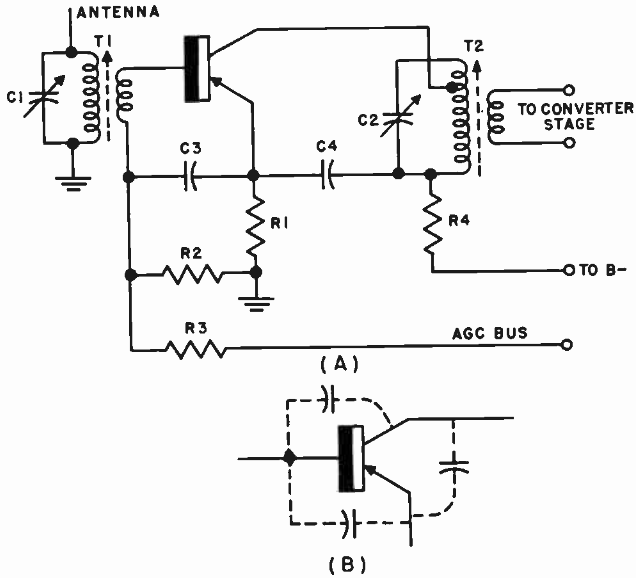


Fig. 408. *Typical rf amplifier stage found in the more expensive portables and in auto radios. The illustration (B) shows the capacitances that may exist around a transistor.*

manufacturer but rather is based on lack of need. Most home and portable receivers, both transistor and vacuum-tube, operate in areas of strong signal strength and low noise levels. In addition, the gain and sensitivity of the modern superheterodyne receiver are extremely good. The notable exception to all of this is in the production of transistor (all-transistor) and hybrid (combination of tubes and transistors) auto radios. Auto radios work under conditions of high noise levels and low signal inputs, hence such receivers generally come equipped with an rf amplifier stage in both tube and transistor receivers.

A typical rf amplifier stage is shown in Fig. 408-A. The antenna input transformer, T1, can be capacitor-tuned, slug-tuned or both. The transformer is a stepdown type to match the low impedance of the base input circuit. The most common arrangement for this circuit is the grounded-emitter amplifier.

Since we are working with a straightforward radio-frequency amplifier, both the input circuit (represented by T1) and the output circuit (represented by T2) are tuned to the same frequency. This is an ideal setup for an oscillator and most nearly resembles a vacuum-tube type tuned-grid tuned-plate oscillator. Emitter resistor R1 is unbypassed, however, and supplies enough negative feedback to overcome any positive feedback that may be present. (Positive feedback can take place through the invisible capacitances that exist between elements of the transistor, as shown in Fig. 408-B).

The collector lead of the transistor is tapped down on transformer T2 to match the impedance of the collector circuit. The secondary of this transformer can feed the input of a following converter or mixer stage.

Automatic gain control

In a television receiver, automatic gain control (agc) is used to control picture level or amplitude and to keep it constant. Automatic volume control (avc) does a comparable job for the receiver.

In vacuum-tube receivers, it has been customary to use the term avc. However, the present trend in transistor sets is to refer to agc and that is how we will identify it here.

The subject of agc has been introduced at this time since the rf stage of Fig. 408-A is agc-controlled. However, agc and its complete circuitry will be discussed in Chapter 5 in greater detail.

Capacitor C4 and resistor R4 represent a decoupling network and, while it may seem strange to have such components in a receiver having a pure dc supply (a battery), the battery can act as a coupling device between stages of the receiver. R4 and C4 act to decouple this stage from the others and to prevent signal energy from being fed back (via the battery) from other stages in the receiver. Capacitor C3 is an rf bypass and places the bottom of the coil at rf ground potential. It also serves as part of the agc filter.

The incoming signal is picked up by the antenna and is then transferred from the primary of T1 to the secondary by mutual induction. The signal voltage developed across the secondary of

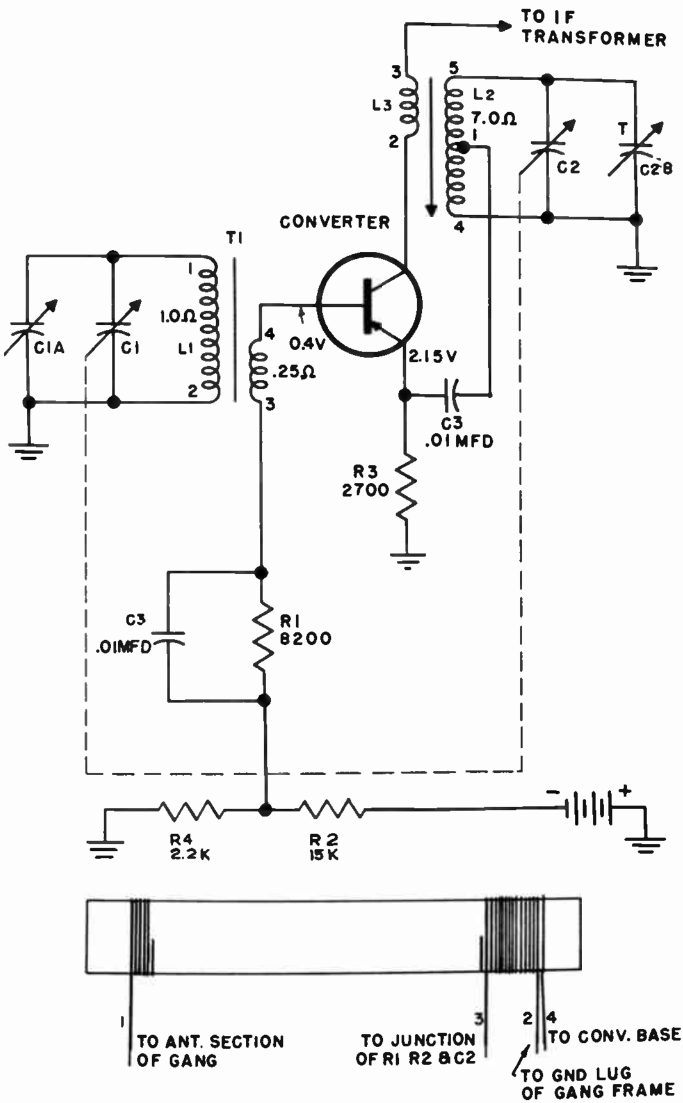


Fig. 409. *Typical converter circuit. A Hartley oscillator is used. L3 is a feedback coil and is in series with the if transformer.*

T1 is actually impressed between the base and emitter since C3 offers very little opposition to the rf signal. Since the input signal voltage is ac (even though it is high-frequency), it alternately aids and opposes the bias on the base-to-emitter input circuit. But when the bias is varied, the collector current is varied accordingly.

The changing collector current, circulating in the primary of transformer T2, induces a voltage across the secondary which is then fed into the following converter or mixer stage.

Thus, this circuit (like the other circuits we will study) follows very much the same techniques and theory of similar vacuum-tube circuits. Since, at this time, we are trying to become acquainted with the basic principles of transistor receivers, servicing information will be reserved for a later chapter.

The converter

A converter, whether in a transistor or vacuum-tube receiver, performs a double job. Part of the converter acts as the local oscillator. The local oscillator generates a signal and this locally generated signal voltage is fed into the converter transistor. At the same time, the modulated rf signal received from the broadcast station is injected into the same transistor. These two voltages mix (or heterodyne, or beat), producing a number of new frequencies. Of these frequencies, the one selected for the if (intermediate frequency) is the difference frequency — that is, the local-oscillator frequency minus the signal frequency.

A typical converter circuit is shown in Fig. 409. The incoming signal is tuned in by capacitor C1 shunted across coil L1. The rf signal is electromagnetically coupled to the base through a step-down rf transformer. L1 is a high-Q coil having a ferrite core.

The oscillator coil, L2, is tapped to form a Hartley oscillator. Capacitor C1 (for the rf section) and C2 (for the oscillator section) are ganged variable capacitors — just as they are in ac-dc vacuum-tube receivers. The 2700-ohm resistor in the emitter-circuit is known as a stabilizing resistor. It reduces the sensitivity of the transistor to temperature changes and permits replacement by a transistor whose characteristics might be slightly different than the original.

Another type of converter circuit is shown in Fig. 410. Fundamentally, this circuit works in exactly the same manner as the one illustrated in Fig. 409, but there are some interesting circuit differences. First, note that the negative terminal of the battery is grounded in Fig. 410, whereas in Fig. 409 the positive terminal is grounded. It is essential that we note this difference well since it demonstrates that we cannot always assume that the negative end of the battery is the ground point. N-p-n's are used in both circuits.

Now examine the input circuit. The primary and the secondary of the input transformer are connected at the ground end. This is usually an internal transformer connection. As a result, capacitor C1 must be inserted between the base of the transistor and the input transformer. If a direct connection were to be made between the input transformer and the base, the bias would be short-circuited through the low-resistance winding of the secondary of the input transformer (resistance usually less than 1 ohm).

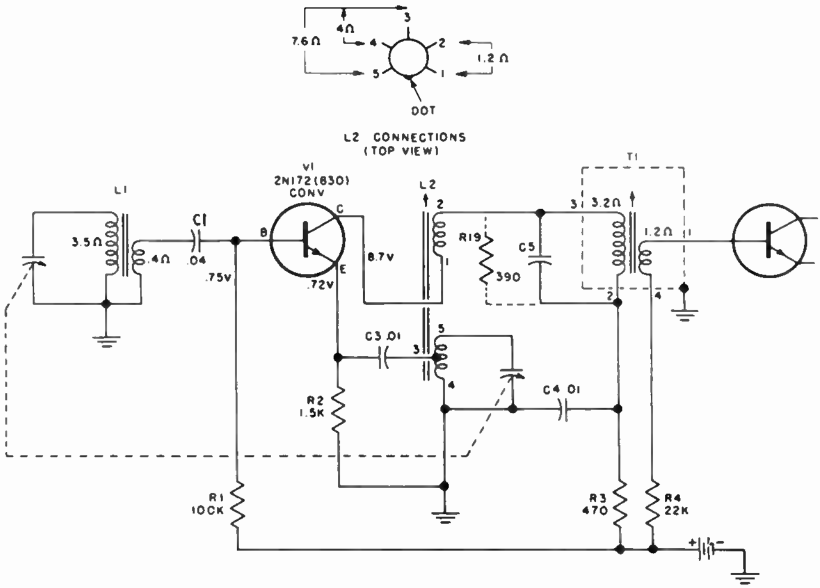


Fig. 410. *Converter circuit using an n-p-n transistor. The input rf transformer is connected to the base through a capacitor.*

Not all rf input transformers in transistor converter circuits are two-coil units (that is, have a primary and a secondary). Sometimes, as shown in Fig. 411, an autotransformer is used. As a general rule, an autotransformer is a three-terminal unit while a two-coil transformer is a four-terminal unit — but you cannot use this as a positive rule. If the transformer is the type that has the primary physically wired to the secondary (Fig. 410), it can be mistakenly identified as an autotransformer.

The local oscillator

The local oscillator, whether in a transistor or vacuum-tube receiver, performs the same function. It generates a signal of its own — and this signal voltage usually has a higher frequency than that of the rf signal delivered by the antenna transformer. The local-oscillator frequency is higher than the signal rf by the value of the intermediate frequency. Thus, if the if is 455 kc and the incoming rf signal is 1200 kc, then the local oscillator is 1200 plus 455, or 1655 kc.

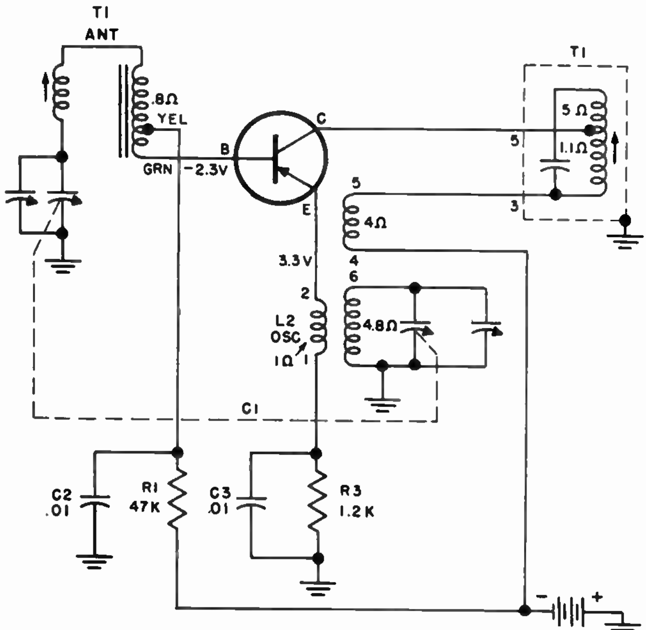


Fig. 411. *Converter circuit using an autotransformer type of antenna transformer. The collector is tapped down on the primary of the if transformer.*

The local oscillator can be a completely separate circuit with a a tube or transistor of its own, or it can be a part of the rf input and share a transistor (or tube) with it. However, whether the local oscillator is separate as a unit in its own right or whether it is joined with the rf into a converter arrangement, the circuitry of the oscillator is the same. You will find that most portable receivers do not use a separate local oscillator, but there are a few that do. You will find the separate local oscillator much more commonly used in auto radios.

A Hartley oscillator using a transistor is shown in Fig. 412. When the circuit is first turned on, a small amount of current flows from the battery B1 into the collector. This current flows through the upper portion of L1. Because this current starts at zero and gradually increases, it produces a growing magnetic field across the upper part of L1. This magnetic field induces a voltage across the lower part of L1. This voltage is placed across the input (base-to-emitter circuit) through C1 and C2. The effect of this input voltage is to increase collector current. But a growth in collector current means a greater amount of feedback voltage.

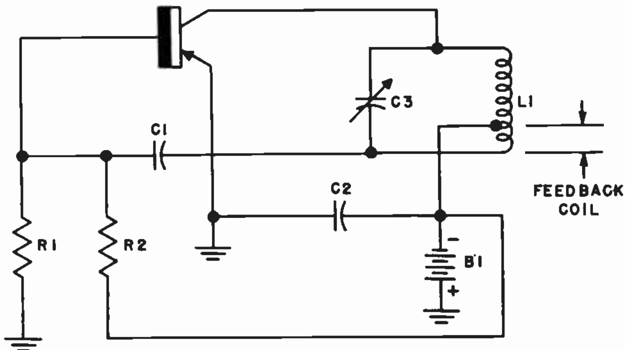


Fig. 412. *Hartley oscillator. Oscillator action is the same as in a vacuum-tube type.*

This continues until maximum current flows in the collector. By this time, the magnetic field around the upper part of L1 has reached a steady value and can no longer induce a voltage across the feedback coil. In the absence of a feedback voltage, the collector current drops rapidly. However, this induces a voltage across the feedback coil once again. But this time the polarity of induced voltage is in the form of a reverse bias applied to the input. This reduces current flow in the input circuit and as a result, collector current drops rapidly. When the collector current reduces to a very small value, the entire process repeats.

Another type of oscillator is one that uses the feedback arrangement shown in Figs. 413-A and 413-B. Actually, this circuit is practically identical with the Hartley oscillator we have just considered. The Hartley uses a tapped coil which simply behaves like an autotransformer. In Fig. 413 we have, instead of a tapped autotransformer, a coil having individual primary and secondary windings.

The theory of operation, though, is exactly the same as that of Hartley. Current flowing from the battery to the collector must pass through the secondary winding of transformer T. This produces an increasing magnetic field around the secondary. The growing magnetic field induces a voltage across the primary winding. This induced voltage increases current flow in the input circuit, resulting in more current flow in the output or collector circuit. The current in the collector circuit rises to a maximum and then decreases. Every time the collector current increases or decreases it feeds back a voltage to the input. The rate at which all of these current changes takes place is determined by the secondary coil of transformer T and capacitor C1 shunted across it.

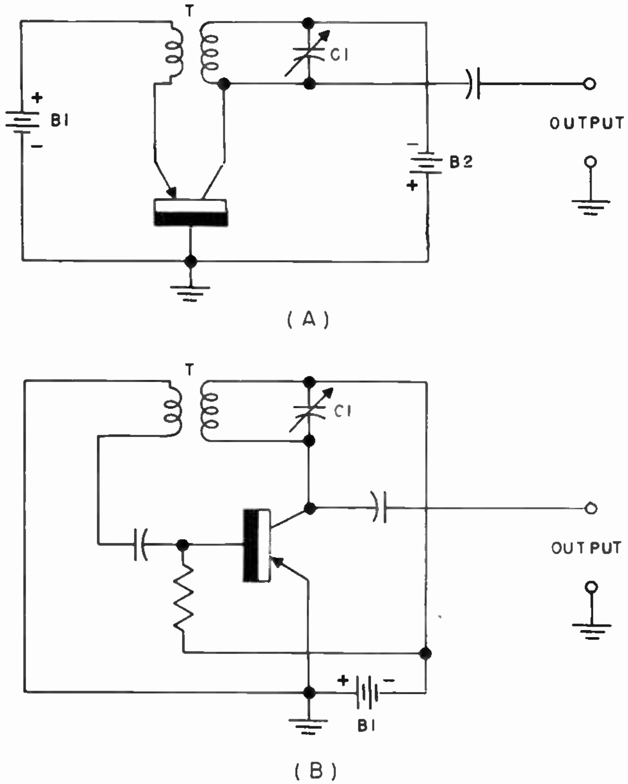


Fig. 413. *Grounded-base and grounded-emitter oscillators using a transformer for feedback.*

Sometimes a Colpitts oscillator is used in place of the Hartley. The only difference is that the Colpitts uses two capacitors in series across the tank or tuning coil instead of a coil with a tap. A connection taken from the junction of the two capacitors is equivalent to the connection of the tap on the coil in the Hartley circuit.

If you will now return to the circuits shown in Figs. 409, 410 and 411, you will see how the oscillator is connected in a converter circuit. In each instance, as shown in these illustrations, the current flowing through a coil in the collector circuit induces a voltage across the oscillator coil. In Fig. 409, for example, the feedback coil is L3 and is placed in series with the following if transformer.

A modification of the circuit is shown in Fig. 410. A different circuit arrangement is used in Fig. 411, though. Here the collector output goes directly to the if transformer and then to the series feedback coil. Actually, it makes very little difference whether the feedback coil precedes or follows the if transformer since the collector current must flow through both units. In Fig. 411, we can also see that the oscillator is similar to the arrangement shown in Fig. 413. The circuit of Fig. 411 is not a Hartley (that is, it is not an autotransformer) since the oscillator does have a coil with a separate primary and secondary.

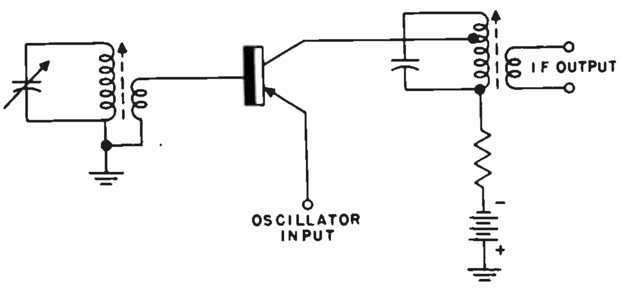


Fig. 414. *The oscillator circuit can be connected to the emitter of the mixer or converter.*

To simplify matters a bit, please take a look at Fig. 414. By itself, the circuit is an ordinary rf amplifier. If the output is tuned to the same frequency as the input, this is exactly what it will be. To change the circuit to a converter or mixer, all we need to do is to inject the signal produced by a local oscillator and connect this signal to the emitter input. And, since we tune the oscillator at the same time that we tune the incoming signal, our output (or intermediate frequency) will be a single frequency no matter what the position of the rf and oscillator tuning capacitors may be.

The intermediate-frequency stage

In an intermediate-frequency amplifier (if amplifier), both the input and output circuits of the stage are tuned to the same frequency. For this reason, an if stage is quite simple, the only complicating factors being the arrangements made for coupling the if signal from one stage to the next.

If coupling circuits can be inductive (as in the case of an if transformer) or can be combined inductive-capacitive arrangements. Typical transformer coupling is shown in Fig. 415. The

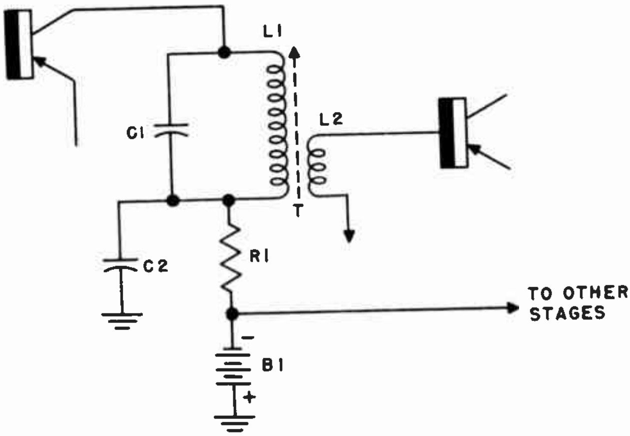


Fig. 415. *The if transformer is a stepdown type. The collector circuit has a higher impedance than the base circ .it of the following stage.*

inductance of L1 is much greater than that of L2. However, it isn't just the inductance of L1 which determines the impedance of the primary of transformer T. L1 and C1 form a parallel circuit and at the resonant frequency (the frequency of the if stage) has its maximum impedance. If C1 or L1 should be detuned, the impedance will decrease and the amount of signal transfer to the secondary L2 will also be less. The impedance of L2 is small so as to match the input impedance of the base-to-emitter circuit of the following if stage. In many sets, L2 is an untuned coil. R1 and C2 are decoupling units and act as a filter to prevent the signal voltages of other stages from getting into the if.

Sometimes, as shown in Fig. 416, the primary of the if transformer is tapped down in the collector circuit for better impedance matching. The .01 μf capacitor and the 470-ohm resistor form the decoupling network. These values are typical.

Another coupling arrangement makes use of the fact that capacitors can be used as voltage dividers or impedance dividers. In Fig. 417-A, we see how two series resistors can be used as voltage dividers. The voltage from A to B is less than that from A to C, the amount depending upon the ratio of the two resistances. Obviously, the resistance from A to B is less than that from A to C. So, if we wish, we could regard this circuit as a sort of "resistance stepdown."

In Fig. 417-B we have two series capacitors connected across

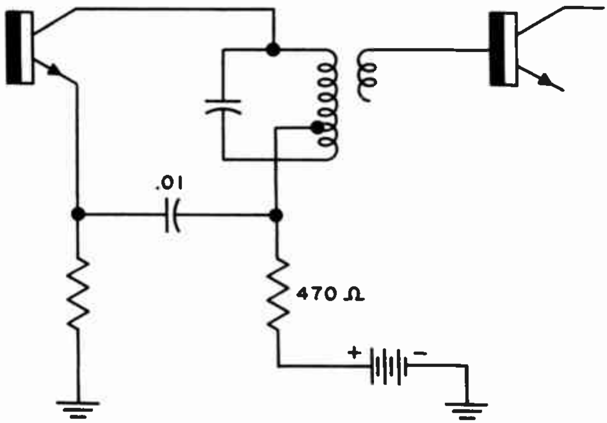


Fig. 416. *Because of the presence of the .01 μf capacitor, the tap on the primary of the if transformer is at signal ground potential. Tapping down is a widely used method of obtaining a suitable impedance match.*

an ac generator. The two capacitors act as voltage dividers, the amount of voltage across each capacitor depending upon the value of capacitance of the individual unit. The total capacitance from A to C is less than that from A to B, hence the capacitive reactance is larger. (Remember – series capacitors have less capacitance than the separate capacitors.) But impedance is made up of reactance (and resistance) so we can use the technique of Fig. 417-B as a coupling scheme in if stages. This is illustrated in Fig. 418.

As far as the collector of the first transistor is concerned, it sees the high impedance of the tuned circuit. The base of the following

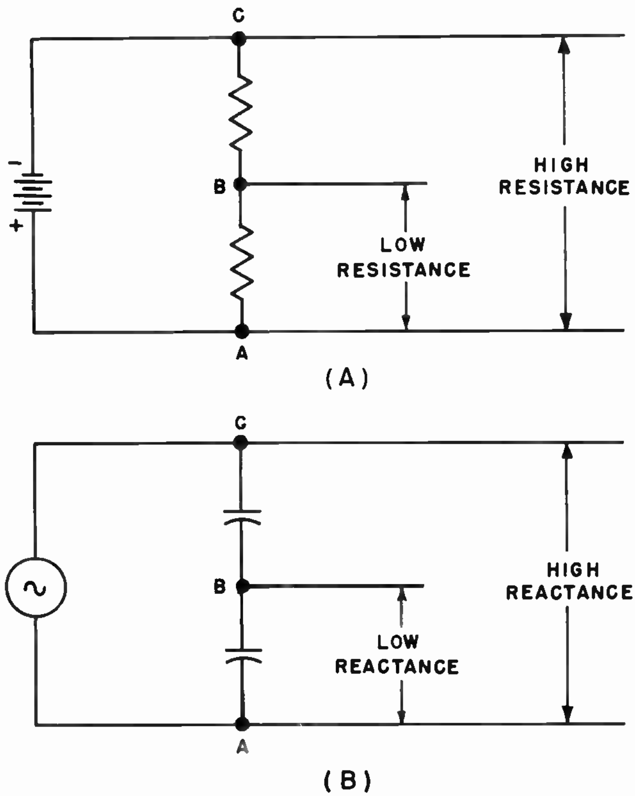


Fig. 417. *Resistors and capacitors can be used as voltage dividers.*

stage regards the tuned circuit as an "impedance divider." The input impedance of the second transistor looks into or is matched into the low impedance it requires.

This type of if transformer has a single adjustment — the poly-iron slug which tunes the coil. In a typical receiver, C1 might have a value of 200 μμf while C2 would have a value of 1,000 μμf — a 5-to-1 ratio. The ratio of capacitance values usually ranges from about 4 to 1 to as high as 6 to 1.

Other coupling circuits are shown in Fig. 419. In Fig. 419-A the collector impedance is matched since it is connected to the tuned circuit C1, L1. The input circuit of the following stage is tapped down on L1 and so this lower impedance point correctly matches the base-emitter circuit. In Fig. 419-B both primary and secondary of the if transformer have taps. The same arrangement appears in Fig. 419-C except that a single coil is used in conjunction with a coupling capacitor.

The complete if amplifier

A complete if amplifier circuit is shown in Fig. 420. The dashed lines represent shield cans around the if transformers. The values

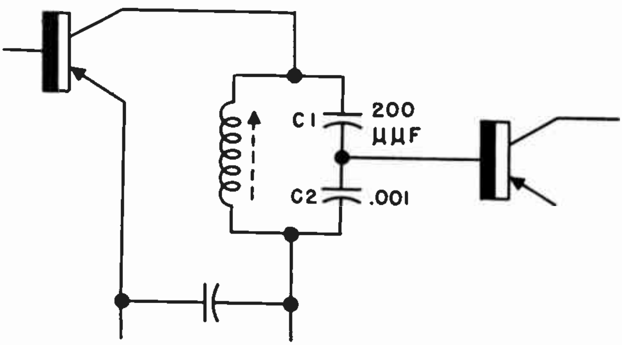


Fig. 418. *Method of coupling if stages through the use of series capacitors.*

of resistance given for the primaries of the if transformers are shown to be in the neighborhood of 11 ohms or less. Primary resistance will vary from one receiver to the next, some being as low as 3 ohms. The resistance of the stepdown secondary winding will be in the range of 2.5 ohms to as little as 0.5 ohm.

Each of the emitters is biased by series resistors and each of these resistors is bypassed. Note that the bypass capacitors across the emitter resistors in the if stages are larger in value (0.1 μf) compared to the bypass across the converter emitter resistor (.047 μf). Also observe the voltages marked on the schematic. In the case of the first if stage, for example, we have —3.9 volts on the base and —3.7 volts on the emitter. This makes the emitter 0.2 volt positive with respect to the base. The collector voltage is —8.1 although the full battery emf is 9 volts. Compared to the emitter the collector is 4.4 volts negative. This is correct operation since the transistors are p-n-p units.

Most if transformers have five leads. These are numbered on the if transformer plastic base and correspond to the numbers shown

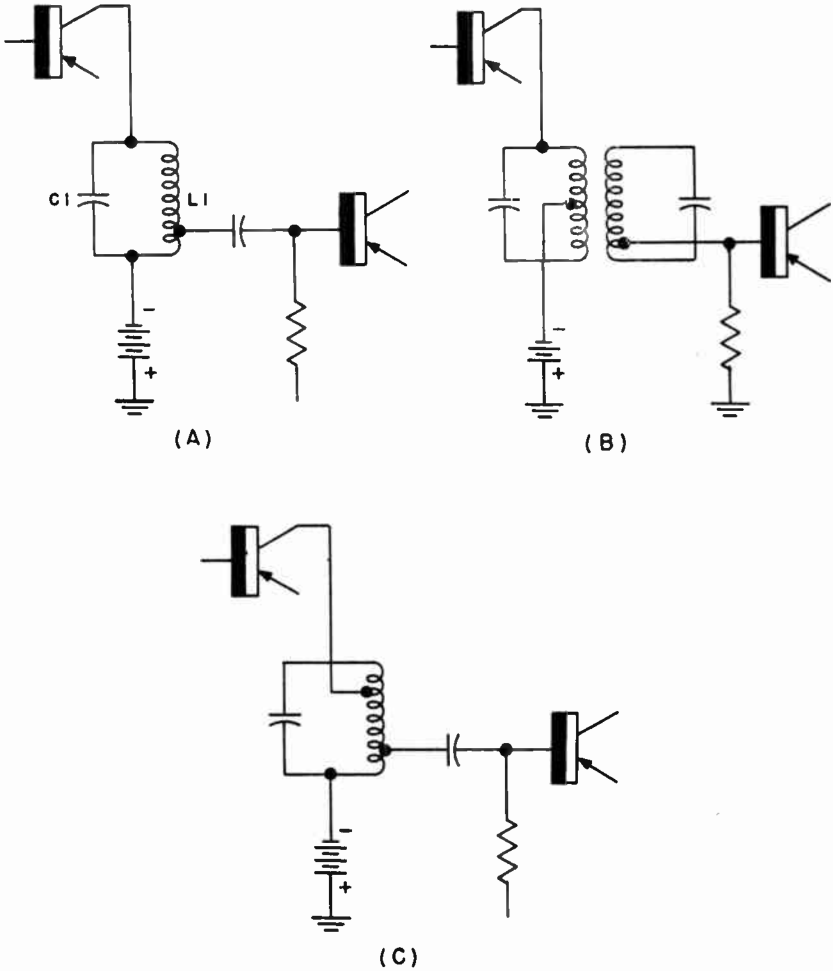


Fig. 419. *Other methods used in coupling if stages.*

in the circuit diagram. The numbering arrangement will help you identify the leads; an ohmmeter check will also help. The higher resistance winding is the primary, the lower the secondary. (Some if's have a color dot instead of the numbering system.)

Neutralization

Some types of transistors oscillate readily while others do not. Where the transistor shows a tendency toward oscillation, neutralization of the intermediate-frequency stage may be required.

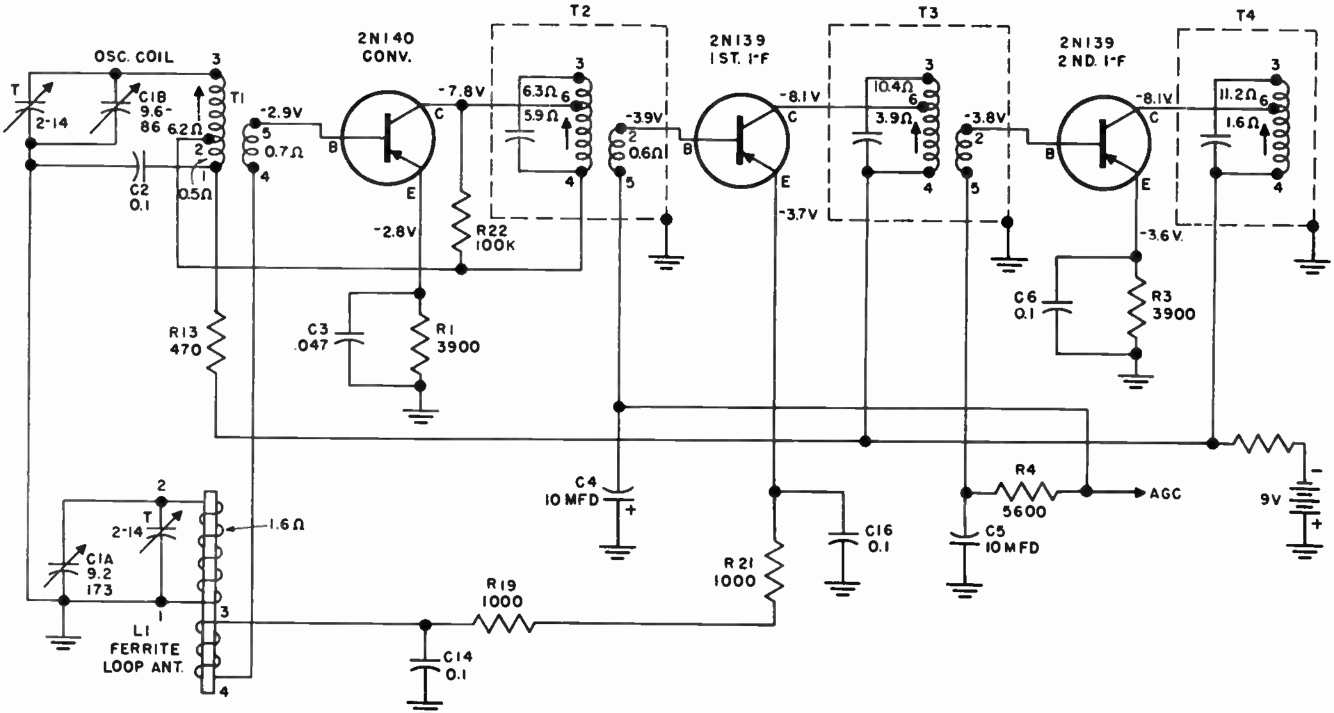


Fig. 420. *A complete if amplifier circuit.*

1-99

Certain transistors, such as the 2N293 or 2N168 n-p-n units, require no neutralization.

The term neutralization is used in connection with some if amplifiers although it is really a form of negative feedback. In Fig. 421, R1 and C1 and also R2 and C2 represent negative feedback paths for the two circuits. The signal voltage at the input to the second transistor is 180° out of phase with the signal voltage at the base of the first transistor. A resistor is used to feed back a small portion of this out-of-phase voltage, thus providing negative feedback. The capacitor acts as a blocking unit since the base of each transistor is at a slightly different dc potential.

Neutralization isn't used too widely. Many receivers either use certain n-p-n units that require no neutralization or else they omit the bypass capacitor across the emitter resistor, thus supplying negative feedback in this manner.

Facts to remember

N-p-n unit The emitter is made of n-type germanium. Current flow decreases when a negative voltage is applied to the base. Current flow increases when the base voltage becomes less negative (becomes more positive).

Base current This is very small. The amount of base current in a typical transistor is in the order of microamperes, a value of 20 μa being typical.

Base-to-emitter voltage Only a small amount of voltage is needed between the base and emitter. The base-to-emitter voltage is generally a small fraction of 1 volt.

P-n-p unit The collector voltage is measured with respect to the emitter and is negative with respect to it. The base is also negative with respect to the emitter.

Circuit arrangement Transistors may be operated with any one of the elements as the common unit. In transistor receivers, the most usual arrangement is with the emitter grounded or grounded through a resistor. The base is the input element, while the collector is the output element. The grounded-emitter arrangement is one in which there is a reversal of phase – that is, the output signal is out of phase with the input signal (just as in vacuum-tube circuits). The grounded-emitter circuit has an

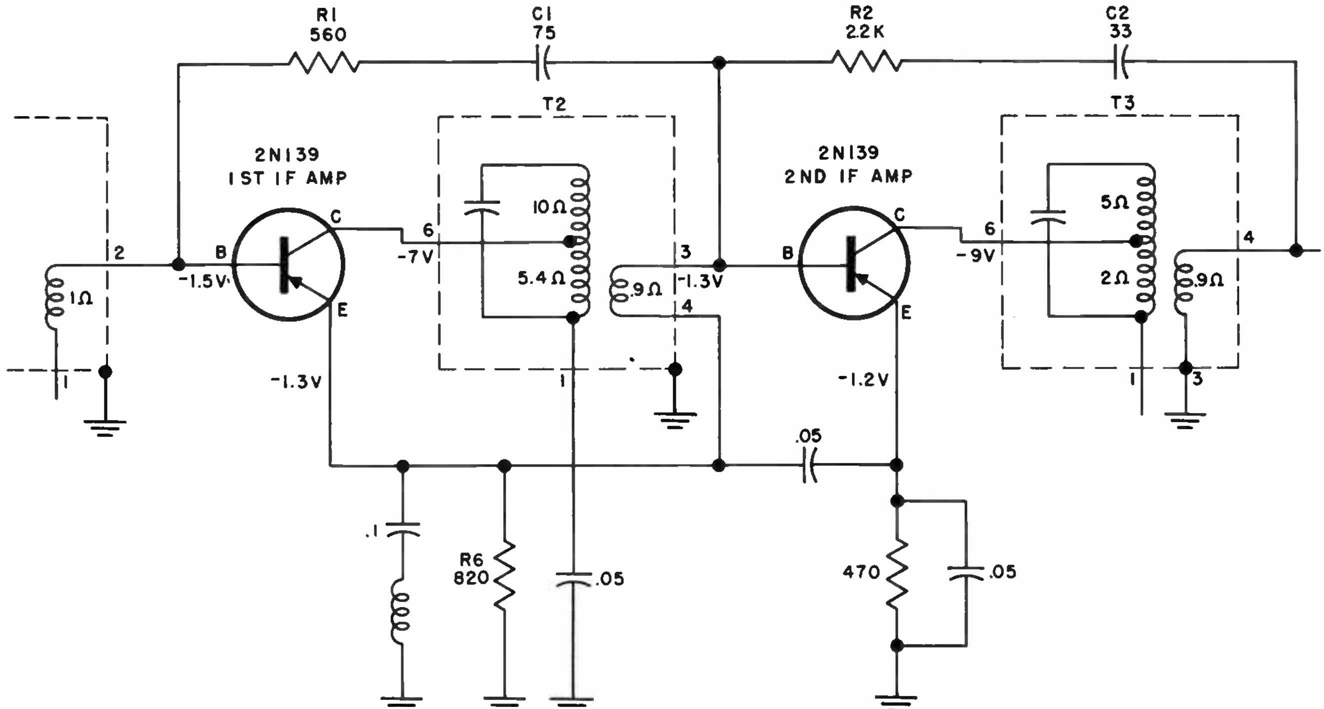


Fig. 421. *Neutralization of transistor if stages.*

output impedance that is high compared to its input impedance.

Transistor characteristics Important voltage and current measurements for transistors are: emitter voltage and emitter current, base current, collector voltage and collector current, input bias.

Bias Two types of biasing are used. Fixed bias and self-bias. A transistor receiver may use one or the other or both of these methods for biasing.

Current carriers These consist of electrons and holes. Electrons are negative, holes are positive. Electrons always

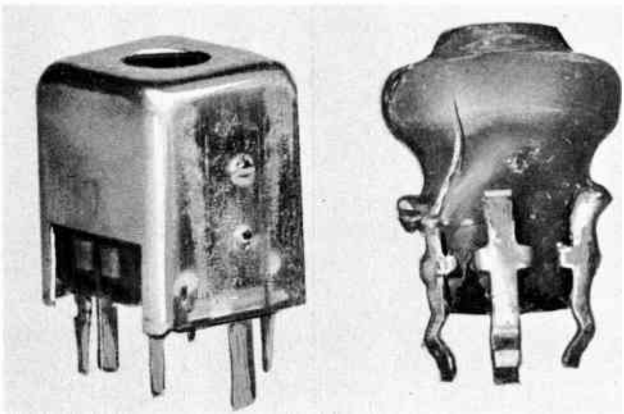
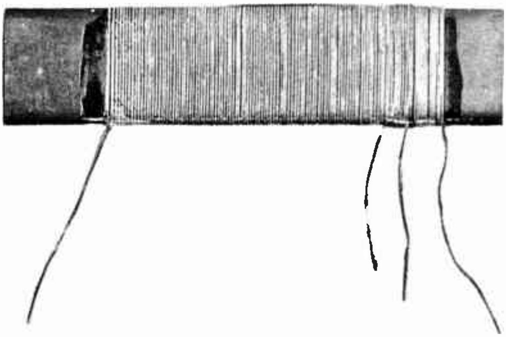


Fig. 422. *Oscillator coil (left) and if transformer are attached to the printed-circuit boards by terminal lugs that are designed for easy insertion.* (Thordarson-Meissner.)

move toward a positive region, away from a negative region. Thus, they will drift toward the positive terminal of a battery, out of and away from the negative battery terminal. Hole flow takes place in the transistor only, not in wires or components external to the transistor.

Amount of current The amount of current required for transistor operation is small, values generally being less than 25 ma. However, some power transistors require a collector current as much as 1.5 amperes. Current for such transistors is generally supplied by an automobile battery. Transistor receivers operate with voltages of less than 15. A common value is 9 volts.

(A)



(B)

Fig. 423. *Ferrite antenna coils may be as long as seven inches (A) or as short as two inches (B).* (Thordarson-Meissner.)

Component characteristics

The low-impedance characteristics of the transistor often make tuning of both the primary and the secondary of if transformers impractical. Even the comparatively high output impedance of the collector would load a high-Q tuned circuit to the point where the tuning would be exceptionally broad. For this reason, it is necesssary to connect to a tap on the tuned winding of the if transformer instead of using the connections encountered in vacuum-tube receivers. The extremely low input impedance of the base makes taps on the winding even more difficult, but it is done. So you see, the major components can change the whole circuit configuration, as far as the physical characteristics are concerned. The schematic varies somewhat but the symbols do not even hint at the physical changes. The wiring diagram of a 6-transistor receiver covers as much paper as would that for a receiver with six vacuum tubes.

Oscillator coils

Similar problems are encountered with the oscillator coils used in the converter stage. The low impedance here also requires the tuned circuit to be tapped. This autotransformer configuration not only matches impedances but also reduces the loading on the L-C circuit, thereby increasing the Q and making it easier for the circuit to oscillate. The terminals of these miniature components

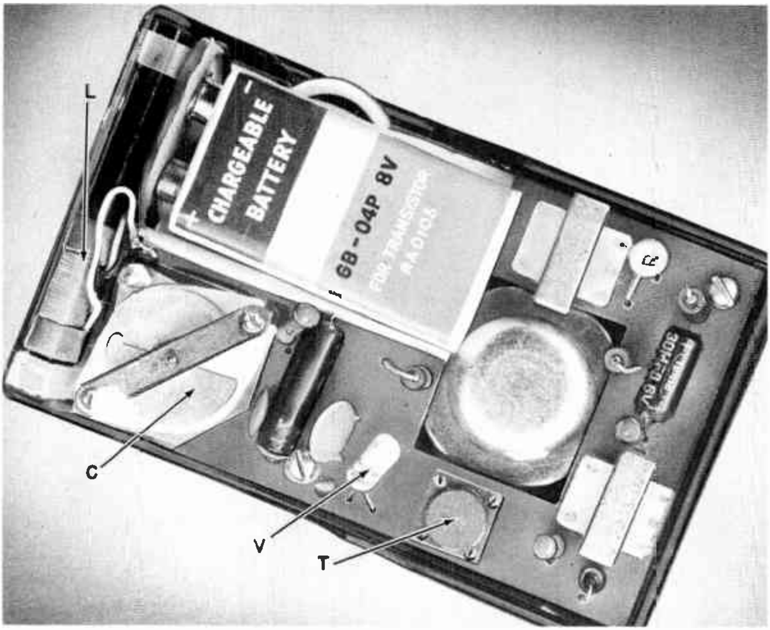


Fig. 424. *The printed-circuit board of a two transistor reflex receiver is not very crowded.*

(Fig. 422) are designed for easy insertion into printed-circuit boards – no other means of securing these lightweights are needed.

Antenna coils

Converter stages have one other important inductor that forms a tuned circuit. Wound on a ferrite core to increase the Q (which is very important in all tuned-circuits) it may assume a variety of shapes. Two of the most popular forms are shown in Fig. 423. Connections are similar to those indicated in Fig. 409. This coil, with the help of a section of a variable capacitor gang, selects the stations to be received. A side view of a coil (similar to that in Fig. 423-B) is shown

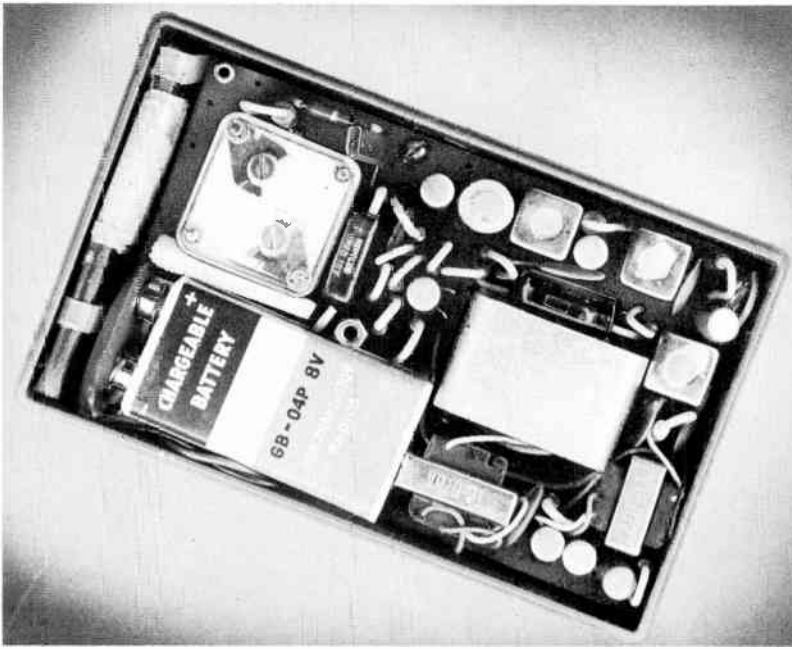


Fig. 425. *Circuitry for six transistors fits compactly in the same space used by the receiver in Fig. 424.*

mounted in a two-transistor reflex receiver (Fig. 424).

A reflex circuit is one in which the amplifing element of one stage amplifies at two widely separated frequencies. In this case, one transistor is an rf amplifier feeding a diode detector, transformer-coupled by T. The detected signal is then fed back to V as an audio frequency and again amplified before being fed to the output stage. These receivers are quite inexpensive. Strong local stations are received at a comfortable loudspeaker listening level. Some stations are hard to separate from others due to the lack of sufficient tuned circuits, as found in superheterodyne sets. No servicing can be spent on the repair of this circuit. Many receivers of this type sell for under $10, and the cost of repairs other than batteries may equal or exceed the original purchase price.

Capacitors

Capacitors are also affected by transistor impedances. To act as an efficient bypass, a capacitor must have a reactance of only a fraction of the impedance or resistance it is to bypass. Normally, this will be of greater importance in low-frequency

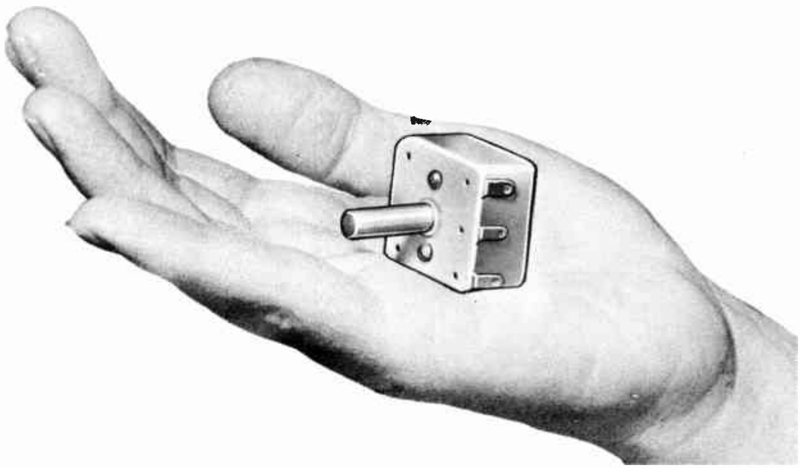


Fig. 426. *Tuning capacitor is completely boxed in plastic.* (Argonne Electronics Mfg. Corp.)

circuits such as audio amplifiers and power supply decoupling and filtering circuits.

The extreme compactness of the transistor personal portable (Fig. 425), has led to other changes in the tuning components. The variable capacitors, in some cases, have been totally enclosed in plastic boxes (Fig. 426) to protect the plates, which have very close spacing, not only from physical damage (bent plates) but from dust, dirt and moisture. A less expensive method only separates the plates with a thin sheet of plastic (Fig. 424-C). This has an additional feature. The plastic has the ability to increase the capacitance of the unit, thus requiring the use of fewer plates in both types.

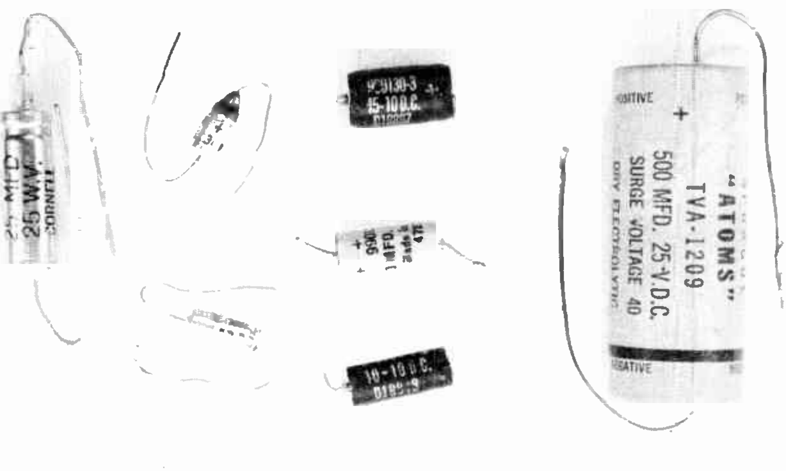


Fig. 427. *These electrolytic capacitors are approximately one-half actual size.*

Electrolytic capacitors need to be rated at only a few working volts; only slightly more than the battery voltage is required. Since transistors are current-amplifying devices, the peak voltages are seldom greater than the battery voltage.

With thinner dielectrics and more efficient electrolytes, a 30-μf capacitor (Fig. 427) is about the size of a pencil eraser. The seemingly huge 500-μf 25-volt capacitor may be used for a battery-eliminator filter or across an aging battery supply. The 25-μf 25-volt capacitor is the miniature replacement type used as cathode bypass capacitors in vacuum-tube circuits. Economical, they are ideal for use in substitution boxes and for temporary or test purposes. The miniature units may cost several times as much as a standard replacement type used in vacuum-tube circuits, and are easily lost because of their small construction. The heavier leads on the test capacitors may be cut short and flexible leads substituted. This will work satisfactorily for most applications — several inches of lead length may not even matter when used for bridging interstage coupling capacitors.

For printed circuits, it is common to find that a capacitor may have two wires projecting from one end, the rest of the capacitor being completely insulated. Replacing these is sometimes a headache. As special parts, they may have to be ordered from the manufacturer of the receiver. While it is sometimes possible to substitute single capacitors, dual units are usually quite impractical to replace with anything but original parts.

Capacitors of smaller values consist of metallic films plated directly on the surface of paper-thin ceramic wafers and stacked to get the capacitance needed. The thickness of the wafer is the determining factor in the voltage rating. Some of these capacitors are extremely delicate. Be careful when flexing the leads or moving the capacitor to get to the circuitry beneath.

Resistors

In pocket transistor portable receivers, it is seldom necessary to resort to high-wattage resistors. For most applications, the familiar ½-watt resistor is more than adequate. In cases where production techniques require extreme compactness, ¼-watt and ⅛-watt resistors are available. Here again you must be careful as some of these components are hardly thicker than a pencil lead.

High-wattage resistors may be found in the emitter circuit of power transistor amplifiers used in automobile radios. Even here it is unusual to find the large wirewound units familiar in vacuum-tube circuits.

Volume controls

Volume controls are variable resistors. Their wattage and their resistance values are also low, in keeping with the low-impedance character of all transistor circuits. For the most part, they are of open construction. This makes them easier to clean, but it also makes it easier for the carbon elements to get dirty or damaged.

The on-off switch is usually an integral part of the volume control and cannot be replaced separately. Receivers using tapped batteries or separate bias cells need a double-pole switch. If one half fails, the receiver will not work although near normal voltages may appear at many points.

Thermistors

The thermistor is a temperature-sensitive resistor just as the transistor is a temperature-sensitive current amplifier.

Thermistors are inserted into the circuitry to counteract the normal increase of current through the transistor as the temperature increases. The thermistor changes resistance value with temperature, increasing the applied bias, reducing the zero-signal current flow.

The thermistor, as used in transistor receivers, not only maintains proper bias to keep the transistor operating on the proper portion of its characteristic curve (keeping distortion at a minimum as the temperature increases), but it also protects the output transformer by preventing the flow of excessive current through it. These transformers are usually wound with a wire size that does not provide too much leeway in overrated operation. This is necessary when designing such compact units.

Thermistors are often considered a type of semiconductor. They have been adapted to many useful applications. Aside from temperature compensation, they are also used for temperature measurement, power measurement, time delay and a type of switching.

Manufactured in the shape of discs, washers, rods and beads, they find many applications as transducers. Bead types of this negative-temperature-coefficient resistor are used as transducers at temperatures up to 600°F.

Heavy-duty counterparts are utilized in series-filament vacuum-tube circuits to increase the applied filament voltage slowly, prolonging the life of these tubes.

Batteries

The power source of transistor radios must also be considered as a component.

Batteries are groups of cells connected together to give, usually, maximum current or maximum voltage output. The size of the cell is the factor that determines its current capacity. The electrodes and electrolyte determine the cells' efficiency.

The storage battery is familiar from its use for many years in automobiles. Few people remember the early radios that used lead-acid batteries for filament power.

Many types of storage cells have been manufactured. The nickel-cadmium cell has reduced, if not eliminated, the corrosion normally associated with lead-acid storage cells. Many of these cells are in sealed cases that can be operated in any position without fear of spilling. Rechargeable (storage) cells are used in flashlights and electric razors as well as in transistor receivers (Figs. 424-425).

Cells made with mercury have almost four times the life of a conventional dry cell, but do not cost four times as much.

Alkaline cells are rated as high as 20 *amperes* compared to the standard flashlight cell (of one-third the cost) which they replace directly.

More important than the structure of the cell, to the technician, are its electrical characteristics. A common trouble is the increasing internal resistance of the cells with age, making the cell a signal-coupling device for all stages. Some receivers will be more subject to this problem than others. Additional filtering within the receiver will do much to reduce the normal effects of increasing internal resistance of the cells.

If motorboating and squealing are cured by a new battery but seem to recur too frequently, and battery life seems short, check the electrolytic filters in the filter or decoupling circuits. They may be weak or open. Bridge the suspects with another capacitor while using the old battery. If this cures the squeals and motorboating, change the filter capacitors for longer battery life.

chapter

5

detectors and agc

By now, in your study of transistors and transistor circuits, you must have realized that not everything connected with transistors is new or strange. We haven't studied any circuits you haven't seen before. All we have really done is to use existing and familiar components — resistors, capacitors and coils — in connection with a vacuum-tube substitute. This doesn't mean that, to change from a vacuum-tube circuit to one using transistors, we just substitute a transistor for the tube. It isn't that easy. But going from a vacuum-tube ac-dc receiver to a transistor type is less of a mental jump than going from ac-dc receivers to television.

In chapter 4, we stopped just short of the detector. The detector seems to be a very nice division point in a receiver, both from a theory and a practical servicing point. In servicing, everything that follows the detector is audio (low frequency) and everything that precedes the detector is if or rf (a higher frequency). In servicing, you know that a signal placed across the volume control, and resulting in sound out of the speaker, means that the audio section is working. On the other hand, if you put a modulated rf signal into the converter input and get an audio signal voltage across the output of the detector, you know that all stages, up to and including the detector, are doing a job. This brief description of two widely used servicing tests emphasizes the reason for considering the detector as a dividing point. The detector is to the receiver what that imaginary line — the equator — is to the earth. The detector has an advantage. You don't have to imagine it. It's as real as any other component in the receiver.

The diode detector

Because of its small size and because it has no power requirements (it does not need filament or plate power), the crystal diode is quite a logical unit to use as a detector. It does have one big disadvantage. It detects – but it does not amplify. That is why some transistor receivers use a transistor type detector. It has all the advantages of the crystal diode plus gain.

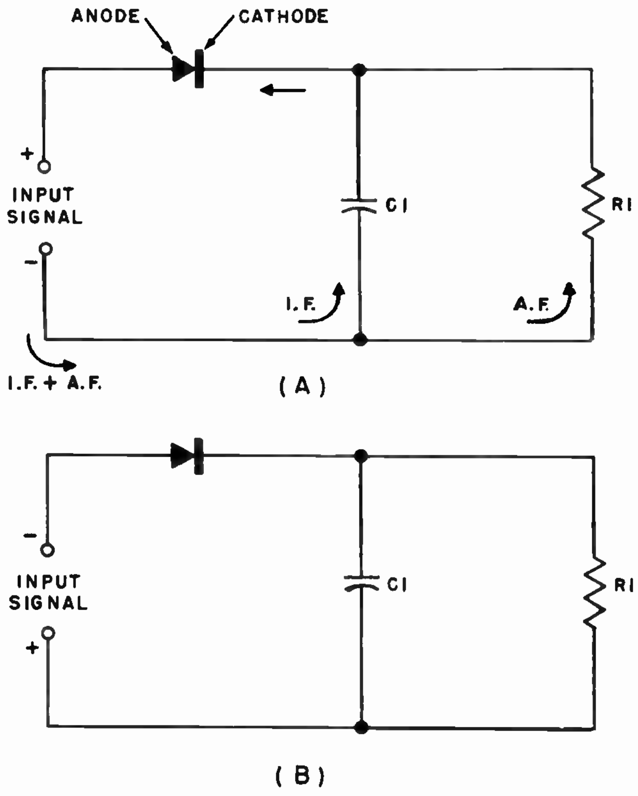


Fig. 501. *When the input signal is of the proper polarity, current will flow through the diode, as indicated in A. When the input signal is reversed, practically no current will flow B.*

For an item as small as it is, the detector has a surprisingly large number of names. Sometimes, in a superheterodyne set, it is called the second detector. It is often referred to as the signal rectifier (which it really is) and, on occasion, as the demodulator.

The detector has just one job—to slice the radio signal in half. Each half of the radio signal contains the audio, so it makes little difference which half is rejected by the detector. It's just like having a pair of identical twins apply for a job — with only one job available. It makes no difference which twin goes to work. Our audio amplifier is quite satisfied to get the audio signal. It doesn't care whether it comes from the top of the wave or the bottom — since top and bottom are identical twins.

A diode detector can be arranged as shown in Fig. 501. The straight-line portion of the crystal symbol is the "cathode" while

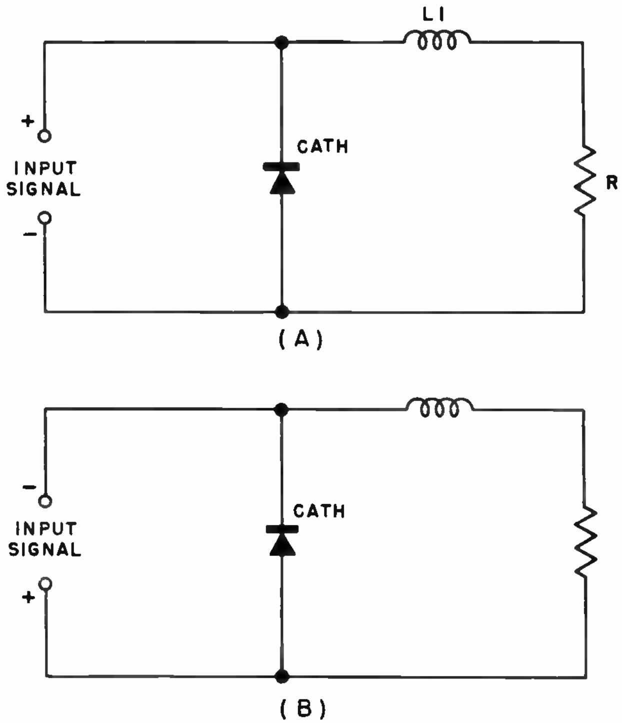


Fig. 502. *Alternate arrangement of the diode in a crystal detector circuit.*

the arrow is the "plate" or "anode." Theoretically, current can flow only from cathode to anode, but there is also a small reverse current. When the input signal has the polarity shown in Fig. 501-A, current will flow from the negative input terminal, through the capacitor and resistor, through the crystal diode and toward the positive input terminal.

Now what is this current we're talking about and where does it come from? If we imagine the input terminals of Fig. 501-A con-

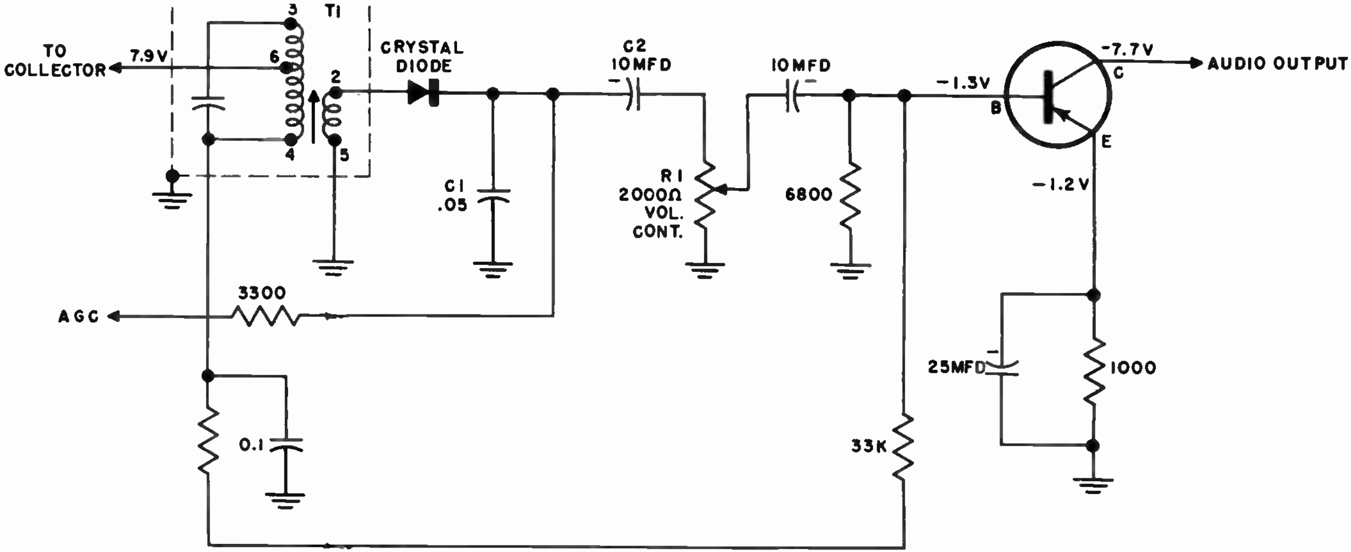


Fig. 503. *Typical crystal detector circuit. The agc bus is taken from the output of the detector.*

nected to the secondary of an if transformer, it's easy enough to see where we get the input signal.

This if signal is a two-part affair. It's made up of the intermediate frequency (or if) and, going along just for the ride, the audio signal. These two currents, if (intermediate frequency) and af (audio frequency), move along the bottom conductor when the input signal has the polarity shown in Fig. 501-A. These two currents are given a choice – they can go through C1, through R1 or through both. The if is about 455 kc; that of the audio can vary from less than 100 cycles to more than 5,000. It is because of this big difference in frequency that we can separate them. C1 has a high reactance (or opposition) to low frequencies, so the audio barely gets through. But there is a nice easy path for the audio through R1, which it promptly takes. The much higher if finds it quite easy to go through C1 – much easier in fact than going through R1 – and so it takes this path. R1 is sometimes called the diode load resistor, or more simply, the diode load. Quite often it is a variable resistor, and is then known as a volume control.

Another type of diode detector is shown in Fig. 502. Here the crystal detector is placed in shunt (or in parallel) with the signal source. Let's start with the condition shown in Fig. 502-A. The signal has put a positive voltage on the cathode side of the diode and a negative voltage on the anode. No diode will work under these conditions and, as far as the signal is concerned, the diode represents an extremely high resistance – practically an open circuit.

The signal has another path, however. It can flow through the diode load resistor R1 and through coil L1. But we really have two currents in one – a low-frequency (or audio) current and a much-higher-frequency (or intermediate-frequency) current. Take a look at coil L1. If there is anything it dislikes, it is a high-frequency current – and the higher the frequency, the greater will be its opposition. As a result, the current flowing through R1 is mostly audio, with very little if.

When the signal polarity reverses, as it will, we get the condition shown in Fig. 502-B. This the diode likes. It likes it so much that almost all the current – both af and if – flows through the diode. The diode is practically a short circuit across the coil and resistor. During this part of the input cycle, the diode load gets practically no current.

Practical circuits

The diode circuits we will study look very much like those shown in Figs. 501 and 502. In Fig. 503, for example, we have a circuit that is the same as Fig. 501. The input signal is supplied by the secondary of if transformer T1.

Let's see what happens when the top half of the secondary winding becomes positive. This is the right polarity for conduction through the diode. The direction of current flow is through the coil (from top to bottom) and into ground (or the chassis). The chassis is a pretty good conductor, so the current flows over to the bottom end of the volume control, through C2, through the diode and touches home plate when it gets back to its starting point at the top of the coil. Now you might object to our statement about the current flowing through C2, but remember we are dealing with a varying current (an audio current) even if that current is moving just in one direction.

Now how about the separation of if from af? See that capacitor marked C1 in Fig. 503? It has a value of .05-μf and is practically a short circuit for the if. As a matter of fact, we lose some audio through it also, but that's a pretty small price to pay for such a simple and effective filter. In the circuit of Fig. 503, our diode load resistor is a 2,000-ohm volume control. You may also be somewhat surprised at the size of coupling capacitor C2. It has a value of 10-μf, which immediately calls for an electrolytic.

We need a large value of capacitance here since we are really playing in the backyard of the input circuit of the first transistor audio amplifier. This is a low-impedance region and so we cannot do anything that will change this to a higher value. Electrolytics in transistor radios make nice coupling capacitors but that doesn't mean we can forget about the fact that electrolytics are polarized — and we must watch polarity carefully. In Fig. 503, the positive terminal of the electrolytic connects to the top end of the volume control. This makes sense since the top end of the volume control is positive. Remember — we said that current flows up through the volume control. That makes the bottom end of the control minus and the top end plus.

In the circuit of Fig. 503, coupling capacitor C2 is also needed to keep the agc voltage from disappearing through the volume control.

In Fig. 504, we have a few more circuits using diodes, but, as you can see, these are quite similar to those we have studied.

Incidentally, in speaking of crystal diodes, we can use the same language that we use with transistors. When the polarity of the voltage permits the crystal to pass current, we say that the crystal is biased in the forward direction. The crystal behaves as though it were a resistance of low value. When the signal polarity is wrong as far as the crystal is concerned, we can say that the crystal is biased in the reverse direction. Under these conditions, the crystal passes very little current. It behaves like a very high value of

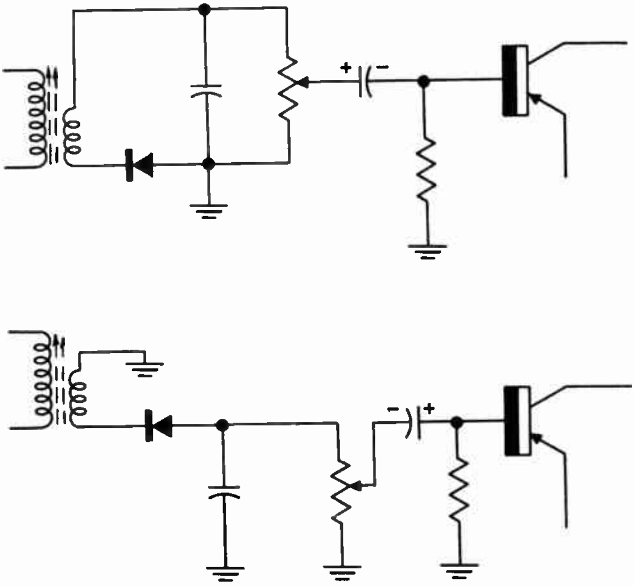


Fig. 504. *Circuit arrangements using crystal diodes.*

resistance. A vacuum-tube diode cuts off completely with reverse voltage (plate negative, cathode positive). A crystal diode does not —but the amount of current that flows through the crystal when it is reverse-biased is extremely small.

The transistor detector

The grandpappy of the transistor is the crystal diode, and, if the offspring is much younger, it is also more powerful. The crystal diode is satisfied to rectify. The transistor takes detection in its stride and, then, just to show what it can do, throws in amplification for good measure.

To get the transistor to think and behave as a detector, we must do something to the transistor — otherwise it will not rectify, but will amplify only. One easy method is to bias the transistor so that it operates class-B. All that this means is that the transistor is biased at or near the cutoff point. Practically no collector current will flow in the output of our transistor. If we bring a signal into our transistor detector at this time, the signal will add to and subtract from the bias. One half of the input signal will increase the existing bias, but this will have no effect since the collector current is cut off anyway. The other half of the input signal will reduce the existing bias. Collector current will now begin. The

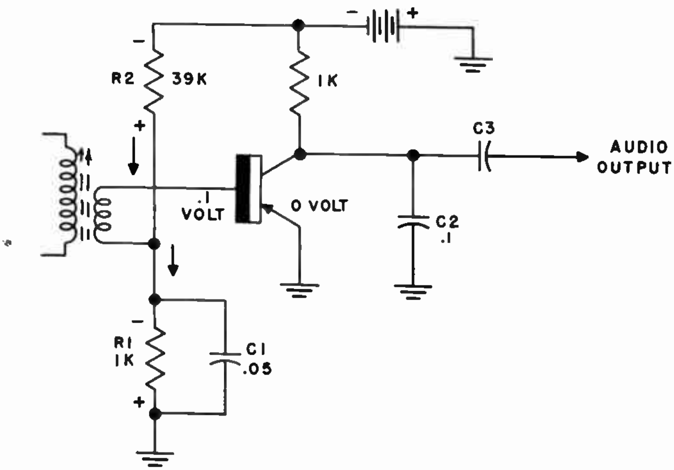


Fig. 505. Schematic showing a transistor used as a detector. The transistor has an advantage over the crystal diode in that it supplies gain.

collector current will follow the variations of one half of the input signal — this is equivalent to detection (or rectification). There is a bit more to this story, however. The collector current flowing through the collector load produces an enlarged (or amplified) version of that half of the signal that was of use.

If you have trouble visualizing class-B operation, just think of a half-wave rectifier in a power supply. That's an easy job for you. The rectifier sits happily in its socket, conducting only 50% of the time. A class-B transistor detector works the same way, the only difference being that we bias it to make sure.

A transistor detector circuit is shown in Fig. 505. The emitter is connected to ground. Now please examine the voltage divider made up of resistors R1 and R2. As you can see, R1 and R2 are in series. Not only that, but R1 and R2 are connected across the battery. The current path is very easy. We start our current flow at the negative terminal of the battery, move through R2, through R1 and right into the chassis. But the chassis is our ground connection so we are right back at our battery again. The arrows in the drawing show the direction of current flow.

Normally, in a grounded-emitter circuit using a p-n-p transistor, the emitter is positive with respect to the base. This is the proper condition for forward biasing and it is with this voltage arrangement that we get emitter current and, as a consequence, collector current. But what has happened in the circuit of Fig. 505? A current flows through R1, making the top end of R1 negative. The top end of R1 is connected to the base through the very low resistance of the secondary of the if transformer. The bottom end of R1, which is positive, is connected directly to the emitter. We have made the base negative or, stating the same thing in other words, the emitter is positive with respect to the base. Now you might say – and quite correctly – that this is ideal for amplifier action and so it is, except for the very small amount of voltage we are using. The biasing voltage is so low that very little emitter current flows.

Before we continue further, examine the secondary winding of the if transformer. One end is connected to the base and the other end to R1. This means that the winding is in series with R1. The signal voltage that will appear across the secondary will either add to the voltage across R1 or will oppose it, depending on the polarity of the signal.

Now suppose that a signal comes in. This signal will be ac and its frequency will be (in a typical set) 455 kc. If we could manage to stretch time a bit, we would see that our signal voltage is alternately positive and negative. When the positive portion of the signal comes in, it makes the base positive. As a result, the tiny flow of collector current we had when we started trickles almost down to zero. But when the polarity of the signal changes, the base becomes more negative than before (or the emitter becomes more positive) and as a result emitter current increases. Of course, collector current increases also.

Generally, when we think of a transistor detector, we simply mention that it is biased at or near cutoff and let it go at that. However, that isn't the whole story. If the voltage we put on the collector is lower than normal, lower than the voltage we would put on it for pure amplifier operation, then collector current is much more at the mercy of input bias. Keep in mind that there are two forces at work on collector current. One of these is the bias and, just as in a vacuum tube, a very slight change in bias means a big change in output current. The other factor is the voltage placed on the attracting electrode. This is the plate in the vacuum tube and the collector in the transistor. The smaller the collector voltage, the easier it is for the bias to keep the collector current near the cutoff point in the absence of a signal.

That capacitor you see across R1 – the unit marked C1 – performs a useful job. It helps maintain a steady bias voltage on the transistor.

The agc system

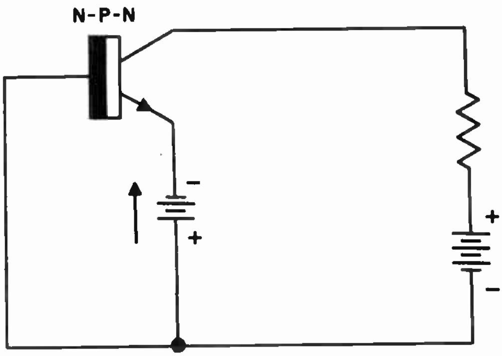
The whole idea of automatic gain control – abbreviated as agc – is to keep the speaker from blasting full volume at one moment and then dropping to a whisper as the tuning dial is changed from one station to the next. Most agc setups are simple and we can't expect miracles from them. They definitely will not make a weak, hard-to-pull-in station sound as good as a local broadcast. Agc definitely does not increase the sensitivity of a receiver. All it can do is to cut down on the gain of the rf and if stages when a strong signal comes tearing through. Agc is like the handle on your shower. It will help control the volume of water, but, if you've got rotten plumbing elsewhere, the handle is just another ornament.

We have been busy comparing transistor circuits with those you use in vacuum-tube radios, but when it comes to agc we have to watch our step. Avc in a vacuum-tube receiver is always a negative voltage. This negative voltage adds to the negative bias of the rf or if sections. In a transistor receiver, however, agc can be positive or negative, depending upon whether we are working with p-n-p or n-p-n units.

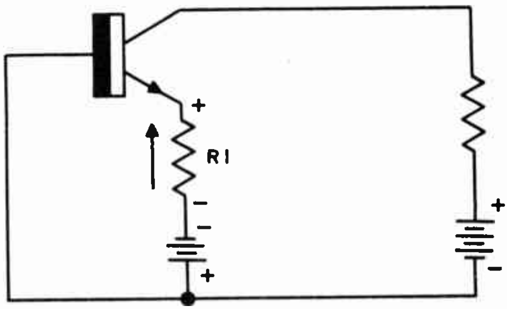
At this time, let us do a small bit of thinking. Just what is it we want agc to do? Simply this: We want the gain of the transistor receiver to go down when a strong signal comes in, but we want the gain to go up for a weak signal. Agc does that for us. It persuades a strong signal not to flex its muscles (partially, at least) while it spreads a great big welcome mat for weak signals.

As in vacuum-tube receivers, agc is fed back from the second detector to the if stages and in some instances to the rf amplifier as well.

To see how agc can be made to function, let us consider the simple case of a single n-p-n transistor stage shown in Fig. 506-A. The single arrow near the emitter indicates the direction of current flow. Current moves out of the emitter bias battery as shown.



(A)



(B)

Fig. 506. *Fundamental operation of an agc circuit.*

Suppose now we were to place a resistor R1 in series with the emitter bias battery as in Fig. 506-B. You could regard this resistor in one of two possible ways — neither of them complimentary. You could say that R1 reduces the effectiveness of the emitter bias battery — and so it does. When current flows through R1, it produces a voltage drop across the resistor, thus reducing the available voltage for the emitter. Since emitter bias is reduced, emitter current decreases and collector current drops.

The other way of considering this matter is to say that the voltage drop across R1 is in opposition to the voltage of the emitter bias battery. If the bias battery has a voltage of 3 volts and the drop across the resistor is 1 volt, all that we really have left for the emitter is just 2 volts. In this arrangement, the emitter just gets what is left over.

An elementary agc circuit is shown in Fig. 507. The collector is tied to the positive terminal of the battery through a load resistor. Both emitters, the if and the detector, go to the negative end of the battery. Now suppose that a strong signal comes into the detector.

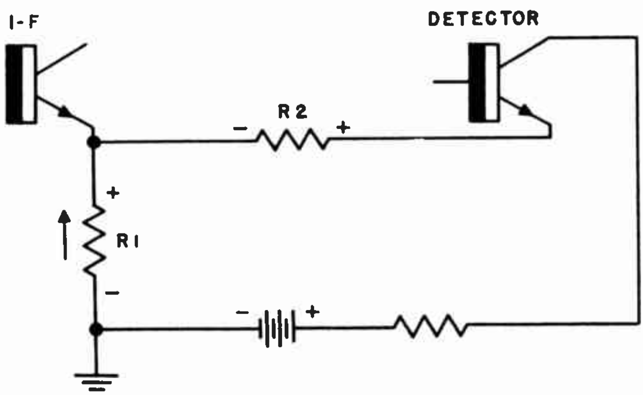


Fig. 507. *Basic arrangement of an agc circuit.*

To handle the strong signal, the detector needs more emitter current, and the only place it can get this is from the battery. Current starts to move from the negative terminal, through resistors R1 and R2. But in going through R1, the current produces a voltage drop across R1 which opposes the battery voltage. But R1 is connected to the if transistor and, because the emitter of the if transistor will now get less bias voltage, its gain will go down. As a result, the signal going into the detector will become reduced in strength.

Now let us imagine that a very weak signal reaches the detector. Much less emitter current is required and, as a result, a smaller demand is made on the bias battery. Since a weaker current will now flow through R1, the if transistor gets the maximum bias voltage. But this condition of maximum bias voltage permits the

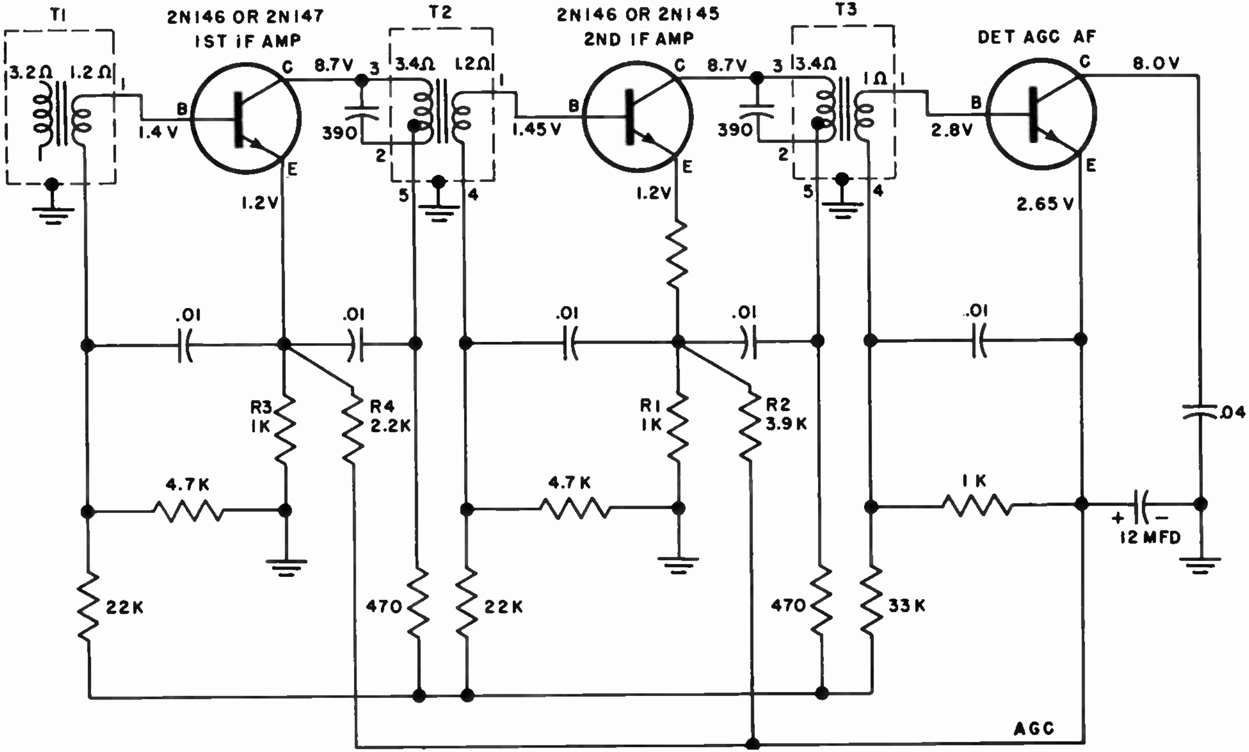


Fig. 508. *Automatic-gain-control circuit. The transistor at the output of the if stage acts to supply agc and audio voltages in addition to working as a detector. While in this circuit the agc controls the if stages, in some sets (especially automobile receivers) the agc is fed back to the rf amplifier as well.*

if transistor to work at full gain – and so the weak signal gets vip treatment.

A representative agc circuit is shown in Fig. 508. The agc bus consists of resistors R1, R2, R3 and R4. These resistors are in the emitter circuits of the first and second if amplifier stages. If you will trace the connections, you will see that these resistors are also tied in to the emitter of the combined detector and agc transistor.

As you have probably suspected, agc in receivers using p-n-p transistors works in a manner exactly opposite to that of n-p-n

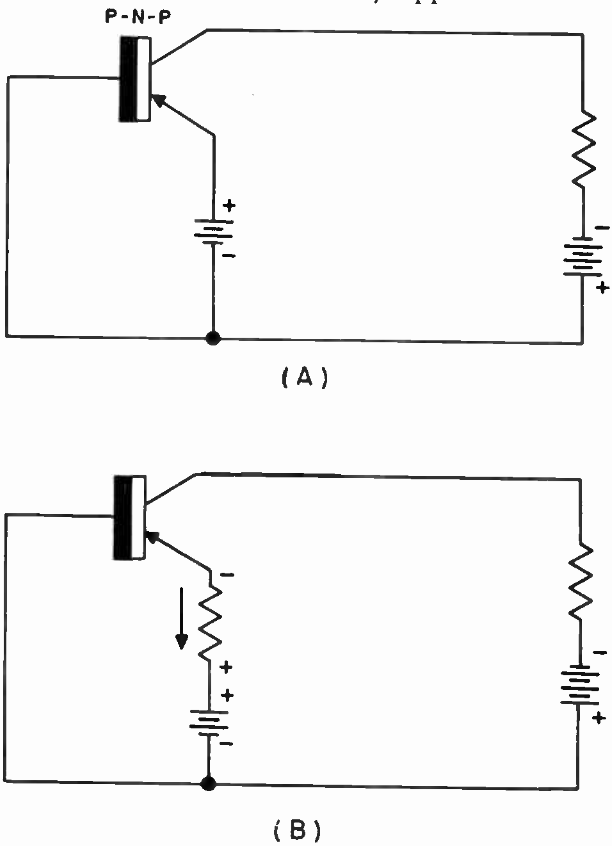


Fig. 509. *The gain of the transistor is reduced by putting a resistor in series with the emitter.*

units. But just to make sure that we know this (and not just imagine that we do), consider the easy circuits shown in Fig. 509. In Fig. 509-A, we know that current flows from the emitter into the plus terminal of the bias battery. We can play a few tricks on the emitter by putting a resistor in series with the emitter, as shown in Fig. 509-B. Once again the effect is to reduce the amount of forward bias, thereby lowering the gain of the transistor stage. Note that the voltage across the emitter resistor is in opposition to the emitter bias voltage — and once more the emitter just gets what is left over.

An agc bias setup for p-n-p units is shown in Fig. 510. This is exactly the same circuit that we showed for n-p-n transistors in

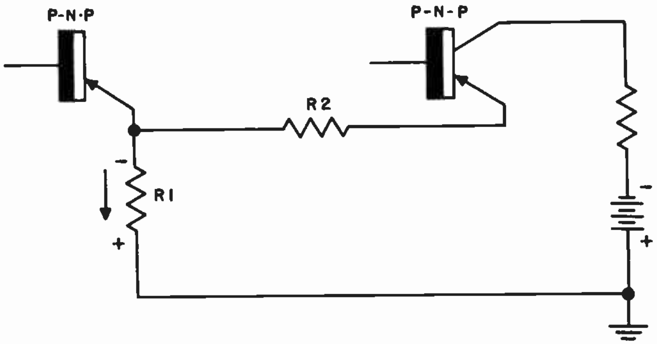
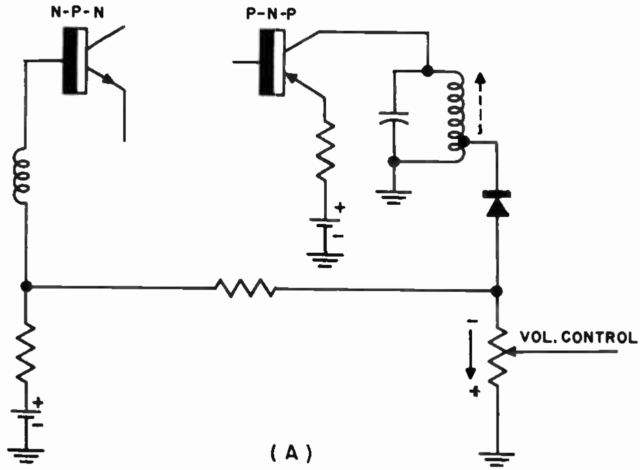


Fig. 510. *Agc bias network for p-n-p transistors. Note that the voltage across bias resistor R1 is in opposition to the emitter bias voltage. Current flowing from the emitter through R1 reduces the forward bias, thereby lowering the gain of the transistor stage.*

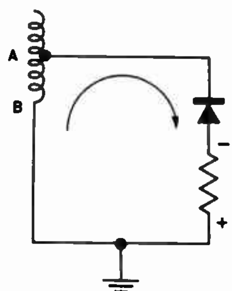
Fig. 507. The only difference is in the direction of current flow. All that has actually been done is that the bias battery has been turned around. Once again the emitter resistor opposes the battery voltage — and the stronger the signal, the greater will be the opposition voltage developed across R1.

Agc voltage does not necessarily require that we have a transistor as a detector. We can use a diode demodulator and still obtain the agc we want. But before we get too deep into this discussion, let's turn back just for a minute to Fig. 506. In examining this circuit, we see that the emitter is negative with the respect to the base. Another way of saying exactly the same thing — but in different words — is to say that the base is positive with respect to the emitter. We can reduce the gain of the n-p-n transistor by making the emitter less negative or by making the base less positive. These statements apply to p-n-p transistors, except that the polarity of the voltages is reversed.

In Fig. 511-A we have the circuit of a crystal detector. The crystal is tapped down on the if transformer of the last stage. To make the action a little clearer, we have taken that part of the circuit that interests us and have shown it in Fig. 511-B. An if voltage appears between points A and B. When the polarity of this voltage is correct, current will flow from point A, through the diode, through the volume control in the direction shown, through the chassis or common connector and, finally, from point B back to home base or point A.



(A)



(B)

Fig. 511. *Agc bias circuit for receivers using both n-p-n and p-n-p transistors. The agc voltage is used only by the n-p-n transistor.*

When this current flows through the volume control, the voltage that develops across it is negative at the top and positive at the bottom. This voltage (see Fig. 511-A once again) is fed back to the base of an earlier stage. Note several things: Both n-p-n and p-n-p transistors are used. The voltage fed back is negative and opposes the positive voltage on the base of the n-p-n unit. When the signal current through the diode is strong, due to a lusty signal, the negative voltage fed back is large. This voltage, applied to the base of the n-p-n transistor, reduces the forward-bias voltage between base and emitter. Result – gain goes down. If the signal is weak, the agc voltage is lower and the n-p-n transistor is permitted to operate with more gain. Of course, you will find quite a number of variations of agc circuits and we have already explained several of them. But you will have no trouble if you keep in mind that, no matter how unusual the circuit arrangement may be, it must do the job we have described.

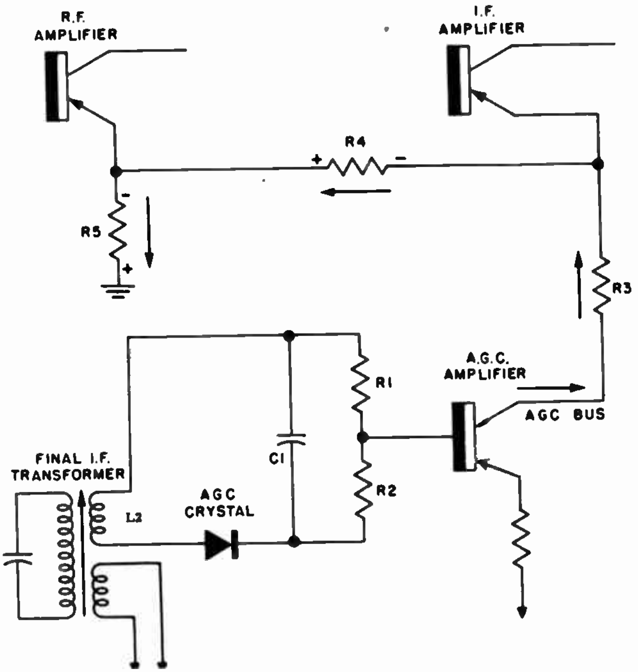


Fig. 512. *Some transistor receivers use a crystal diode as an agc detector and a transistor as an agc amplifier.*

Amplified agc

The complexity of the automatic-gain-control circuit is quite often in direct relationship to the cost of the receiver. In less expensive sets, you will find the detector serving as the takeoff point for the agc bus. However, in some receivers the automatic gain control is a circuit or a system all of its own.

An arrangement of a more elaborate type is shown in Fig. 512. The last if transformer is somewhat unusual in that it has three instead of two windings. The secondary consists of a pair of coils, one of which feeds the detector while the other is connected to a crystal whose only function is to serve as the agc rectifier. When the if signal voltage across L2 is of the proper polarity, the agc crystal will conduct. Shunted across the crystal output is a capacitor C1 which removes the if component. However, what we are really interested in is the resistive network, R1 and R2. This is the diode load for the agc crystal. A single resistor could have been used but in this instance only part of the rectified agc voltage is employed.

Now let us take a look at the transistor marked agc amplifier. It is a p-n-p unit – and we know that this type calls for a positive emitter. We can achieve the same purpose by making the base negative with respect to the emitter – and that is exactly what we do here.

Please examine the load resistors in the collector circuit of the agc amplifier. When the incoming signal causes the agc amplifier to conduct, collector current flows through the collector load in the direction indicated by the arrows. This produces a voltage drop across each of the resistors. Note that the emitter of the rf stage and the emitter of the if stage are connected to these resistors. But what about the polarity of the voltage that is developed across the resistors? The flow of current is such that the ground end is negative. This means that when agc amplifier current flows through the resistors, the emitters of the rf and if amplifiers are made more positive. But this is a condition which opposes amplification of these n-p-n units. Note also that a strong signal will produce more current flow through the agc amplifier, hence the gain of the rf and if transistors will be strongly reduced. For a weak signal, however, the amount of gain reduction will be less.

The polarity of the agc crystal is extremely important. Also, if you should need to replace the last if transformer for any reason, make sure that the correct leads go to the crystal and to the crystal load.

Disabling the agc line

Sometimes, in servicing or in alignment, it may become necessary to disable the agc bus. Agc cuts down on receiver sensitivity and so can interfere with your efforts to align or repair a stage.

If a crystal detector is used for both signal rectification and also as the agc source, you can easily disable the agc by running a 100-ohm resistor from the cathode of the crystal (marked CATH or "+") to chassis. This is shown in Fig. 513. If the crystal isn't easy to reach, connect one end of the resistor to the chassis and the other end to the "hot" side of the volume control. Since disabling

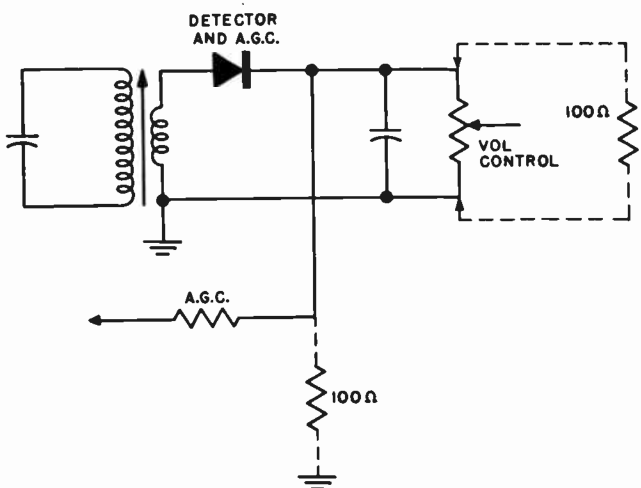


Fig. 513. *To disable the agc, connect a 100-ohm resistor from the agc bus to ground.*

the agc is quite a usual routine, it will be helpful to have a ready-made unit always at hand. Take a 100-ohm resistor and extend each lead with about two inches of flexible wire. At the end of each wire solder a tiny clip. The value of resistance isn't critical. A 200 ohm resistor will do just as well. Use a half-watt unit.

With the 100-ohm resistor as indicated in Fig. 513 it might be a bit difficult for you if you plan to use the speaker as an output indicator for alignment. When aligning, make sure that the volume control is set for maximum. You will probably get no signal output unless you do. For best alignment, however, it would be advisable to use a more sensitive indicator, such as a vtvm set to read low ac volts connected across the voice coil of the speaker. If you do not have a vtvm and you can get no signal output when using a 100-ohm resistor to kill agc, you may have to use larger values of resistance. No strict rule can be set up on this since so much depends on the output of your signal generator and the gain of the receiver.

Quite a number of manufacturers issue alignment instructions but say nothing in these instructions about disabling the agc line. This does not mean that they are right or wrong. You can align without touching the agc. The difference lies in the fact that agc tends to make tuning adjustments rather broad. If you work with very low values of signal voltage from your generator, the amount of agc developed will be so little as to be of no consequence. However, many inexpensive generators are not too well shielded and leak quite a bit of test signal. If you prefer working with the least amount of trouble, keep the generator as far from the receiver as the test leads will permit. Use a coupling coil at the ends of the test leads and loosely couple this coil to the receiver input. If, to get a signal through the receiver, you must use a larger value of test signal, do so, but remember to keep the test signal turned down as much as possible when alignment or repair brings up the gain of the set.

Weak or distorted signals

Trouble in the agc circuit can cause signals to be weak or distorted. If agc is excessive, the effect will be to reduce the gain of the controlled transistors to such an extent that output will be very low. The agc represents a bias which adds to or subtracts from the existing bias of the controlled stages, whether rf or if. Thus, the agc shifts the operating point of the transistors. If this shift is strong enough, the signals will be distorted.

If you get distortion on weak stations, but distortion seems to disappear when the set is tuned to strong stations, try substituting a new detector. In cases where all stations sound distorted, make sure that the agc voltage is of the proper polarity. Check the agc voltage with a high-impedance instrument such as a vtvm.

In some receivers an overload diode is used to cut down the gain of if stages for strong signals. If distortion occurs with strong signals, try substituting a new overload diode.

Finally, keep in mind that the distortion may not be due to any defect in the receiver. If the signal sounds distorted with the volume control turned up and the distortion is not eliminated when the volume control is turned down, try turning the receiver around so that the antenna picks up less signal. If the distortion disappears when you do this, it is entirely possible that the receiver isn't capable of handling the signal voltage being fed into it.

Biasing the detector diode

In some transistor receivers using a crystal diode as the detector, you will find a small amount of dc voltage placed on the detector. This resembles the forward bias placed between base and emitter of a transistor. It may seem strange to bias a diode, since this is a technique we usually reserve for transistors or tubes, and yet the bias on the crystal diode does a useful job.

If you will examine the characteristic curve for a diode you will see that a part of it is curved. The curve of the characteristic is the region in which distortion takes place. Bias is placed on the diode to avoid using the curved part of the diode characteristic. This is very useful when the input signal is weak. The use of bias on the diode permits reception of weak signals with very little distortion.

Control voltage and current

The avc circuit of a vacuum-tube receiver and the agc network of transistor set resemble each other so closely and the objectives are so much alike that it is very easy to get the idea that the networks are alike in every respect. In a vacuum-tube receiver, the avc voltage is fed back to the control grids of rf or if amplifier tubes. Now the grid of a tube is usually so biased that it doesn't draw any current — at least, it isn't supposed to. Because the control grid requires no current, it doesn't take any power from avc bus. To have power you must have both voltage *and* current.

Unlike the tube, the transistor is current-operated. To change the input bias on the transistor, power must be supplied. This means that the agc network in a transistor set supplies power to the tubes it controls — and this control power must come from the second detector. For proper operation, current (agc current) must flow from the second detector to the stage or stages being controlled by agc.

This will now give us a clue as to why transistors operated in class-B are sometimes preferred to crystal diodes as second detectors. The amount of power that a crystal diode can supply is quite limited while a transistor working in class-B can take the power demand in its stride. It is true, though, that the amount of power required for agc control is also quite small.

Checking agc effectiveness

The bias voltage existing between base and emitter of the usual transistor rf or if amplifier stage is quite small — a fraction of a volt. You can check the effectiveness of the agc network by connecting a vtvm between base and emitter. Do not use a vom. The vtvm must be able to read 3 volts full-scale deflection (dc), preferably less. Set the instrument on its lowest scale. For p-n-p transistors, connect the positive test lead to the emitter, and the negative test lead to the base. For n-p-n units, reverse these connections. With the leads connected, adjust the tuning dial of the receiver to a strong station and note if the voltage indicated on the meter scale fluctuates. You should get some indication as the signal changes from minimum to maximum value.

Keep in mind that with n-p-n transistors the agc voltage becomes more negative as the signal increases. If the circuit uses p-n-p transistors, the agc voltage becomes more positive as the signal increases.

If you do not wish to connect your vtvm to the leads of the transistor in making bias voltage measurements, locate the agc filter capacitor. You will generally find this unit wired to one end of the if transformer and the other end tied to the chassis. Connect the vtvm leads right across the capacitor, remembering to watch polarity.

chapter 6

audio amplifiers

THE audio amplifier is another example of a rags-to-riches story. Some of you oldtimers may remember the time when the only job of the audio amplifier was to make the signal loud enough so that a speaker could be used. It made little difference that the sound was distorted. You didn't have to wear earphones, and ownership of a speaker put you one notch above your neighbors who had to strain their eardrums. The loudspeaker was the Cadillac of its day.

Today, however, we are very concerned about the amplifier. And so we have a variety of audio systems that are a bit more complex. However, the audio amplifier that we find in ordinary receivers still does its job, and still requires some attention and servicing.

The volume control

Before we settle down to the main course (amplifiers), let us whet our appetites with a little side dish (volume controls). You will often find the volume control where you would expect to find it — directly at the output of the second detector. In this application it works as the second detector load, whether a diode or transistor is used.

Fig. 601 is an example of a volume-control circuit. If you will trace the circuit, you will see that the volume control forms a series network with the detector and the secondary of the last if transformer. The volume control is a voltage divider and picks out the desired amount of audio voltage which appears across it.

The signal is coupled to the first audio amplifier stage through a small electrolytic. In a representative receiver, the volume control will be 5,000 ohms or less. The .01-μf capacitor across the volume control is an if bypass. It serves to keep the if carrier out of the audio system. Incidentally, we hope you do not have the idea that the detector permits only audio to get through. The detector

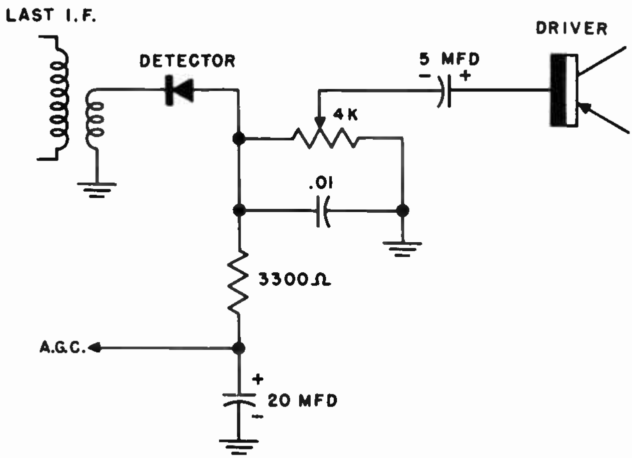


Fig. 601. *Volume control circuit. Note the large-value coupling capacitor between the volume control and the base input circuit of the driver stage.*

couldn't care less, and passes both if and af. If you are in a weak-signal area, you might try reducing the size of the .01 to a .005-μf unit. Maximum signal is obtained when the arm of the volume control is at the crystal end of the control; minimum or zero volume when the arm of the control is toward the ground end.

Sometimes the volume control is part of the input of the first audio stage. In such cases the diode load resistor for the detector is a fixed resistor. This is illustrated in Fig. 602.

The volume control can also be placed across the secondary of the input audio transformer, as shown in Fig. 603. The .01-μf capacitor that you see across the secondary of the audio transformer does the same job as the capacitor you will usually observe hanging from the plate of the audio output tube in an ac-dc set. This capacitor weakens the high-frequency portion of the audio. Since, by comparison, the bass part of the audio now sounds stronger (or boomier), the set will sound better – to some people. It certainly isn't hi-fi. The audio signal changes the bias on the p-n-p transistor shown in Fig. 603. The audio voltage is placed in series with the forward bias of the input, and as a result the collector current varies at an audio rate.

Tone controls

Tone controls can be variable or fixed. Sometimes the tone control can be placed in the audio section of a receiver in such a way

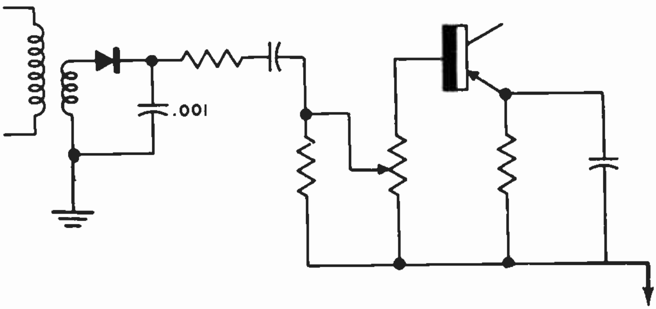


Fig. 602. *In this circuit the volume control is part of the input circuit of the first audio amplifier.*

that we will not immediately recognize it. The capacitor across the primary or the secondary of any audio transformer is really a tone control (Fig. 604-A). The operation of the capacitor is quite simple. As audio frequencies go up (higher tones), the reactance of the capacitor goes down. As a result the higher frequencies are bypassed and we either do not hear them or they are very weak. By comparison, the bass notes seem to be stronger. Actually, we haven't made anything stronger. It just appears to be that way.

The capacitor we have just been describing is a fixed unit and the owner of the receiver has no control over it. If the owner objects to the sound as being too bassy or boomy, just substitute a capacitor having a lower value. If the capacitor is a .05-μf unit, try a .01 in its place.

The simplest type of variable tone control (Fig. 604-B) is one using a potentiometer in series with the capacitor we have discussed in the previous paragraphs. The capacitor still has a low reactance to high frequencies and a high reactance to low frequencies. But the variable resistor now lets the owner of the receiver decide just what he wants. When the variable resistor is set to its maximum value, the high notes will come through the speaker. When the variable resistor is set at its minimum value, the receiver will have its minimum treble output.

Troubles in tone-control circuit

Many set owners are "dial twiddlers." Something compels them to adjust and readjust the controls of the receiver. The tone control is particularly subject to this abuse. The result is that the

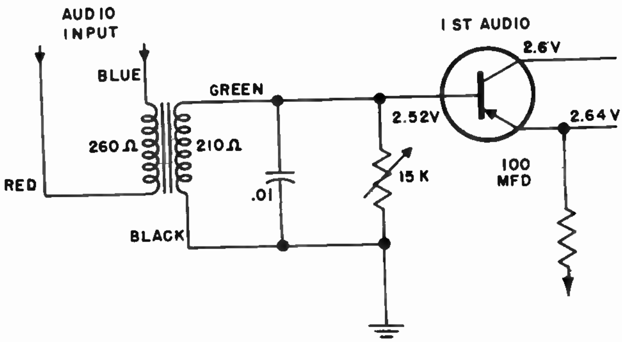


Fig. 603. *In this circuit the volume control is placed across the secondary of the audio driver transformer.*

control gets worn and noisy. In servicing, turn on a station and rotate the control. If you hear scratches in the speaker, either replace the control or try fixing it with one of the various cleaner-lubricants available. If the tone control has absolutely no effect on the sound, then either the control is open (likely) or the capacitor to which it is connected is open (much less likely).

A more elaborate type of tone control is shown in Fig. 604-C. Actually, it is just the same as the type using a potentiometer. Each of the resistors has a different value. Maximum bass is obtained when the switch is placed in position 1.

Troubles with this type of control are much the same as for the circuit of Fig. 604-B, plus a few of its own. A rotary wafer switch is used to change resistors. Switches can get jammed or dirty. If the switch will not turn, do not force it. Examine the rotor of the switch to see what obstacle prevents it from moving. As a general rule, however, if the switch is jammed, the owner has probably made it worse by trying to force it. In such a case, the switch will have to be replaced. If the switch works in only one or two of its

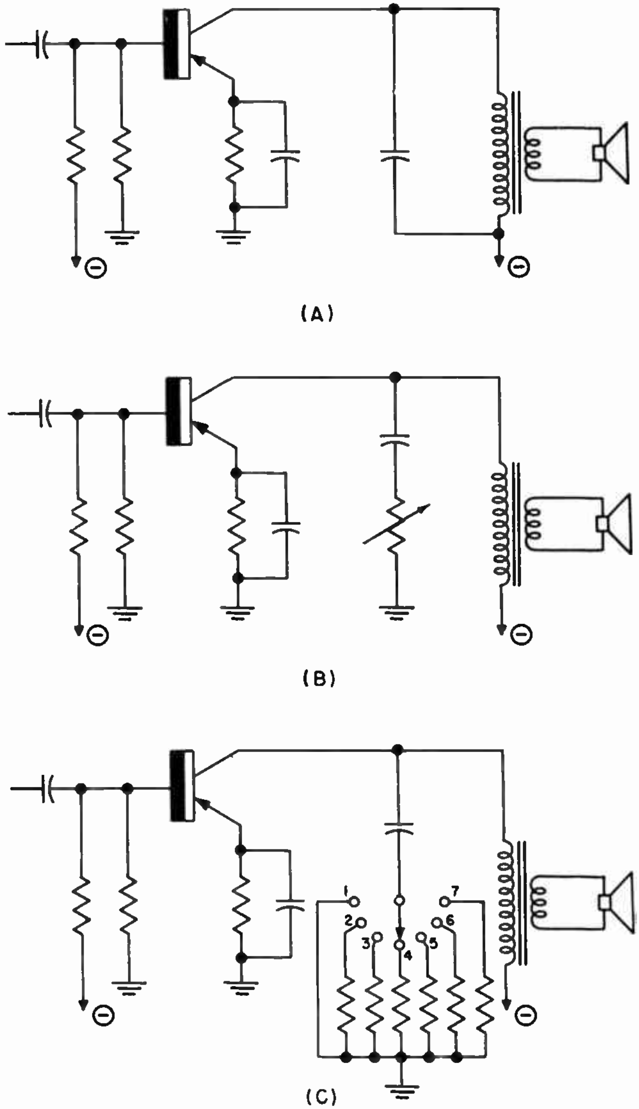


Fig. 604. *Typical control circuits. The resistor can be a potentiometer or a number of resistors which can be switched in and out of the circuit. The tone control can be part of the driver stage or can be located in the audio output.*

positions, one or more resistors may be open or may have become disconnected from the switch. A cleaner-lubricant will eliminate noise and prolong the life of the switch.

Single output stage

Some audio amplifier stages are elaborate, others are less so. The audio output stage can consist of a single transistor stage driving a speaker. This is illustrated in Fig. 605. There are some choice tidbits of information we can pick out of this schematic. First, we see that the on-off switch and the volume control form a single unit operated by a single shaft. This is no surprise since this is standard operating procedure for ac-dc receivers — from which the idea was lifted.

A unique feature, though, is the optional use of earphones or speaker. Earphones aren't popular with ac-dc vacuum-tube receivers since the hum level is so high. But transistor receivers are battery-operated so that old villain hum doesn't even get a chance to get his foot across the door. Fashions are funny. Thirty years ago you had to have earphones if you had a radio and today they are becoming popular again. In some sets, plugging in the earphones disconnects the speaker, but this isn't always the case.

Note also how the audio signal is coupled into the audio amplifier. The coupling capacitor is a 50-μf electrolytic. The emitter resistor isn't bypassed, resulting in some negative feedback for the output stage, improving its behavior and helping to keep it in line. The .0035-μf capacitor you see connected between the collector and base also supplies negative feedback. If you disconnect this capacitor, you will get more volume and slightly more distortion, but it is also possible that the output circuit might start oscillating. The .02-μf capacitor (a simple tone control) across the primary of the audio output transformer cuts down on high audio frequencies and makes the receiver sound as though it had excellent bass response.

The primary and the secondary of the output transformer are connected at one end and they are grounded. This is difficult to get accustomed to if you've done much work on ac-dc receivers where this represents a B-plus point. But don't get the idea that, because the transformer is grounded, this is some kind of zero spot. Ground is a B-minus point and in this case it is 9 volts. For a transistor, 9 volts minus is just as "hot" as 150 volts B-plus is for an ac-dc set.

The thermistor

A thermistor is a resistor. Its value ranges from as little as 10 ohms to as much as 150 ohms. While it is a resistor, it enjoys a distinction all its own. It has a high negative temperature coeffi-

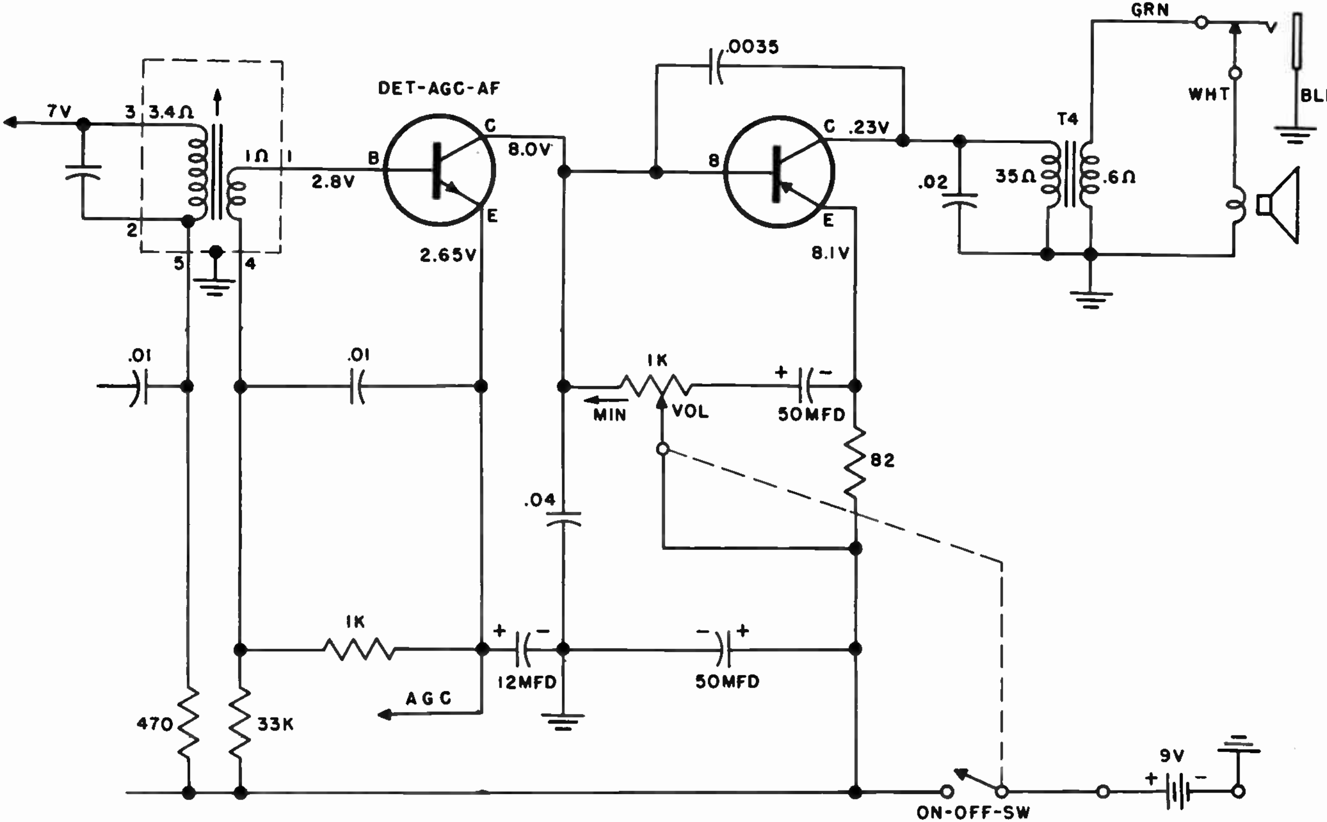


Fig. 605. *Simple audio amplifier using two transistors. The detector transistor also supplies some audio gain.*

cient. In plain English, all that this means is that it keeps running away from temperature. The hotter the surrounding air, the lower the resistance of the thermistor. When the temperature goes down, the resistance of the thermistor goes up. The thermistor is mounted very close to the audio output transistor. The thermistor is inserted in the input circuit of the audio power amplifier (that is, it is wired in between base and emitter). It helps keep emitter current steady.

Driver stages

A single transistor used as an audio output stage is both a voltage and a power amplifier. Since it tries to do two jobs, it ends

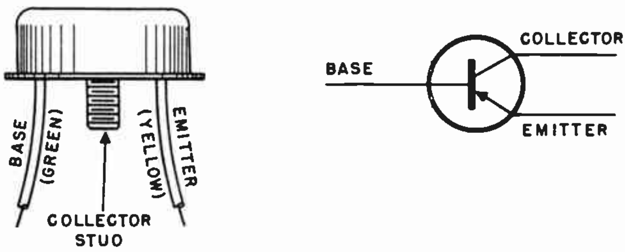


Fig. 606. *Power transistors come in various shapes. The electronic symbol for all three-element transistors is the same.*

up by doing neither particularly well. Of course, the single-transistor audio output stage does get some help when the detector is an amplifying transistor or, in the case of vacuum-tube receivers, when the detector is a diode-triode.

In better-grade receivers, however, the jobs of voltage amplification and power amplification are separated. A transistor stage is used as a voltage amplifier and is known as a driver. A separate stage, usually consisting of push-pull transistors, is the power output amplifier.

Power transistors

To handle large amounts of audio power, special power transistors have been developed. One of these is shown in Fig. 606. Because such transistors have been designed to work with power measured in watts, they generate a considerable amount of heat. We have the same trouble with a power transistor that you have with the engine in your car. Something must be done to get rid of the heat.

In your car you use a water-filled radiator and a fan. Some transmitting tubes do exactly that — they use fans and a water coolant. For a transistor, where small size is so important, these cooling techniques are out, but we all know that a good way to get rid of heat is to have as large a surface area as possible. To convince yourself, just look at any radiator in your home. Or

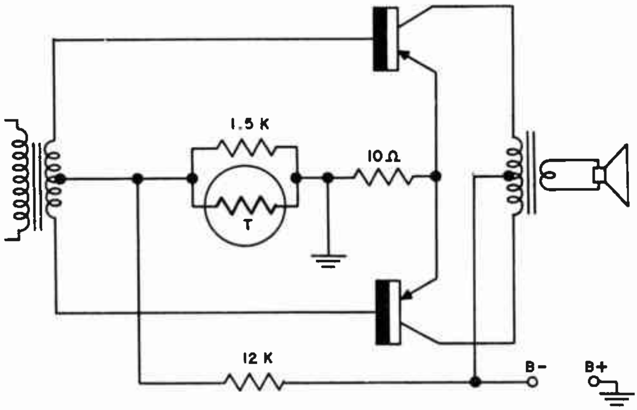


Fig. 607. *The thermistor is placed in shunt with the common-base resistor of the two transistors.*

look at the radiating fins on the engine of a motorcycle. In each case a large radiating surface is used.

This idea (not new or original) has been carried over to power transistors. Sometimes the package or housing of the transistor is designed to have as much surface area as possible. Or the transistor is mounted on the chassis to give more area. Sometimes, as in the case of power transistors used in auto radios, the transistor is mounted on a little radiator or wavy fin arrangement all its own. Every one of these devices is known as a heat sink, the idea being to pour heat down it the way water goes down a drain.

Collector current stabilization

Power transistors bring along a few troubles of their own. Because they generate so much heat, they bring about the possibility of collector-current runaway. In an earlier chapter we learned that as the temperature of a transistor rises, so does its collector current. But this, in turn, raises the temperature still further — a state of affairs that continues until the transistor burns itself out. Several techniques are used in power output stages to prevent

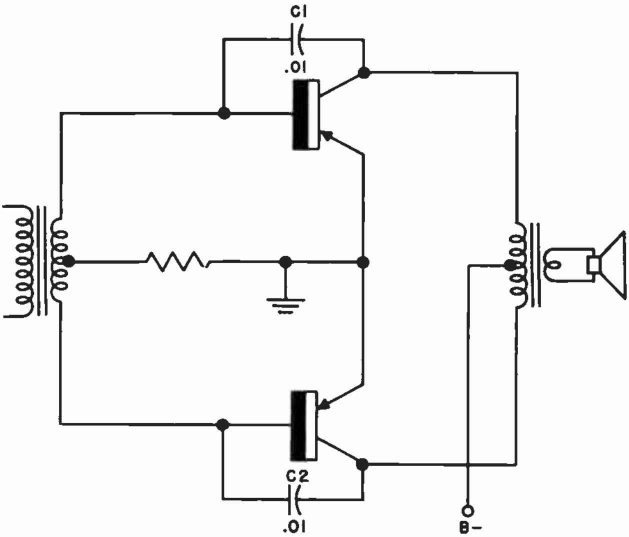


Fig. 608. *Feedback capacitors are used to improve the stability of the output stage.*

this; two of these have been mentioned. One is the heat sink and the other is the thermistor.

A push-pull output transistor circuit using a thermistor is illustrated in Fig. 607. Suppose, just as an example, the temperature of the transistor increases. This increases the collector current, calling for a rise in emitter current. But the increase in collector current results in a temperature rise. This lowers the resistance of the thermistor T. But as the emitter resistance goes down, so does the forward bias. When the forward bias decreases, emitter current also decreases. But collector current depends upon emitter current — hence collector current goes down.

The biasing voltage for the input circuit of Fig. 607 depends upon the 10-ohm resistor and also upon the thermistor. Note that the thermistor is shunted by a 1,500-ohm resistor but, since this is so much larger than the value of the thermistor, it is the thermistor that is the controlling element. The 1,500-ohm resistor acts to prevent sudden changes in input bias.

Current stabilization

There is still another technique that can be used to keep collector current under control. Quite a simple one, it uses a stabilizing resistor. In some instances, the resistor is bypassed by an electrolytic. In other cases, it is not. If the receiver is single-ended — that is, if it uses but one transistor in a class-A amplifier stage — then only one resistor is required. For push-pull operation in class B, a single resistor can be used as a common element for both transistors or each emitter can have its own stabilizing resistor.

Current flowing through the stabilizing resistor produces a voltage drop across it. But the polarity of this voltage drop is such as to oppose the forward bias of the base-to-emitter network. If collector current becomes stronger, the reverse bias of the input is increased by the stabilizing resistor. The result is a decrease of collector current to normal.

Some receivers depend on a thermistor for current stabilization; others use both a thermistor and a stabilizing resistor. Most current-stabilizing resistors are quite low in value; 10 ohms is quite common. However, a few sets use values larger than this.

Push-pull output

The arrangement of a push-pull transistor stage resembles that of a vacuum-tube circuit quite closely. The push-pull input transformer supplies out-of-phase audio voltages to the inputs of a pair of transistors. Unlike the interstage transformer used for vacuum tubes, the input transformer is a stepdown type to match the higher impedance of the collector driver to the lower impedance of the bases of the power stage. The push-pull output transformer is also a stepdown type.

The use of a stepdown transformer is quite interesting. In vacuum-tube circuits, we need voltage to drive the grids of the tubes. In other words, the input of the usual vacuum-tube circuit is a voltage-operated device. The input to a transistor, though, is current-operated. The voltage requirements of the transistor input are small — the current needs are more substantial.

In some push-pull grounded-emitter circuits you will see a capacitor, usually .01 μf, connected from the collector to the base of each of the push-pull transistors (Fig. 608). These are feedback capacitors and are used to stabilize each of the transistors.

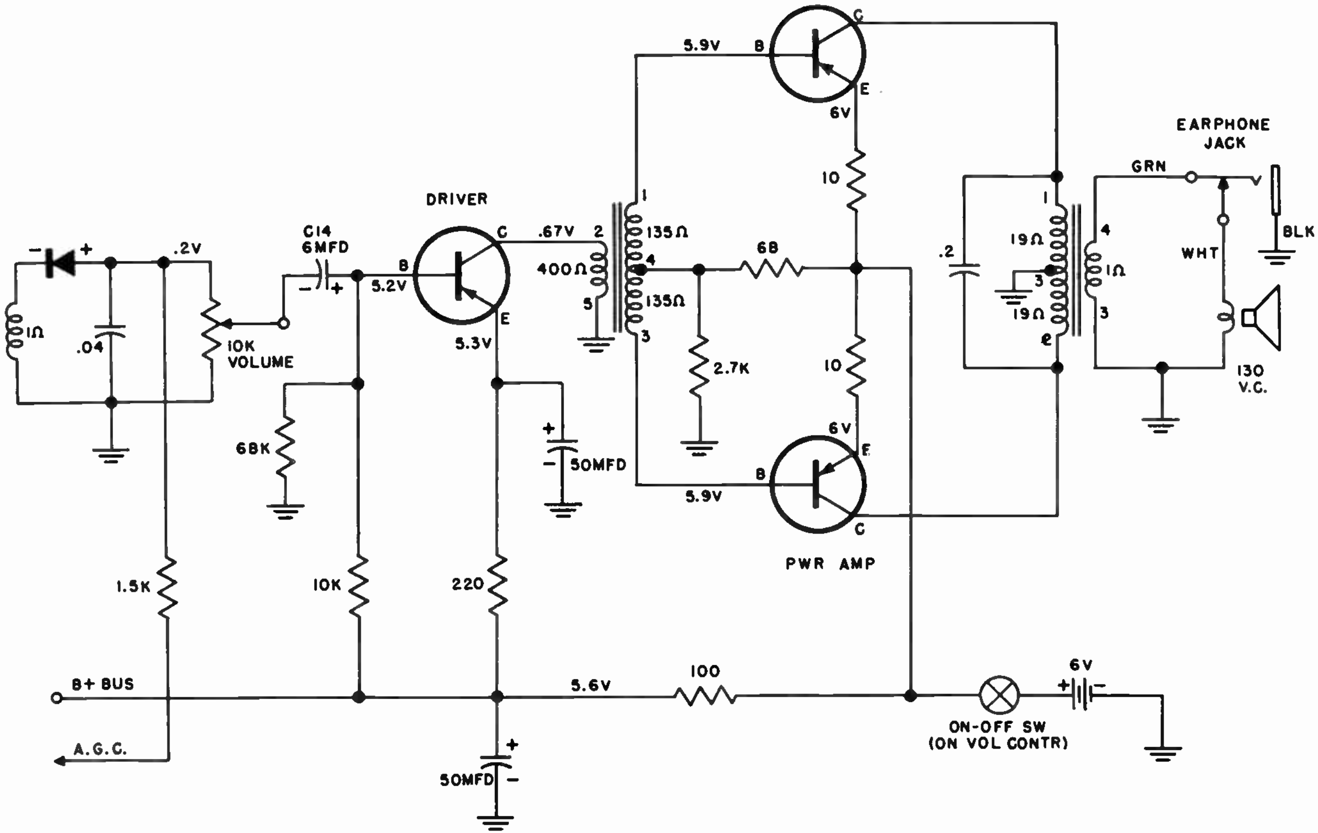


Fig. 609. *Transistor audio amplifier using push-pull output.*

The exact amount of capacitance of the feedback capacitors isn't too important. What is more important is that the two capacitors be as closely matched as possible — that is, the units should be fairly identical in capacitance. The push-pull transistors should also be matched. This means that the two transistors require fairly similar characteristics. A push-pull stage is illustrated in Fig. 609.

To avoid the necessity for using matched feedback capacitors,

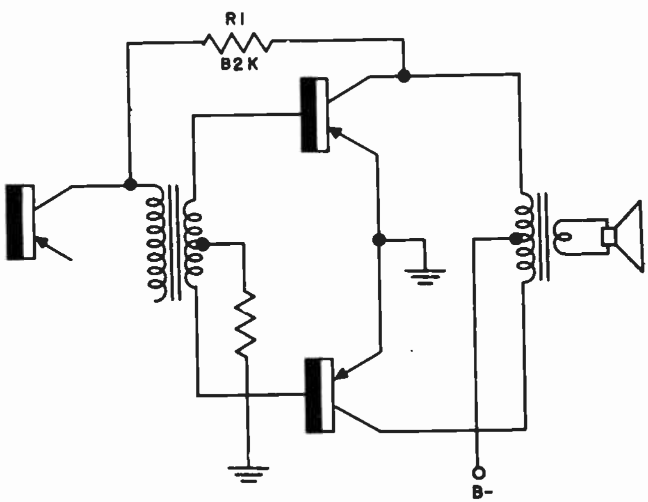


Fig. 610. *Resistor R1 in this circuit supplies negative feedback.*

a single resistor is sometimes used. However, if we were to use but one resistor between collector and base, it would upset the balance between the push-pull transistors. This is cleverly avoided by the method shown in Fig. 610. In this circuit, the feedback resistor connects to the primary of the input transformer. This means that negative feedback is injected at the primary and the effects of the feedback are then equally distributed across the secondary. In Fig. 610 the feedback resistor is the 82,000-ohm unit, R1, connected as shown in the circuit. The larger the value of this resistor, the smaller will be the amount of feedback. Removing the resistor increases volume, raises distortion and decreases the stability of the output stage.

Sometimes two resistors are used. When this is done, you will find them connected between collector and base in just the same manner as the balanced feedback capacitors. A typical value for balanced feedback resistors is approximately 18,000 ohms.

Hybrids

In some cases you will find receivers consisting of combinations of tubes and transistors. Most often the only transistor portion of the receiver will be the output stage, as shown in Fig. 611. Note that we have a grounded-collector arrangement. Resistor R1 is a 210-ohm potentiometer. This resistor is adjusted, after receiver warmup, so that the emitter current of the transistor is 500 ma. This resistor is not a customer adjustment and is not mounted where the customer can get at it (fortunately). The component is a screwdriver-adjust type of pot and is mounted below the chassis. Once it has been set, it can be ignored until such time that the transistor needs checking or replacement.

There is a difference in the driver transformer connecting the tube to the output transistor. Since the plate of the driver tube is at a much higher impedance than the collector of a driver transistor, the primary of the transformer is wound with many more turns of wire.

The driver tube is interesting. It works with about 10 volts on the plate and screen. The tube is a tetrode, a rather unusual development since tetrodes haven't been popular for almost 30 years. A specially designed, coated plate permits tube operation at very low voltages.

Class A and Class B

The bias placed on the input side of a transistor determines its class of operation. Voltage amplifiers, whether driver or output stages involving a single transistor, are operated class-A. Less bias is used for class A. The whole idea of class A is that the input signal, whether positive or negative at any particular moment, is equally effective in changing the amount of collector current that flows. This means that collector current flows at all times — whether or not a signal is delivered to the input. This is like having your automobile engine running when it is in the garage — it's nice to know that it is working, but it just doesn't get you anywhere. The efficiency of a class-A amplifier is low.

In class-B operation, the transistor is so biased that very little collector current flows in the absence of a signal. The situation is almost like that of a rectifier. Since half of the signal disappears, we need to have two transistors working in push-pull so that the whole signal appears at the output. Class B is much more efficient

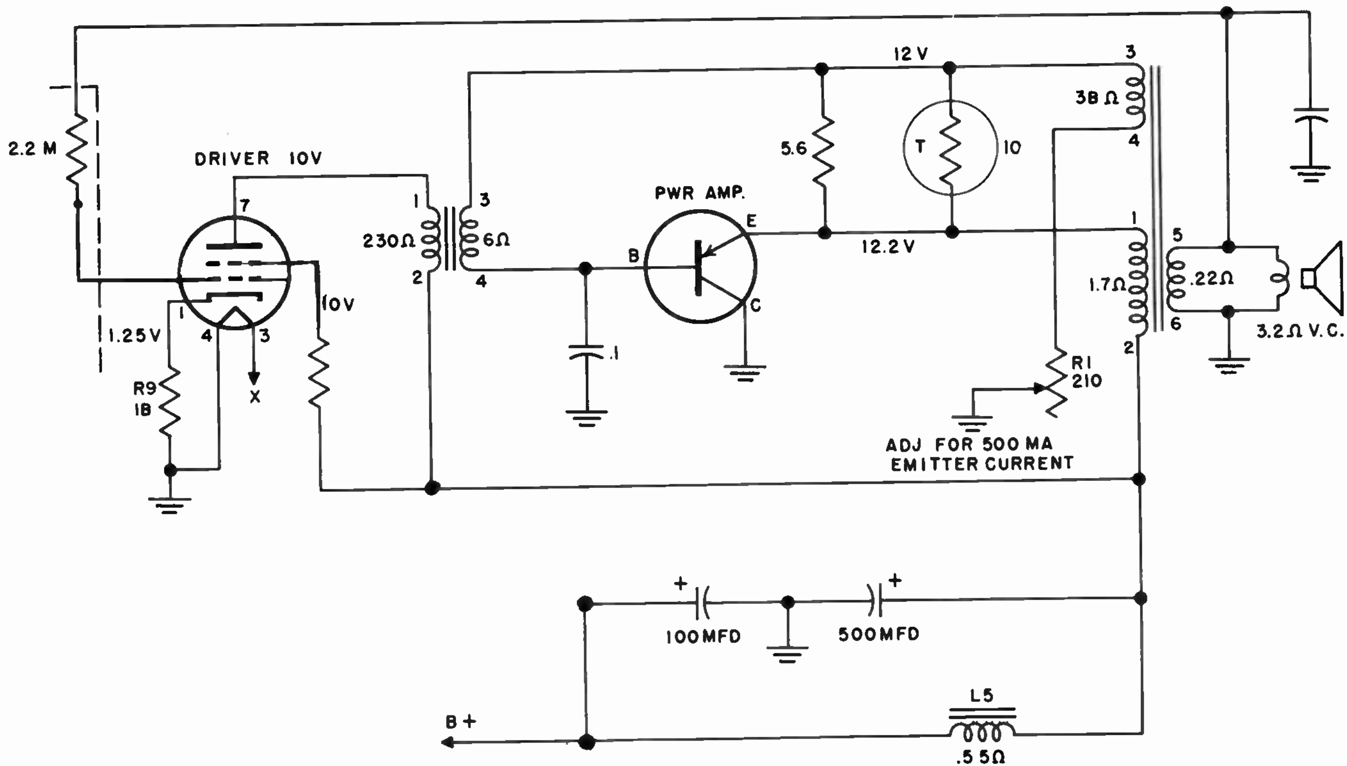


Fig. 611. *Hybrid circuit using a vacuum-tube driver and power transistor for the output.*

than class A. A properly balanced push-pull audio amplifier also cancels even-order harmonic distortion (second harmonic, fourth harmonic, etc.).

Out go the transformers!

Practically all transistor radios manufactured today that use push-pull operation have input and output transformers. Because the impedances involved are much smaller than in vacuum-tube radios, the number of turns of wire required for the primaries

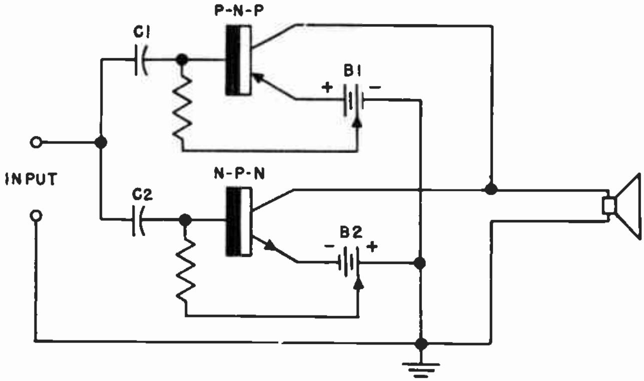


Fig. 612. *Push-pull circuit does not use input or output transformers.*

and secondaries of such transformers is considerably reduced. Advances have been made in core materials, so that a higher permeability is obtained with a smaller volume of core. All of this means that these transformers can be made — and are made — quite small.

However, both input and output transformers can be competely eliminated. The technique is shown in Fig. 612. The principle of operation is based upon a bit of information that we studied in one of your very early chapters. In a p-n-p transistor, current flows from a battery into the collector while in an n-p-n unit current moves in the opposite direction — out of the collector into the battery.

The driver for the push-pull amplifier in Fig. 612 is a single transistor stage. The base of the n-p-n and the base of the p-n-p transistor are connected in parallel. C1 and C2 are coupling capacitors but, as far as the signal is concerned, it is delivered at the same time (and in phase) to the base input of each transistor.

Now just suppose that the input signal is positive at this particular moment. This is exactly the kind of polarity that the n-p-n unit likes — to have its base made positive. Since, as far as the n-p-n unit is concerned, it is biased in the forward direction, we get a nice flow of collector current. But one transistor's bias is another transistor's bugaboo. The n-p-n might rejoice, but the positive input signal applied to the base of the p-n-p transistor

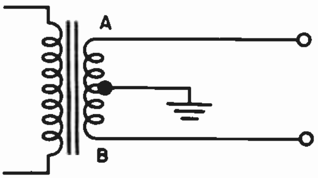


Fig. 613. *An easy way to get out-of-phase voltages is to use a tapped transformer.*

is a form of reverse bias, and as a result its collector current decreases.

When the signal polarity reverses and the input becomes negative, an exactly opposite state of affairs exists. The p-n-p transistor likes to have its base made negative, thus biasing it in the forward direction and permitting collector current to flow.

And so we have true push-pull operation since, as the collector current in one transistor increases, the collector current of the other transistor decreases. We have shown a speaker as the load for the two transistors, but unfortunately the collector is a high-impedance point and most speakers have very low-impedance voice coils. Special high-impedance voice-coil speakers are manufactured, but there doesn't seem to be much advantage in making the trade. A voice coil has to move. A transformer sits still. At the moment the transformer seems to have the upper hand and the circuit isn't used in receivers. It is very interesting, though, to see how the diverse characteristics of n-p-n and p-n-p transistors can be employed.

Intermixing power transistors

In vacuum-tube receivers, the service technician has often found that one tube can readily be substituted for another — especially if the type that is needed is out of stock. A 12SL7 has sometimes been put in place of a 12SN7, and a 6V6 in place of a 6K6. Since such substitutions often resulted in satisfactory receiver operation, both customer and service technician were happy.

This situation does not apply to transistors used in power output push-pull stages (although substitutions can be made elsewhere in the set). It isn't advisable to intermix power transistors — exact replacements are best.

Phase inversion

A driver transformer, like many parts used in radio sets, holds down two jobs. The first of these is fairly clear. The transformer couples the output of the driver to the input of the push-pull stage. But the push-pull stage is like a seesaw — when one end is up, the other must be down. In push-pull, as the collector current of one transistor increases, the collector current of the other push-pull transistor must decrease. The easiest way to do this is to supply signal voltages that are out of phase, and the easiest way to get out of phase signals is to use a center-tapped transformer. This is shown in Fig. 613.

A current flowing through the primary will induce a voltage across the secondary. When point A is positive with respect to the center tap, point B is negative with respect to the same point. The polarity at points A and B depends upon whether the current in the primary is increasing or decreasing at any particular moment. It does not and it can not depend upon a reversal of current flow in the primary. The primary current moves in only one direction.

The driver transformer now being widely used in many push-pull transistor receivers has practically disappeared from high-quality vacuum-tube receivers. In place of the transformer a tube is used. The tube cost less, was easier to install and did the job as well as the transformer.

A transistor can be used as a phase splitter. The circuit is shown in Fig. 614. The arrangement is much the same as in a vacuum-tube circuit where the load is split between the plate and cathode circuits — that is, half the load resistor is in the plate circuit and the other half is in the cathode.

If you will examine Fig. 614, you will see that the collector load and emitter load have identical values. In a grounded-emitter stage, the output (collector) is out of phase with the input signal. But the emitter is part of the input, hence its signal is in phase with the input. In other words, collector and emitter are out of phase with each other. Signal voltages can be taken from the collector and emitter of the transistor phase inverter and used to drive a pair of push-pull transistors.

The speaker

Speakers in transistor sets are small PM units (Fig. 615) and seldom present problems but, when they do, they can be just as time-consuming as any other receiver trouble. If you keep speakers in stock, store them away from heat. The little magnets used in modern speakers are fairly sturdy and they have to be mishandled severely for them to lose their magnetism. If you have any doubts

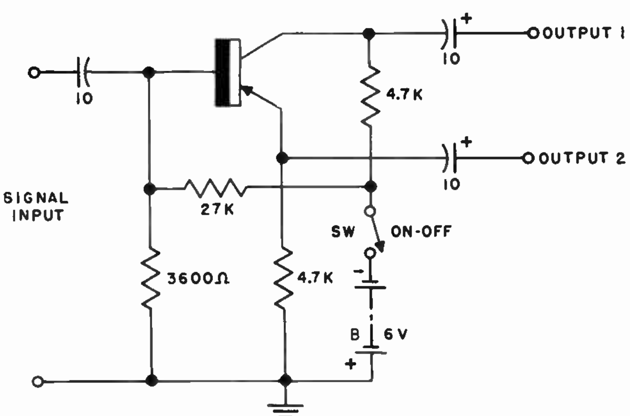


Fig. 614. *A single transistor can be used to supply two outputs.*

about a speaker, however, check the attraction of the magnet with a small screwdriver. The pullover should be strong and positive. A rattling sound can be caused by a rip in the speaker cone. A gritty sound or severe distortion can be caused by dirt (usually metallic particles) between the voice coil and the surrounding magnet.

You can check a speaker with your ohmmeter. Set the instrument on the low-ohms scale and briefly touch the leads to the voice coil terminals. You should hear a click.

Speaker replacement isn't difficult if you get an exact replacement. If you do not, you may have a physical interference in mounting the unit. If you cannot get an exact replacement, at least make sure that the substitute speaker is the same size and shape and that it has its mounting holes in the same place.

Sometimes one lead of the voice coil is grounded to the chassis.

If such is the case, the voice coil may be part of a feedback network. If, when making a replacement, you get an oscillating sound out of the speaker, try transposing the leads to the voice coil.

If, when removing a speaker from its cabinet, you have a screwdriver floating around on your bench, you can be certain that the screwdriver will find its way right through the cone of the speaker. A whole cone is much better than a patched one, so the best thing is to weigh yourself up an ounce of prevention. Cut a piece of cardboard to the outside diameter of the cone. Fasten the cardboard to the metal surround of the speaker with bits of

Fig. 615. *PM speakers have magnets of many shapes. Many styles are quite shallow.* (Argonne Electronic Mfg. Corp.)

Scotch tape. Keep the tape away from the cone material itself. You will now be able to put the speaker flat down on the bench without fear of damaging the cone.

Incidentally, iron filings and metal dust often find their way around the tops of workbenches. Those little speaker magnets are much stronger than most people realize, so at least make sure that your bench is clean. It's practically impossible to get metal filings out from inside a speaker.

It's always helpful to have at least one test speaker (with output transformer attached) at hand. This can be mounted in a small box with a pair of test leads coming from a pair of connectors mounted on top of the box.

Another component to be reckoned with in transistor pocket portables is the earphone, which is making a comeback along with the crystal detector. The earphone also has a new style in keeping with the crystal detector's modernization. The unit has dwindled until it is so small and so light its plastic earplug fits right into the ear opening (Fig. 616). Gone are the uncomfortable spring clamps that used to cover the head and ears.

Where personal activity is strenuous, a more secure method of holding the earphone in place is that shown in Fig. 617. This hooks over the ear in a manner similar to eyeglasses. The sound-producing unit rests gently against the ear opening.

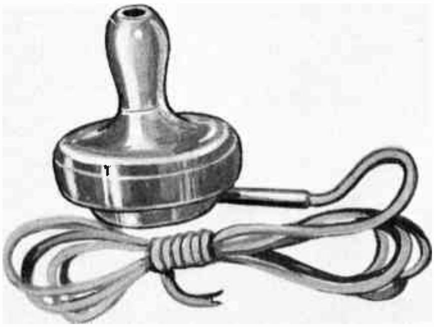


Fig. 616. *The earphone plugs into the ear cavity. It excludes almost all outside noise.* (Argonne Electronic Mfg. Corp.)

Since these earphones plug in, the best test here is substitution. Some transistor receivers use the earphone in the output of the audio driver stage. It is necessary for the earphone to have the same impedance as the secondary of the driver transformer. With a circuit of this sort, it is possible to have the earphone operate normally and to have no sound out of the speaker.

Trouble could occur in any of the components from the shorting type earphone jack to the loudspeaker itself. The shorting type jack can be a problem in itself. Being very small, it is quite easy for the contacts to be held open by a microscopic particle of dirt. The contacts can be cleaned best with a strip of paper or the corner of a business card. It should never be necessary to use anything coarser. If by some remote chance some component defect should ruin the smoothness of the contacts, limit the coarseness of an abrasive paper to the extra fine types used for polishing and finishing metals. Torn or cut into narrow strips, a single sheet of this abrasive polishing paper should last many years.

Problems created by broken earphone cords will give considerably more trouble. These cords are composed of tinsel wrapped around threads to give greater flexibility. Usually the cords break at the ends, near the point where the twisted pair of wires enter the phone body and at the phone plug. This trouble is usually indicated by normal speaker operation with the sound from the earphone either intermittent or nonexistent. This is one reason why it is better to substitute a suspected earphone assembly than try to test it.

Any one of three impedances is used in the types of earphones

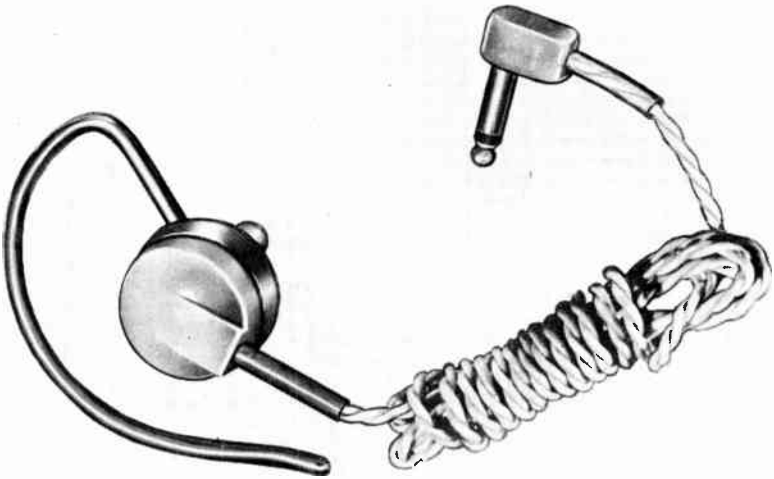


Fig. 617. *Band attached to this earphone hooks over the ear like a pair of spectacles.* (Argonne Electronic Mfg. Corp.)

likely to be encountered. Those earphones intended to replace the speaker can vary from 2 to 25 ohms. A second type, made to operate as the collector load of the driver transistor, might be anywhere from 500 to 2,500 ohms. The third type, sometimes referred to as "infinite-impedence," is made of the same material as the crystal cartridges used in popular record players. In the record player, the movement of the needle creates or generates a voltage. These piezoelectric crystals also work in reverse; that is, they will move in proportion to the voltage applied to them. This has also been applied to the equipment used for making phonograph records. Of course, there it is necessary to use considerable power to move the needle when cutting the acetate film on the recording blank.

Where the earphone is connected to the speaker circuit (the secondary of the output transformer) through a shorting type jack, it is quite easy to use this to connect a resistive load to replace the speaker. A miniature plug can be fitted with a pair of wires to which is connected a resistor of the same value as the speaker impedance. Prolonged testing of a receiver can be done silently this way. A scope or voltmeter of the audio or ac variety can be used for an indicator.

Color coding

The average receiver, whether it uses single or double transistor output, will have two audio transformers. One of these is the driver transformer connecting the audio amplifier transistor to the power output transistor. The other is the output transformer serving as a link between the power output transistor and the speaker.

Where the output consists of a single transistor in class A, each transformer will have four leads. For push-pull receivers, however, both the driver and the output transformer will have five leads. The extra lead in these cases is for the center-tap connection of the transformer.

Let us first consider a receiver using single-ended output. The primary of the driver transformer will be color-coded blue and red. The blue lead goes to the collector; the red lead to the B supply. The secondary will be color-coded green and black, with the black lead grounded directly or through a resistor. The green lead (or signal-carrying lead) is usually connected to the base input of the following stage. In some receivers, white is used as a color instead of green. In still another set, the signal lead is an uninsulated wire while the "ground" lead is yellow.

The output transformer has the same color coding as the driver transformer. Remember, if a receiver has only one transformer, it will be an output transformer with R-C coupling used between voltage and power amplifier stages. If, for some reason, you cannot identify primary and secondary leads, remember that the primary winding has more turns and therefore a much higher resistance than the secondary. This applies to both input (driver) and output transformers.

If the transformer has no color coding or if the color coding is quite different from what we have described here, you still do not have a serious problem. First, before you install the transformer, make a resistance check to learn which is the primary and which is the secondary. Install the transformer, using either primary lead for the collector connection. The other primary lead will then be the B-lead. Work the same way with the secondary. Do not worry as to which secondary lead is the "signal" lead. If, after you make your connections, you get a squeal out of the receiver, simply transpose either the primary connections or the secondary connections, but not both. This condition of squealing is particularly likely to occur in cases where you replace the output transformer and one lead of the secondary (voice-coil lead) is to be grounded.

Transformers used in push-pull stages are often coded as follows:

Driver transformer: Primary, red and blue. Secondary, green and yellow. The center lead, black.

Output transformer: Primary, blue and brown. Center tap is red. Secondary, green and black.

It is easier to identify the primary and secondary of push-pull transformers than those for single-ended stages. No resistance check is needed. If the transformer is a driver type, the secondary has three leads. If the transformer is an output type, the primary has three leads.

Replacing transformers

When replacing transformers, try to get exact replacements. If, for any reason, you must substitute transformers, try to use shielded types. It is always a good idea to mount transformers at right angles to each other. If the transformer is an uncased type, you can shield it with soft magnetic foil. This material can be cut with a scissors. The foil is wrapped around the transformer and kept in place with a tiny bit of tape. In all instances make sure that the shield is connected to the ground or common lead of the receiver.

Advance notice

We have now covered the complete transistor receiver from stem to stern, from input to output. But don't throw away your thinking cap and don't push the stop button since we are only about halfway through our learning trip. All of the material we have studied so far is extremely useful, but there isn't much use in fashioning a tool and then not using it. And so, in our next volume we will learn servicing procedures. We will learn more about the various ailments that afflict the transistor radio, how to recognize the symptoms and how to cure them. And, for added measure, we will also learn something about alignment.

Some of you may be worried about new developments in transistors that we haven't as yet described — units such as the tetrode transistor, the spacistor, etc. These are interesting subjects for discussion, but let's get the main meal out of the way before we start in on the dessert. Our job is to learn what makes the transistor tick — and how to keep it ticking. That is why new developments, not yet used in receivers, are being kept for last.

index

I

J

L

M

N

O

P

Q

R

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